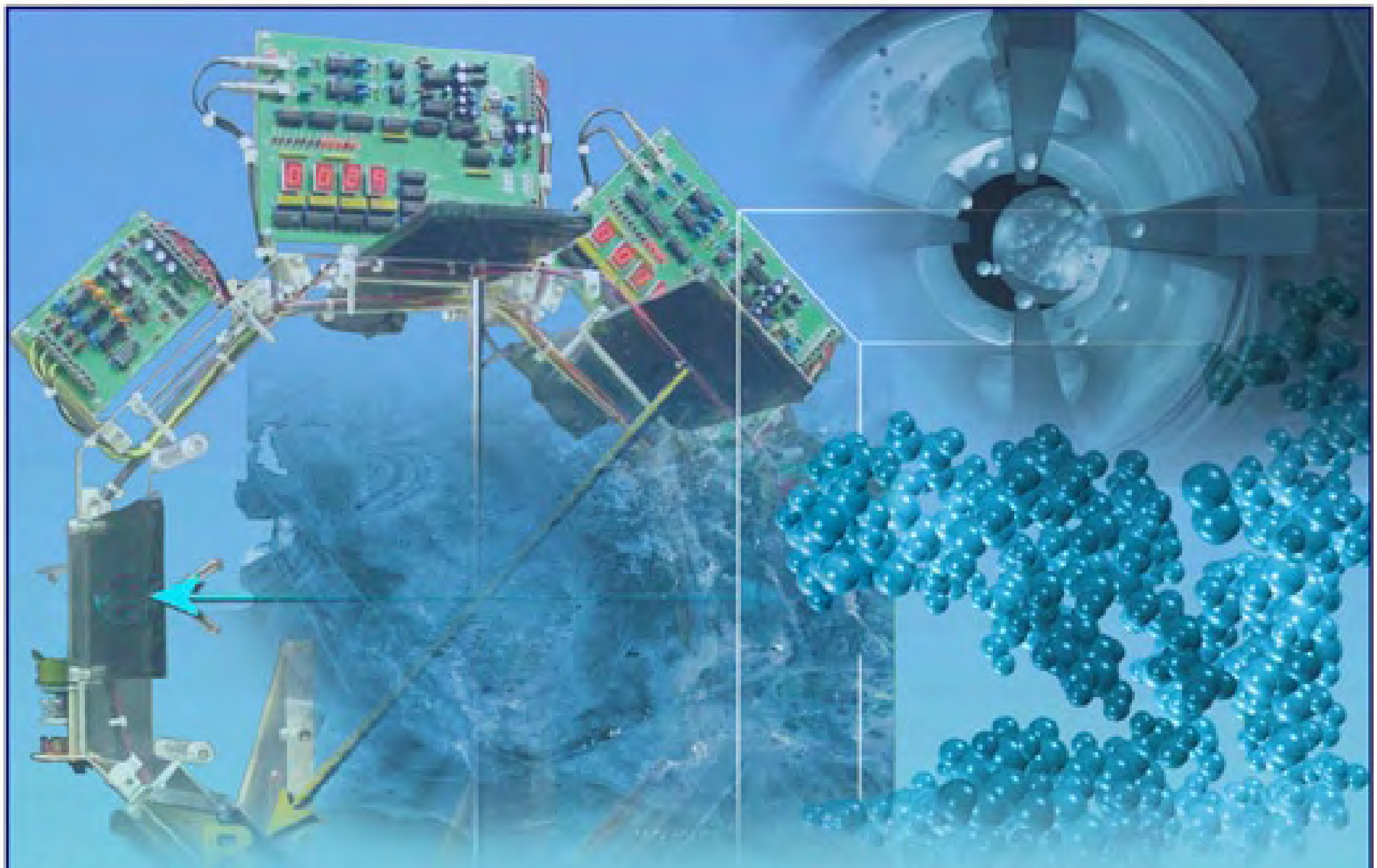
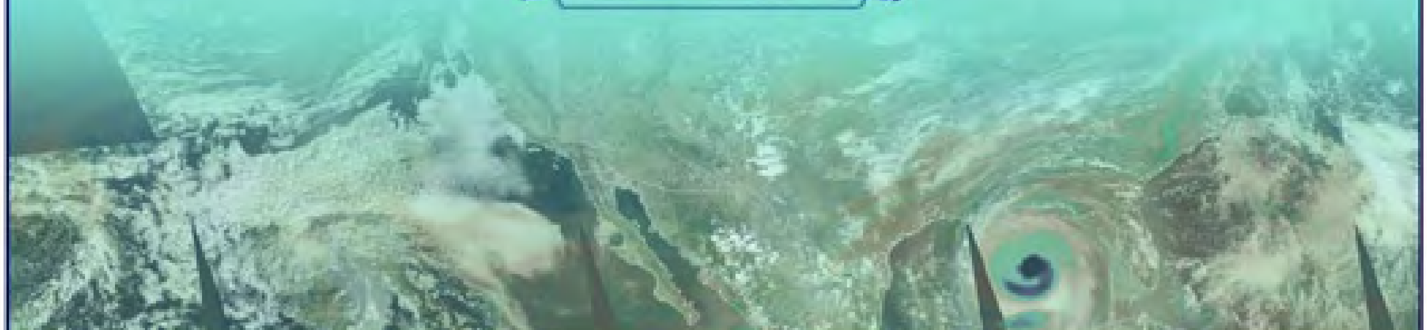


California's Federal Laboratories: A State Resource

February 2006

FEDERAL LABORATORY AFFILIATES

CCST



CALIFORNIA COUNCIL ON SCIENCE AND TECHNOLOGY

California's Federal Laboratories:

A State Resource

California Council on Science and Technology

Principal Author, Patrick H. Windham

February 2006

California's Federal Laboratories: A State Resource

February 2006

ISBN-13: 978-1-930117-35-8

ISBN-10: 1-930117-34-5

Note: The California Council on Science and Technology (CCST) has made every reasonable effort to assure the accuracy of the information in this publication. However, the contents of this publication are subject to changes, omissions, and errors, and CCST does not accept responsibility for any inaccuracies that may occur. CCST is a non-profit organization established in 1988 at the request of the California State Government and sponsored by the major postsecondary institutions of California and affiliate national laboratories, in conjunction with leading private-sector firms. CCST's mission is to improve science and technology policy and application in California by proposing programs, conducting analyses, and recommending public policies and initiatives that will maintain California's technological leadership and a vigorous economy.

ACKNOWLEDGEMENTS

This report has been under the oversight of CCST's Large Science Project committee whose members include: Miriam E. John (Chair), Michael R. Anastasio, Linda Cohen, Lawrence B. Coleman, G. Scott Hubbard, John P. McTague, and Anneila Sargent. We express gratitude to CCST members for the many contributions made to the report and especially to Patrick Windham who is the principal author.

For questions or comments on this publication contact:
California Council on Science and Technology
1130 K Street, Suite 280
Sacramento, California 95814
by voice at (916) 492-0996
by fax at (916) 492-0999
or email at ccst@ccst.us

TABLE OF CONTENTS

PREFACE

At the request of Senator Jackie Speier, chair of the Senate Subcommittee on Higher Education, CCST has prepared this report to start a discussion on how the California federal laboratories are a unique and largely untapped resource in the state. It describes both the opportunities presented by these facilities and the practical impediments, where applicable, that inhibit fuller collaboration between federally funded laboratories and the state government.

The federal government owns approximately 600 laboratories that help it carry out its missions in areas such as defense, energy, space, health, commerce, agriculture, forestry, and fisheries. The laboratories are seen as national facilities with a federal focus, working on major issues with long-term impacts. They are called upon to help the nation with long-term projects, such as the National Aeronautics and Space Administration (NASA) Spirit and Opportunity Mars rovers, built at the Jet Propulsion Laboratory. They can also meet immediate needs such as setting up emergency communications networks after hurricanes Katrina and Rita. In this context, Lawrence Livermore National Laboratory and Sandia National Laboratory also provided infrastructure failure analysis that was part of the daily brief to the President in order to support decisions on where to position response assets.

However, while these facilities exist to serve federal missions, they also provide important scientific, technological, economic, and educational benefits for California, which has more of these laboratories than any other state. Some of these benefits involve the application of technologies developed for national missions at a local level, such as anti-terrorism technologies and energy research. There is also the direct social and economic impact caused by the presence of research facilities supporting thousands of high-tech workers. And there is the benefit of having large pools of world-class expertise readily available. These federal laboratories interact with their surroundings in many ways, collaborating with university and private sector researchers, and working with schools. In an era when technological leadership and an educated workforce are more essential than ever to California's economic future. These federal laboratories are an important resource for the state.

There is more, however, that this extraordinary collection of facilities could do for the state. The focus of their mission may be federal, but they are able and willing to provide services to the state. This is a tremendous and a relatively untapped asset to California.

To better realize these opportunities, the six research laboratories described in this report have entered into a partnership with CCST as affiliate members. Through a multi-year partnership, an important link with these key science and technology organizations is being created. The collaboration will help create direct links to the laboratories' capabilities and talent. It will also help CCST better respond to state needs particularly in providing state policy leaders with high-quality, evidence based science and technology (S&T) guidance.

It is to California's advantage to help these federal laboratories succeed and compete nationally and internationally for resources. Clarifying what these facilities represent is the first step in helping California make the most of what they have to offer, and act to maximize their chances for success.

We feel that the potential of the federal laboratories has long been unrealized. In 1999, CCST helped to highlight their role as a part of a comprehensive study, the California Report on the Environment for Science and Technology (CREST). The CREST report indicated that the wide range of expertise at the federal labs was underutilized by the state, and recommended that California work to help companies, and local and state agencies become aware of the lab resources available to them.

A great deal has changed in the past six years, during which time the federal laboratories have expanded beyond their traditional work into new areas of information technology, robotics, biotechnology, and nanotechnology — all areas of importance to the California economy as well as to the nation as a whole — and new S&T policy challenges have come to face the state, ranging from natural disaster and anti-terrorism measures to information technology to genetically modified foods. However, six years after the CREST report, a significant gap remains, and once again a central message of our analysis is that the great potential of these facilities is underutilized. It is our hope that the discussion started by this report and the Legislature will lead to a better understanding of the value and the opportunities these facilities offer the state, and how California can work with them for the good of the state and the nation.

Information for this report was gathered from the laboratories directly or from external sources. The principal author of the report is Patrick Windham. However, policy recommendations and actions are from multiple sources. As with all California Council on Science and Technology reports, careful attention has been given to the peer review process.

Lawrence Papay
Council Chair

Cornelius Sullivan
Council Vice Chair

Miriam John
Large Science Project Committee Chair

Susan Hackwood
Executive Director

Letter of Request

California State Senate

SENATOR JACKIE SPEIER

November 8, 2005

Dr. Susan Hackwood, Executive Director
California Council on Science and Technology
1130 K Street, Suite 280
Sacramento, CA 95814

Dear Dr. Hackwood:

It is my understanding that the California Council on Science and Technology is preparing a report on the six major federal affiliated laboratories in California. I would like to request that, if feasible, the report be addressed to me. I am very interested in looking at the contributions the laboratories make to California and what we must do to keep this great asset in our state.

Specifically, I am co-chairing a series of five hearing on the challenges that UC must meet to remain a premier public institution of higher learning and research. The fourth of these hearings by the Senate Subcommittee on Higher Education is set for November 9, 2005 at UC Merced. The committee will examine issues of access to/and cost of an undergraduate degree. The final hearing, to be held at the State Capitol in February or March of 2006, will showcase how UC partnerships have created new industries in California and the nation. It is at this hearing that I would like to have testimony on the importance of the six major federal affiliated laboratories in California. The council's report will be most helpful.

I appreciate your consideration of my request. Please contact me, or my staff director, Richard Steffen (916-651-4773), if you have specific questions.

All the best,

Jackie Speier

Jackie Speier, 8th District
State Senate

EXECUTIVE SUMMARY

Federal laboratories are an important part of California's science and technology capabilities and infrastructure. California is home to over 40 federal laboratories, the largest concentration of federal laboratories in the nation, ranging from small facilities to two laboratories with annual budgets over $1.5 billion each. The six largest of these provide a wide range of direct benefits to the state, including:

- *$5 billion in annual spending.*
- *More than 23,000 jobs.*
- *Partnerships with local industry.*
- *Collaboration with research universities in the state.*
- *Research opportunities for young university graduates as well as seasoned scientists.*
- *Science education for thousands of school students.*
- *Expert assistance to state and local governments — from environmental clean up, to port security, combating wildfires, detecting agricultural diseases, and beyond.*

At a time when California's economic future increasingly relies on scientific and engineering expertise, the federal labs provide critically important know-how and highly specialized facilities. Their presence spurs innovation in California's high-tech industries; collectively, they serve as a magnet for some of the best scientific minds in the nation. And today, going beyond their federal missions, the labs are working with California state and local agencies, industry, and universities to collaboratively solve local problems and pursue new research initiatives.

Even so, these laboratories remain a largely untapped resource by the state. Most of them are regularly called upon by the federal government to assist in disaster response; for example a team from Sandia National Laboratories/California helped analyze Hurricane Katrina's long-range effects on physical infrastructure, including the levee system, and industry in Louisiana. NASA used satellite imaging from NASA's Jet Propulsion Laboratory to characterize the extent of flooding and damage to homes. However, while the federal government regularly calls upon these facilities, laboratory officials often find themselves struggling to determine how to best inform the state government of these same resources.

THE LABORATORIES IN BRIEF

Given their many contributions, remarkable potential, and the intense competition for resources today, it is to California's advantage to ensure that federal laboratories housed here flourish. This report focuses on the six largest in the state, each of which offers a multitude of benefits and tremendous potential:

Lawrence Berkeley National Lab — a Department of Energy facility run by the University of California, Berkeley Lab conducts unclassified research in physics, energy, advanced computing, materials science, biology, and nanotechnology. Berkeley Lab has an active technology transfer program, working closely with many California companies, both large and small. The lab also helps create new jobs by licensing technologies that become the basis for startup companies. Technologies developed there have led to the creation of more than 18 start-up companies with a combined market capitalization of more than $2 billion. Symyx Technologies, Inc., for example, is the result of a Berkeley Lab license. Begun as a start-up, it is now a publicly traded company with a market capitalization of more than $900 million and more than 275 employees, many of whom hold well-paid, highly skilled positions. Joint research projects and other research endeavors with major California companies are numerous, and include activities with Chiron, General Atomics, Hewlett-Packard, Kaiser Foundation Hospital, and Genentech, to name a few.

Lawrence Livermore National Lab — concentrates on national security, particularly the reliability and safety of nuclear weapons, nonproliferation, and homeland security. The Department of Energy (DOE) owns LLNL; the University of California operates it. Livermore helped state farmers successfully battle Newcastle poultry disease and soybean disease. In addition, the Lab pioneered summer programs for California science and math teachers; has assisted state and local governments with groundwater clean up, air quality assessment and monitoring; and assists with assessing the state's homeland security needs, including port, border, and airport concerns.

Sandia National Laboratories (California branch) — with responsibilities in national security, homeland security, and energy. The Sandia Corp., part of Lockheed Martin, operates Sandia/California. Sandia/California has a robust technology licensing program that in 2004 had 1,090 active licenses, many with California companies. In energy research, the Lab is at the forefront of work being done on hydrogen fuel systems, in partnership with California firms. A vigorous set of educational programs supports some 200-300 students each year; the Lab also runs a number of institutes for students and faculty in cybersecurity, explosive detection technology, advanced sensors, computational science and mathematics, and three-dimensional modeling and simulation, among others. Moreover, as with Lawrence Livermore, Sandia/California works directly with the state to tackle security issues. It evaluated the preparedness of Southern California Edison's grid management system and helped officials in Riverside and Alameda counties learn how to use a patented technology for disabling unexploded bombs. In a long-term partnership, Sandia and San Francisco International Airport have jointly developed models, introduced detection technologies, performed exercises, and developed response procedures to mitigate the risk and consequences of possible chemical and biological attacks.

Stanford Linear Accelerator Center — conducting fundamental research in physics as well as research in imaging for advanced materials and biology. SLAC is owned by DOE and run by Stanford University. Using SLAC's powerful imaging tools, researchers are able to look deeply into materials and analyze their composition. In medicine, scientists are investigating parasite proteins associated with breast cancer. They're using SLAC equipment to learn more about protease inhibiters — to combat HIV, and they're finding out about how the structure of the bone is affected by osteoporosis. In environmental science, researchers are learning how certain types of plants clean up the environment by removing toxic substances. Researchers from the semiconductor industry use the facility to detect and remove microscopic specks of metals from silicone wafers that can impair computer memory.

Ames Research Center — involved in robotics, spacecraft re-entry systems, advanced computing, aviation safety, astronomy, astrobiology, and nanotechnology. Ames is run by NASA with an affiliated research center managed in partnership with the University of California. In the 1990s, Ames used its remote-sensing technology to help California's multi-billion-dollar wine industry detect and manage phylloxeria, a root louse that destroys grape vines. Ames also runs a host of education programs — robotics camp for students; summer research experiences in industry for teachers; and opportunities for high school seniors to work at Ames, to name a few. At the college level, the Lab runs a variety of programs, among them, a summer program for minority students, competitively awarded graduate fellowships, and summer research opportunities for college faculty.

Jet Propulsion Laboratory — designs and manages many of the nation's robotic missions in space, along with orbiting telescopes and a deep-space communications network. Caltech operates JPL for NASA. From 2000-2003, JPL obtained nearly 140 patent licenses — more than any other NASA center — contributing to the state's economy through the commercialization of high-tech inventions. Over the past 10 years JPL has licensed, among other inventions, a methanol fuel cell to a Los Angeles-based company, a high–performance gyroscope to the Hughes Space and Communications Co. in El Segundo, and a new radar mapping technology to EarthData International in Fresno. Educational opportunities abound and include robotics competitions, summer employment, materials seminars, tours for teachers, and research awards and fellowships for college and university faculty.

ISSUES AND LIMITATIONS

Despite the benefits the federal laboratory facilities offer the state, they remain a largely untapped resource for California. State agencies of course have their own technical capabilities, but the laboratories could also contribute more to the state. For example, the labs could provide additional expertise in such areas as homeland security, water management, energy efficiency, and science and math education.

There are, however, significant issues to address before the gaps between the state and the federal laboratories can be bridged. The principal challenges fall into five main categories:

Challenges facing state government. State agencies that want assistance from federal laboratories face several challenges. The state's contracting rules run counter to the federal government's: state law generally prohibits agencies from paying in advance for research services; federal law requires advance payments. The difference makes the negotiation of cooperative projects exceedingly difficult. Moreover, different ways of managing indemnification, audits, and intellectual property also hinder the process. And because state agencies appear to have different procurement policies, each agreement must be individually crafted, leading to inevitable delays that impede prompt action on important issues.

Challenges facing local government. At the local level, officials do not routinely have access to the level of expertise they might need to help determine which research trends to follow and which new technologies to adopt. In other words, they may not know what they don't know, and so would have no way of assessing where to go for assistance, and even what questions to ask. The potential for local governments to benefit from what the federal labs are doing in the area of homeland security, for instance, is great, but a mechanism is needed to help facilitate the transfer of that knowledge down to the local level.

Challenges facing industry. While some of California's large corporations enjoy steady, ongoing relationships with the federal laboratories, smaller companies are not likely to know about the technical opportunities the labs offer. Intel, for example, works closely with several of California's federal facilities. But an examination of the list of collaborations among the labs and private firms reveals that few small companies are so engaged. And even large firms may not have the know-how to deal with the rules and procedures of the federal bureaucracy.

Competition from other states. The federal laboratories in California compete vigorously with labs in other states to win new projects and facilities. The fact is, other states are becoming increasingly sophisticated in the way they attract federal projects — providing their own money to attract or supplement new federal facilities — ultimately making the competition extremely difficult. California must become more cognizant of that fact, and more connected to its federal labs if they are to compete effectively against other states.

Internal laboratory issues. The laboratories themselves face limitations that sometimes affect their ability to conduct new kinds of research or work with California companies, universities, and governments. The labs must of course give priority to their prime federal missions. Taking on other missions and activities requires careful planning and cooperation among the laboratories and industrial and government officials. But there are many areas of activity where the needs of state based entities are entirely consistent with the laboratories overall missions and hence offer excellent opportunity for federal-state and industry partnerships.

Given the tremendous value already demonstrated by these facilities, and the enormous potential they possess to assist California's government, academic, and industry communities even further, it is in California's long-term interest to keep them in the state and work to overcome challenges inhibiting more successful leveraging of these important resources that contribute jobs, procurement dollars, and technology to California.

RECOMMENDATIONS

Given the reality of increased competition, bureaucratic snags, and other structural challenges, what can be done to help remedy the situation? There are some practical, achievable steps that state officials in the Governor's office, the Legislature, and state agencies could take, possibly in partnership with CCST, that would help reduce these barriers and enable California to take better advantage of what the laboratories have to offer.

1. Streamline the contracting process with the state.

Administrative barriers could be reduced by standardizing rules and procedures. To accomplish this:

- The California Department of General Services should assemble a small working group of representatives from state and federal agencies to propose a set of standardized rules and policies that would facilitate — rather than hinder — collaboration.
- The California Legislature should enact a new law that would permit state agencies to pay for technical services in advance, once the contract has been signed.
- A standardized model contract for working with the laboratories, approved by the state attorney general and the Department of Finance, should be made available to all state agencies.
- The major state agencies with technical missions — such as the California Energy Commission, Environmental Protection Agency, and the Office of Homeland Security — should appoint specific individuals with principal responsibility for working with the federal laboratories — making contact, brokering agreements, and creating partnerships. Reciprocally, the laboratories should designate individuals who would provide liaison back to the state.

2. Create bridges between laboratory and state officials.

For the state to benefit more fruitfully from the federal labs in California, a richer exchange of information first must occur. In keeping with its mission of providing science and technology assistance to the state, CCST could organize special workshops for agency officials, legislators, and laboratory officials — so that they have the opportunity to better understand the missions, roles, and research areas of each, and brainstorm possible collaborative opportunities. Follow-up activities should then occur, including site visits and temporary personnel exchanges.

3. Use the laboratories to enhance state research on key issues such as homeland security.

The federal labs can provide vital expertise and direction for a range of state interests including energy research, water, and other key infrastructure issues. In addition, several of the laboratories, including LLNL, Sandia, and Ames, have important technologies that could help state disaster response at a variety of levels. For emergency response and security related issues, the Governor's Office of Homeland Security should build on recent visits to LLNL and Sandia and establish state-facilitated mechanisms that will help transfer laboratory technology and know-how to California first responders. The laboratories also can provide further training for local agencies. It is possible that new federal funding might become available for these activities, either from the U.S. Department of Homeland Security or through assistance from the California Congressional Delegation.

4. Assess the state's competitive edge.

To ensure California's competitiveness, a study should be commissioned that surveys private industry and universities throughout the state about the research capabilities and facilities that will be needed for the future — particularly in the key fields of information technology, aerospace, energy, biotech, agriculture, and nanotechnology. The survey should ultimately be directed to answer the question: What facilities should the federal laboratories located in the state have in place to ensure competitiveness in these areas?

A related point is that opportunities exist for the state and the laboratories to partner in proposals to 'win' important facility construction programs from the federal government, e.g., in the near term, in proteomics and in energy efficiency from the Department of Energy (DOE). There also could be opportunities to enlist the support of the California Congressional Delegation for user facilities at the laboratories that would intentionally build in mechanisms for university and industry access to these facilities, based on models such as access to the Combustion Research Facility at Sandia or the Advanced Light Source at Berkeley Lab.

CONCLUSION

Along with the state's universities and high-tech companies, the six major federal labs provide the raw talent and research muscle that helps make California a world leader in science and technology. But more — much more — could be done to make the connections among the labs to industry, universities, and state agencies more seamless and more productive. And time is of the essence — particularly in this era of increased competitiveness and a multitude of other challenges including natural disasters and terrorism. We offer these practical, achievable steps in the hopes of spurring fresh thinking, new partnerships, and a heightened sense of urgency and potential.

1. INTRODUCTION

1.1. CALIFORNIA HAS THE NATION'S LARGEST CONCENTRATION OF FEDERAL LABORATORIES

The federal government owns several hundred science and engineering laboratories that help it carry out responsibilities in fields such as defense, energy, space, health, commerce, geology, agriculture, forestry, and fisheries. California is home to more federal laboratories than any other state. The best available analysis is that California has 48 laboratories out of a national total of over 600.[1]

These federal laboratories are a vital part of California's overall capabilities in science and technology. They employ thousands of researchers, conduct both basic and applied research in areas important to the state's industries, help educate new generations of scientists and engineers, and in some cases provide valuable assistance to California state agencies. Figure 1.1. shows that in 2000 — the most recent year for which data are available — research and development (R&D) expenditures for all federal laboratories in California totaled $4.633 billion. This amount represents a significant portion of California's science and technology resources — over eight percent of all R&D in California that year (both public and private R&D) and more than the R&D expenditures that year in all of California's universities.[2]

1.2. CALIFORNIA HAS SEVERAL TYPES OF FEDERAL LABORATORIES

Besides serving different federal agencies, federal laboratories in California vary in several important ways.

- ***Size and budget.*** Individual federal laboratories within the state range from small to very large. Smaller ones with budgets up to $20 million a year include research facilities for fisheries, forestry, and agriculture, as well as clinical research laboratories in veterans' hospitals. Large defense, energy, and space laboratories each have budgets ranging from several hundreds of millions of dollars a year to over a billion dollars.
- ***Staffing and management.*** Federal laboratories also vary in terms of who staffs and manages them. Their staffs and managers can be either federal civil servants or contractors. Most federal laboratories have civil-servant staffs and are called "government-owned, government-operated" laboratories. Examples include all Department of Defense (DOD) laboratories and most NASA centers. However, contractors manage a few of the government's largest laboratories. The contractors can be universities, industrial firms, or non-profit entities. This type of facility is called both a "government-owned, contractor-operated laboratory" and a "federally-funded

[1] No recent numbers are available for the numbers of federal laboratories either nationwide or in California. In 1996, Barry Bozeman, a leading scholar on federal laboratories, calculated that the federal government had 627 R&D laboratories, with total funding of more than $20 billion per year. Barry Bozeman, "Federal Laboratories," available at http://cspo.org/products/conference/bush/partthree. In 1999, a CCST report calculated that California had 48 federal laboratories. See Patrick H. Windham with assistance from David W. Cheney, *An Analysis of Major Federal Laboratories in California. Volume II: Policy Options and Background. http://www.ccst.us/ccst/pubs/crest/index.html* CCST hopes to update this calculation of federal laboratories located within the state.

[2] National Science Board, *Science and Engineering Indicators — 2004*, Appendix table 4-24. In 2000, NSF calculated that R&D expenditures for all federal laboratories in California (not including Sandia/California, which NSF classified with its parent laboratory in New Mexico) totaled $4.468 billion. However, adding Sandia/California's FY 2000 budget of $165.5 million brings the total to $4.633 billion. Total R&D in California universities, from both public and private sources, totaled $4.053 billion in FY 2000.

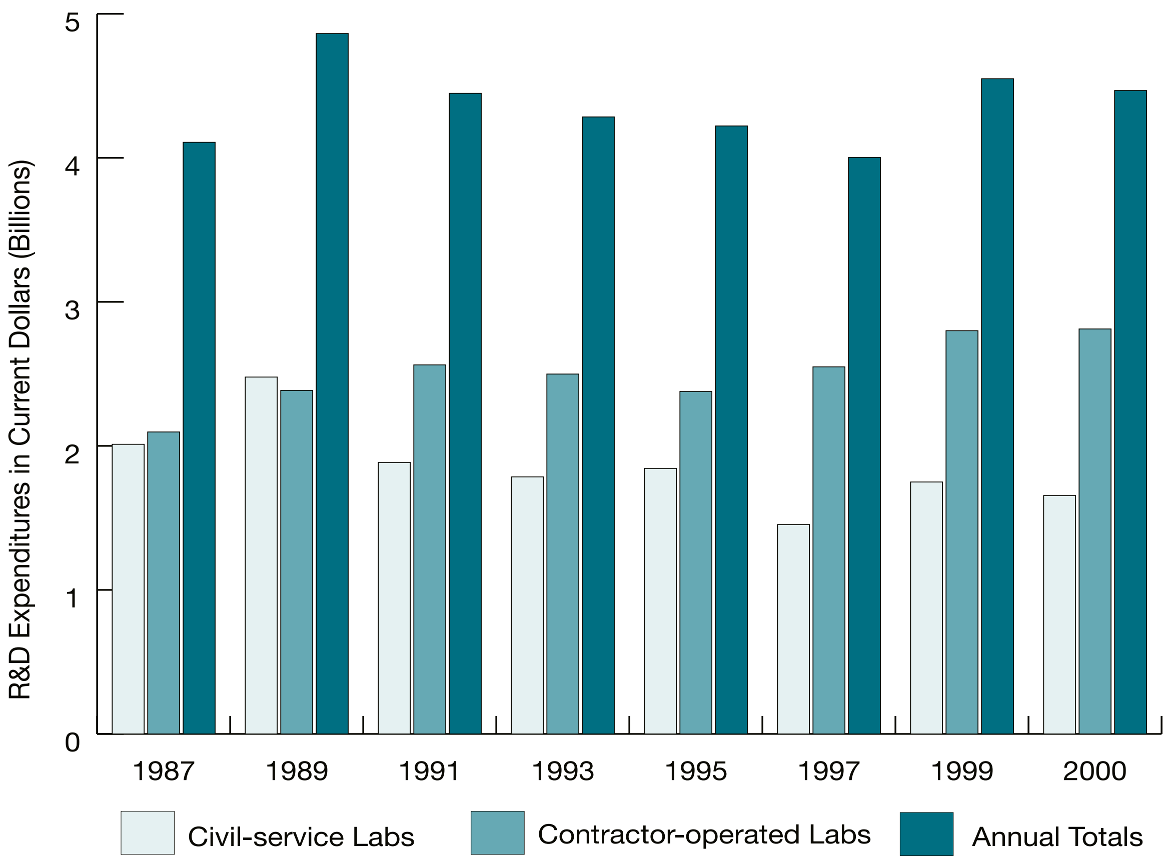


Figure 1.1. Federal Funds for All Federal Laboratories in California (R&D expenditures in current dollars) (excludes Sandia/California) Source: NSF, *Science and Engineering Indicators — 2004*

research and development center" (FFRDC). The laboratories of the Department of Energy (DOE) are almost entirely contractor-operated facilities, and NASA has one, California's Jet Propulsion Laboratory.[3]

- ***Whether they conduct basic as well as applied research.*** Laboratories also vary as to whether they conduct basic research in science and engineering. Many laboratories in California, both large and small, focus on applied research or, in the case of many Department of Defense (DOD) laboratories, on testing and evaluating equipment and systems. Test and evaluation work is very important for the federal government.[4]

[3] The nickname for a government-owned, government-operated laboratory is "GOGO," and the nickname for a contractor-operated facility is "GOCO." The terms GOCO and FFRDC, while very similar, are not identical. The term FFRDC is broader and includes not only GOCO's but also a few organizations that are not R&D laboratories, but instead policy research facilities or engineering services groups. For example, Project Air Force at California's RAND Corporation is an FFRDC that conducts important policy research, but it is not a science and engineering laboratory.

[4] Many of these more applied laboratories in California are world-class leaders in their respective fields. For example, several are leaders in aircraft technology, including the Air Force Flight Test Center at Edwards Air Force Base, NASA's Dryden Flight Research Center, also at Edwards, and the Naval Air Warfare Center Weapons Division facilities at China Lake and Point Mugu.

1.3. CALIFORNIA HAS SEVERAL OF THE NATION'S LEADING FEDERAL RESEARCH AND ENGINEERING LABORATORIES

This report focuses on six major laboratories in California that have broad scientific and technical capabilities, conduct significant basic research, and help train new scientists and engineers. Some of these laboratories maintain large research groups because their core mission is scientific research. Others maintain research groups to help them carry out important operational missions in national security or space exploration. This report will argue that all six of these laboratories are important parts of California's "science and technology infrastructure." Along with the state's universities and high-tech companies, these laboratories help create a "critical mass" of talent and research that makes California a world leader in technology, especially since the laboratories work closely with each other, with universities, and with many California companies.

The U.S. Department of Energy owns four of the six laboratories examined in this report. Contractors manage all four of these DOE-owned facilities. In alphabetical order, the four laboratories are:

- ***Lawrence Berkeley National Laboratory (LBNL or Berkeley Lab),*** a science laboratory conducting unclassified research in physics, energy, advanced computing, materials science, biology, and nanotechnology. The University of California (UC) operates Berkeley Lab. Over its history, ten Nobel Prize winners have been affiliated with the laboratory, and today 3% of the National Academy of Sciences total membership is from Lawrence Berkeley National Laboratory. Berkeley Lab also works closely with the California Energy Commission.
- ***Lawrence Livermore National Laboratory (LLNL, Livermore or Livermore Laboratory)***, whose main mission is national security — particularly the reliability and safety of nuclear weapons, nuclear nonproliferation, and homeland security. To help carry out these missions, LLNL maintains broad scientific and technological expertise, much of it unclassified, in physics, chemistry and materials science, computation, earth and environmental sciences, and biology, giving it great technical depth. UC operates Lawrence Livermore National Laboratory. Livermore is one of the nation's three elite nuclear weapons laboratories, with the other two being Los Alamos National Laboratory in New Mexico (also managed by UC) and Sandia National Laboratories. Livermore also has long worked with California state agencies on environmental issues and more recently on homeland security.
- The California Division of ***Sandia National Laboratories***, another facility with major responsibilities and expertise in national security, homeland security, and energy. The Sandia Corporation, a part of Lockheed Martin Corporation, operates Sandia/California, which is in Livermore and works closely with LLNL. The main branch of Sandia is in New Mexico and works closely with the Los Alamos National Laboratory and LLNL. Recently, Sandia has provided homeland security technologies to California, including the San Francisco Airport.
- ***Stanford Linear Accelerator Center (SLAC),*** which has helped uncover the fundamental nature of physics and recently has expanded its work in imaging for advanced materials and biology. Stanford University operates SLAC. Research at SLAC has led to three Nobel Prizes.

The National Aeronautics and Space Administration (NASA) owns the other two facilities examined in this report:

- ***NASA Ames Research Center***, which conducts scientific and technological research and development in robotics, spacecraft re-entry systems, advanced computing, aviation safety, astronomy, astrobiology, and nanotechnology. Ames is a civil-service laboratory. Ames has recently created a new research park and a pioneering joint research agreement with UC.
- ***Jet Propulsion Laboratory (JPL),*** which designs and manages many of the nation's robotic missions to other planets. It also manages several orbiting telescopes and a deep-space communications network. It has particular technical expertise in robotics and communications. The California Institute of Technology (Caltech) operates JPL for NASA.

In addition to the DOE and NASA labs, national research and information infrastructure facilities such as the San Diego Supercomputer Center significantly contribute to the state's safety and economy as well as providing global leadership in science, engineering and technology.

California also has many other national laboratories, centers, and institutes in science, engineering, and technology, as well as in areas such as defense, agriculture, and forestry. The next text box provides several examples of such resources. In addition, California's universities have world-class research programs and facilities, including large facilities used by companies as well as university professors and students. Other research organizations in California have substantial federal funding[5] as well. In this report, we focus primarily on the contributions of six national DOE-funded and NASA-funded science and engineering laboratories.

1.4. LABORATORY CONTRIBUTIONS TO CALIFORNIA

These six laboratories contribute to California in several important ways. Later sections of this report provide details on the specific contributions made by each laboratory, but here the report summarizes five types of contributions that they make.

Payrolls and Procurements

Direct benefits. The most direct benefits that these laboratories make to California are laboratory jobs and payrolls and their procurements within California. Many goods and services are bought from California's high-tech firms, helping the state's high-tech sector. And many contracts go to women-owned and minority-owned firms. Table 1.1 summarizes the budgets of these six laboratories.

Table 1.1. Budgets of the Six Laboratories — Fiscal Year 2004

	LBNL	LLNL	SNL/CA	SLAC	Ames	JPL
Laboratory budget (millions of dollars)	500	1,630	233	230	904	1,559

[5] Examples include the General Atomics fusion research facility in San Diego, funded by the Department of Energy, and SRI International in Menlo Park, which has funding from the Department of Defense and other federal departments and agencies.

EXAMPLES OF MAJOR UNIVERSITY RESEARCH FACILITIES AND CENTERS IN CALIFORNIA

In addition to unique research facilities and centers at federal laboratories, California also has national facilities and centers that help researchers from both academia and industry stay at the cutting edge of science, engineering, and technology. California's universities have many such centers, and in fact further analysis is needed to create an inventory of their capabilities and resources for California. The following examples illustrate some of California's Centers and national resources primarily funded by the National Science Foundation (NSF), however other federal agencies also support California's Centers.

San Diego Supercomputer Center (SDSC). Based at UC San Diego, SDSC is a national science, engineering, and technology facility for the broad NSF community, and one of three large NSF-sponsored "cyberinfrastructure" centers in the United States. SDSC is a major resource for researchers in the academic, public, and private sectors, providing very large supercomputers for running calculations and simulations, and very large facilities for the management, archiving and preservation of community and reference data collections. SDSC's 400+ multi-disciplinary staff are involved in leading projects from virtually every academic discipline as well as research and education efforts in science and engineering. Very large data-oriented computer simulations run at SDSC have contributed to research in fields as diverse as astronomy, breast cancer, AIDS, renewable energy, and seismology. For example, one important recent collaboration between SDSC and the Southern California Earthquake Center provided the most detailed model yet of what would happen to Southern California if a magnitude 7.7 earthquake occurred along the southern portion of the San Andreas Fault. The model and the massive amount of data generated during the computer simulation will help engineers design more quake-resistant structures. In addition to aiding researchers, SDSC also works with IBM, Sun, and other companies to help keep California a world leader in the advanced computing industry.

Nanofabrication research facilities — Stanford, UCLA and UC Santa Barbara. While SDSC provides critical infrastructure to support research in all fields, other user facilities and research centers at California universities support academic and industrial research in specific areas. California's two NSF-sponsored nanofabrication facilities are examples. Located at Stanford, UCLA and UC Santa Barbara, these advanced laboratories allow researchers to conduct state-of-the-art experiments and build and test new nanoscale products — an important resource in California's efforts to stay a world lead in nanotechnology. At Stanford, for example, over 600 groups from universities, industry, and government use the facility. Work at the UCLA and UCSB facilities shows the range of research and its importance to California industry: electronic circuits, optoelectronic devices, quantum physics, magnetic materials, and biophysics.

Engineering research centers and science and technology centers. NSF also sponsors interdisciplinary centers that work closely with industry to develop and transfer new technology and to train new generations of students. Four such centers in California illustrate the cutting-edge research performed at these sites. The first three are engineering research centers, and the fourth is a science and technology center.

- ***Pacific Earthquake Engineering Research — UC Berkeley.*** This center, run by Berkeley in partnership with seven other California campuses, works closely with California State agencies and private companies to improve the design of buildings, bridges, pipelines, and other structures and to improve tools for assessing the safety of structures after major earthquakes.
- ***Biomimetic Microelectronics Systems Engineering Research Center — University of Southern California (USC).*** In partnership with Caltech and UC Santa Cruz, USC is exploring ways to use miniaturized implants to restore sight, restore motion in paralyzed limbs, and restore damaged brain functions. This research may have major implications for both human health and the California biomedical industry.
- ***Integrated Media Systems Center — USC*** As a leader in multimedia and the Internet, this center has developed technologies for immersive animation, touch-related media, data compression, and wireless communications.
- ***Center for Biophotonics Science and Technology — UC Davis.*** This center brings together academic scientists, industrial researchers, and educators to research and develop applications of biophotonics — the science of using light to understand the inner workings of cells and tissues in living organisms.

Salaries for employees directly contribute to the California economy. Other laboratory funds go for procurements of equipment, buildings, and supplies, and much of that procurement money is spent in California. For example, in fiscal year 2004 Lawrence Livermore National Laboratory spent a total of $599 million on procurements, of which $265 million (or 44%) was spent in California.

Secondary economic benefits. These payrolls and procurements also create additional economic benefits for California. Economists point out that direct expenditures also have an important economic "multiplier" effect. That is, when federal laboratories or their employees spend money in California, that spending generates "secondary impacts" — additional jobs and other benefits for the California economy. So there is an important ripple effect that goes beyond direct spending. The U.S. Department of Commerce's Bureau of Economic Analysis provides a standard methodology (called "RIMMS II") for calculating economic multiplier effects. While no one has conducted a comprehensive analysis of the multiplier effects of all federal laboratories in California, an economic study commissioned by the NASA Ames Research Center calculated that each dollar spent by NASA Ames generates $2.5 of economic output throughout the United States and approximately $1.6 of total economic output within California.[6] So these federal laboratories support significant numbers of additional businesses and jobs within California.

Each dollar spent by NASA Ames generates $2.5 of economic output throughout the United States and approximately $1.6 of total economic output within California.

Contributions to Education and Academic Research

The six federal laboratories make three types of significant contributions to education and academic research in California:

- ***Assistance to students and teachers in kindergarten through community college (K-14).*** All six of the laboratories offer curriculum materials, Web sites, and tours for students from the elementary level through the two years of community college. Some — including Livermore, Sandia, Berkeley Lab, and Ames — also offer summer training courses and even research internships for California high school students and science and mathematics teachers, while JPL works closely with a number of Southern California schools and their teachers. At a time when California faces shortages of qualified science and math teachers, these are valuable programs.
- ***Programs for undergraduate and graduate students and postdoctoral fellows.*** The laboratories offer summer internships for undergraduate science and engineering students, fellowships and internships for graduate students, and postdoctoral fellowships. Special programs are aimed at helping women and underrepresented minorities who are interested in science and engineering. These programs help train California students, attract talented out-of-state students to California, and also help the laboratories themselves by increasing the chances that some of these students will eventually take jobs with the federal facilities.
- ***Academic researchers***. One advantage of large federal laboratories is that they can maintain large state-of-the-art research facilities — facilities often open to California university researchers. While some operations at Livermore and Sandia/California

6 Bay Area Economics, *Economic Benefits Study: NASA Ames Research Center and NASA Research Park*, July 9, 2004, page iii.

are classified, even those laboratories have facilities open to outside researchers. Not surprisingly, Berkeley Lab and Livermore have close ties with researchers from the University of California. However, their facilities and research units are also open to professors from other California schools. SLAC's senior researchers are Stanford professors, and both students and professors mingle easily between the accelerator center and the main campus. Close ties also exist between JPL and Caltech, and JPL involves hundreds of professors from around the country in its space science missions. But even the laboratories not run by universities have close ties with academia: Sandia/California works with many university professors, and last year, NASA Ames signed a 10-year, $330 million contract with the University of California to create a pioneering University Affiliated Research Center to work on research questions important to NASA; UC Santa Cruz is managing that effort.

Direct Contributions to Industry

These six federal laboratories also provide direct assistance to California companies, large and small. This assistance takes several forms:

- ***Research for and with industry.*** Under federal law, unclassified R&D groups in these laboratories (and, again, even Livermore and Sandia/California have large unclassified programs) can work with California companies on joint projects. Department of Energy laboratories may engage in both joint R&D (through what are called "cooperative research and development agreements") and contract R&D ("work for others"). Particularly important is access to unique research facilities. For example, Intel will be one of the first users of Berkeley Lab's new Molecular Foundry, a major new nanotechnology research facility. Companies needing very precise microscopic images of materials and proteins use x-ray imaging devices at Berkeley Lab and SLAC. Several companies use Sandia/California's Combustion Research Facility for research on hydrogen fuel cars. NASA centers have different but similar rules that allow joint work and access to facilities. NASA Ames, for example, has long had wind tunnels that companies use to test aircraft designs and also offers access to its supercomputer and other facilities.
- ***Technology licenses.*** In addition to joint work, federal law allows the laboratories to license their unclassified inventions and software to private companies. All of the laboratories have granted licenses that have helped create California start-up companies.
- ***Small business awards.*** The federal Small Business Innovation Development Act of 1982 requires all federal agencies with an R&D budget of $100 million per year or more to set aside some of this grant money for small businesses. These agencies make two kinds of awards: Small Business Innovation Research (SBIR) grants and a smaller number of Small Business Technology Transfer (STTR) grants, which involve universities as well as small firms. The Department of Energy has centralized its SBIR/STTR process, making the selections in Washington, D.C. But numerous California companies win Department of Energy SBIR awards, and some of them choose to work cooperatively with DOE laboratories in the state. Contracts from DOE laboratories often involve small business subcontractors, and DOE laboratories also provide technical assistance to small companies. NASA Ames and JPL have active SBIR/STTR programs, which help small high-tech start-ups.

Indirect Contributions to Technology and Industry

In addition to the contributions that the laboratories make to individual companies, California also benefits from the role that the laboratories play in strengthening California's overall network of researchers and innovators. Rather than being isolated institutions, these laboratories connect in rich ways with other technology centers in the state. First, through their ties with each other and through connections with California universities and company researchers, the laboratories help California form ***"research clusters***" — groups of research organizations that provide critical masses of talent, facilities, and research projects in important areas of science and technology. By working together and exchanging ideas, the sum of California's research organizations is greater than the individual parts. Second, combining those research clusters with California's vibrant business community creates an overall network or ***"innovation ecosystem"*** of talented people and organizations that contribute greatly to innovation and economic growth in California. Research ideas and individuals move among federal laboratories, universities, and companies — to the benefit of all three sectors and to the benefit of California's economy.

The concept of "research clusters" is not as well known as the older idea of regional economic clusters. Californians are now familiar with the concept of economic clusters — regional groups of companies that cooperate as well as compete with each other, with a push from demanding customers and with help from specialized institutions such as research institutions and skilled professionals in areas such as law, accounting, and real estate. California of course has world-class economic clusters in industries as diverse as aircraft, electronics, biotechnology, motion pictures, and wine-making.[7]

But recently, analysts and policymakers have learned more about the research side of this process and the role of research clusters.[8] The following are several major research clusters in California to which federal laboratories contribute:

- The space technology research cluster that includes not only JPL and Ames but also the Air Force Space and Missile Systems Center and the federally funded Aerospace Corporation, both in Los Angeles.
- The physics research cluster that includes Berkeley Lab, UC Berkeley, SLAC, Stanford, and Livermore. In addition to conducting basic research on the nature of atoms, this cluster also has pioneered the use of x-rays and other techniques to characterize advanced materials, including human proteins and materials for the electronics industry.

---

[7] Important works about clusters, cluster theory, and the role of universities include Michael E. Porter, "Clusters and Competition: New Agendas for Companies, Governments, and Institutions," in Michael E. Porter, *On Competition* (Cambridge, MA: Harvard Business School Press, 1998); AnnaLee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge, MA: Harvard University Press, 1996); Martin Kenney, editor, *Understanding Silicon Valley: The Anatomy of an Entrepreneurial Region* (Stanford, CA: Stanford University Press, 2000); and Lynne G. Zucker and Michael R. Darby, "Star scientists and institutional transformation: Patterns of invention and innovation in the formation of the biotechnology industry," *Proceedings of the National Academy of Sciences, USA*, Volume 93, pages 12709-12716, November 1996. For a discussion of the opportunities and political constraints affecting the ability of federal laboratories to participate in private technology development, see Linda R. Cohen and Roger G. Noll, "The future of the national laboratories," *Proceedings of the National Academy of Sciences USA*, Volume 93, pages 12678-12685, November 1996.

[8] For one discussion of research clusters and their value to regional economic development, see Mary L. Walshok, Edward Furtek, Carolyn W.B. Lee, and Patrick H. Windham, "Building regional innovation capacity: The San Diego experience," *Industry & Higher Education*, February 2002.

- An electronics research cluster that includes Intel laboratories, IBM laboratories, Sandia, Livermore, Berkeley Lab, Stanford, and UC Berkeley. An important project in this cluster was the extreme ultraviolet lithography (EUVL) project described in the first text box on the next page.
- A supercomputing research cluster that includes Berkeley Lab, Livermore, Ames, Sandia/California, IBM, and Silicon Graphics.
- A Department of Energy-sponsored institute is part of the Bay Area's biotechnology/genomics cluster. The Joint Genome Institute (JGI) in Walnut Creek, managed by the University of California for the Department of Energy, includes Berkeley Lab, Livermore, Pacific Northwest National Laboratory (PNNL) in Washington, Los Alamos in New Mexico, Oak Ridge National Laboratory in Tennessee, and the Stanford Human Genome Center. The Institute played a key role in the Human Genome Project, generating the complete sequences for chromosomes 5, 16, and 19. Since then, the JGI has sequenced a number of organisms, plant pathogens, and over 200 microbial genomes.
- Another research consortium contributing to the biomedical community is Berkeley BioSpice, a computational biology group developing open source software for analyzing biomedical data and modeling biological processes. Participants include Berkeley Lab, UC Berkeley, and SRI International, with collaborations with scientists from other institutions. One project, supported by the National Cancer Institute, is developing computer models of breast cancer cell behavior.
- Emerging nanotechnology research centers in Southern California (around the UCLA-UC Santa Barbara Nanosystems Institute) and in Northern California (involving, among others, Berkeley Lab, UC Berkeley, Stanford, Livermore, and Ames).

By recruiting top talent, offering world-class facilities, and building formal and informal collaborations, federal laboratories, the state's universities, and corporate research facilities form a rich network of researchers that provides critical mass in key areas and keeps California at the cutting edge of science and technology. They keep California a world leader in these key areas. While measuring the exact value of these contributions is difficult, because the payoff to the economy is often long-term and indirect, having clusters of this quality constantly developing new knowledge and constantly training new people clearly is a major asset for the state's economy.

The two text boxes on the following pages offer examples of laboratory contributions to California's research clusters and R&D capabilities.

Some quantitative data are available to show how much these six laboratories cooperate with other research organizations. As the insert at the end of this chapter shows, Professors Michael Darby and Lynn Zucker of UCLA have provided data on the extent to which the six laboratories work with firms and universities in the creation of new knowledge in the field of nanotechnology. Professors Darby and Zucker[9] looked at scientific papers in nanotechnology written wholly or in part by researchers from the six laboratories in California from 1982 through 2004, to see how many papers involved co-authors from firms, universities, and other research organizations.

[9] Zucker and Darby are both professors at UCLA, Research Associates of the National Bureau of Economic Research, and fellows of the California Council on Science and Technology. California's six major national laboratories are defined as Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories/California (Sandia National Laboratories in New Mexico treated as a separate, not included lab), Stanford Linear Accelerator Center, NASA Ames Research Center, and Jet Propulsion Laboratory.

RESEARCH CLUSTERS: EXAMPLES OF LABORATORY PARTICIPATION IN CALIFORNIA COLLABORATIVE RESEARCH

- ***Semiconductor production.*** In the late 1990s and early 2000s, scientists from Sandia, Livermore, and Berkeley Lab partnered with an Intel-led industry team to refine a government-developed technology for making advanced microprocessors and memory chips. The technology is called "extreme ultraviolet lithography" (EUVL) and is a way to use ultraviolet light to etch many more features on semiconductor chips than is possible with earlier techniques. The technology will help Intel and others to keep making ever more powerful chips. In 2003, the project won a prestigious "R&D 100" award from *R&D Magazine*.
- ***Sandia/California's Combustion Research Facility*** worked with universities and industry to pioneer laser measurement technology and computer models to better understand automotive engines and power plants and reduce pollution and improve efficiency. Recently, it also has helped develop new ways to store hydrogen for vehicles.
- ***Nanotechnology research.*** Berkeley Lab will open in 2006 an important research facility for nanotechnology research, the "Molecular Foundry." Intel has announced that it will be an active participant in the Foundry's research program.
- ***Ames-UC research collaboration.*** UC Santa Cruz and Ames have established a University Affiliated Research Center (UARC) at Ames, part of a 10-year, $330 million research contract between NASA and UC. UARC has over 100 employees and works in areas such as air traffic management, human space exploration, and nanotechnology. UARC is one part of the new NASA Research Park at Ames.
- ***Telescope design.*** In the 1970s and 1980s, Berkeley Lab's Jerry Nelson and his colleagues proposed a revolutionary way to build telescopes for university astronomers: using many small mirrors to make a reflecting surface rather than using just one large, expensive mirror. Berkeley Lab scientists developed a structural design using this new approach, and JPL contributed a project manager, Jerry Smith. With funding from the Keck Foundation, UC and Caltech built two of these revolutionary telescopes on Mauna Kea on the Big Island of Hawaii.
- ***Telescope improvements.*** One of the two Keck telescopes has just been fitted with new technology designed and built by Livermore scientists. The new system combines a laser system for guiding the telescope to particular stars and new adaptive optics that improve images. The system — the first of its kind on a large telescope — improves images in the near-infrared by an order of magnitude, and increases from one% to 70% the proportion of targets observable in this band in the northern sky.

Figure 1.2. shows that before 1988, most of the scientific papers on nanotechnology published by researchers from the six laboratories did not include co-authors from other organizations. Even today, laboratory scientists publish some papers on their own (the light blue sections at the bottom of each bar in figure 1.2.). But beginning in 1988, an increasing percentage of the papers included co-authors from industry, universities, and elsewhere. Some 69% of nanotechnology papers published by laboratory scientists from 1982 to 2004 involved co-authors from other organizations — a remarkable indication of how much the laboratories are woven into an overall nanotechnology research cluster.

Sixty-nine percent of nanotechnology papers published by laboratory scientists from 1982 to 2004 involved co-authors from other organizations.

As Darby and Zucker point out in their discussion, such close collaboration has important implications for the rapid transfer and commercialization of new knowledge: "Articles with co-authors from a firm indicate direct transfer of tacit knowledge to firms. Since university professors often collaborate with or start firms, co-authorships with university co-authors may

RESEARCH CLUSTERS: EXAMPLES OF RESEARCHERS MOVING BETWEEN FEDERAL LABORATORIES AND CALIFORNIA UNIVERSITIES AND COMPANIES

- ***Paul Alivisatos***, an associate director at Lawrence Berkeley National Laboratory and a professor at UC Berkeley, is an example of a laboratory researcher who helped start a company. Founded in 1998, Quantum Dot uses nanocrystals to reveal biological processes. The company is based on technology developed by Dr. Alivisatos and others, and he is a member of the company's scientific advisory board. In a new development, Quantum Dot and JPL researchers are collaborating on the development of new portable biological detection technology.
- ***Steven Chu***, Berkeley Lab's director, came from Stanford University, and many of the leaders of Berkeley Lab, SLAC, and JPL either worked earlier in universities or continue to have ties to UC Berkeley, Stanford, and Caltech.
- ***Scott Hubbard***, director of NASA Ames, has experience and contacts in a range of California research organizations. Prior to joining NASA in 1987, he served as a staff scientist at Berkeley Lab, was a founder and executive at Canberra Semiconductor (a San Francisco Bay Area start-up), and a senior research physicist at SRI International. Ames' chief technologist, ***Peter Friedland***, helped pioneer the first applications of artificial intelligence to problems in molecular biology while at Stanford in the 1970s; in 1979 founded IntelliGenetics, the first bioinformatics company; and later co-founded another company, Teknowledge.
- UC Santa Cruz professor ***Claire Max*** previously served as director of Livermore's Institute for Geophysics and Planetary Physics and later as director of Livermore's University Relations Program. She is now director of UC Santa Cruz's Center for Adaptive Optics, a National Science Foundation-funded Science and Technology Center that is developing advanced optics to reduce blurring in telescopes, retinal imaging and surgery, and other applications.
- Faculty members ***Chris Edwards*** and ***Reginald Mitchell*** (Stanford), ***Robert Dibble*** and ***JY Chen*** (UC Berkeley), ***Robert Cattolica*** (UC San Diego), and ***Billy Sanders*** (UC Davis) were all members of the technical staff at Sandia's Combustion Research Facility before moving to academia.

be significant sources of indirect impact of the national labs on commercial development." Figure 1.3. focuses on articles co-authored with authors from university or industry.

Contributions to State and Local Government

Several of these six federal laboratories have provided valuable technical assistance to California state agencies. As mentioned earlier, Berkeley Lab has a longstanding relationship with the California Energy Commission (CEC). Livermore also has worked with the CEC as well as with the California Environmental Protection Agency on groundwater clean-up assessments and technologies. Sandia/California's new homeland security technologies are helping the San Francisco Airport and the Ports of Los Angeles and Long Beach. As will be discussed later in this report, state procurement rules make it difficult for state agencies to work with federal laboratories. But if the state could reform those rules, the federal laboratories could contribute even more to California.

State procurement rules make it difficult for state agencies to work with federal laboratories. But if the state could reform those rules, the federal laboratories could contribute even more to California.

1.5. ORGANIZATION OF THIS REPORT

The next six chapters of this report present overviews of the six laboratories, presenting first the DOE laboratories, in alphabetical order, and then the two NASA centers. A concluding chapter summarizes key points and offers observations about some ways in which California might work with federal laboratories to gain more benefits for the state. Appendix B gives more data on selected contributions to California made by five of the six federal laboratories.

A final point is that the information provided in this report comes from several sources: laboratory Web sites, additional data provided by the laboratories, interviews conducted for this study, and other reports. The author is grateful to the many people who provided valuable information and assistance for this study.

MEASURING NANOTECHNOLOGY KNOWLEDGE CREATION AND FLOWS IN CALIFORNIA'S SIX MAJOR NATIONAL LABORATORIES

By Michael R. Darby and Lynne G. Zucker*

Publication of journal articles is a professionally important means of claiming credit for significant scientific discoveries while disseminating them to the scientific community. Total publications over time thus serve as a quantifiable measure of the creation and dissemination of knowledge. This inherently imperfect measure necessarily omits scientific creation, which is not published due to national security considerations. We and our co-authors have demonstrated that bench-level collaboration as evidenced by co-authorship of published papers is an important means of dissemination of tacit knowledge, which is often necessary for commercialization of a scientific discovery.+ That is, the extent to which articles are co-authored and with whom can be an important indicator of the impact of scientific discoveries on economic development.

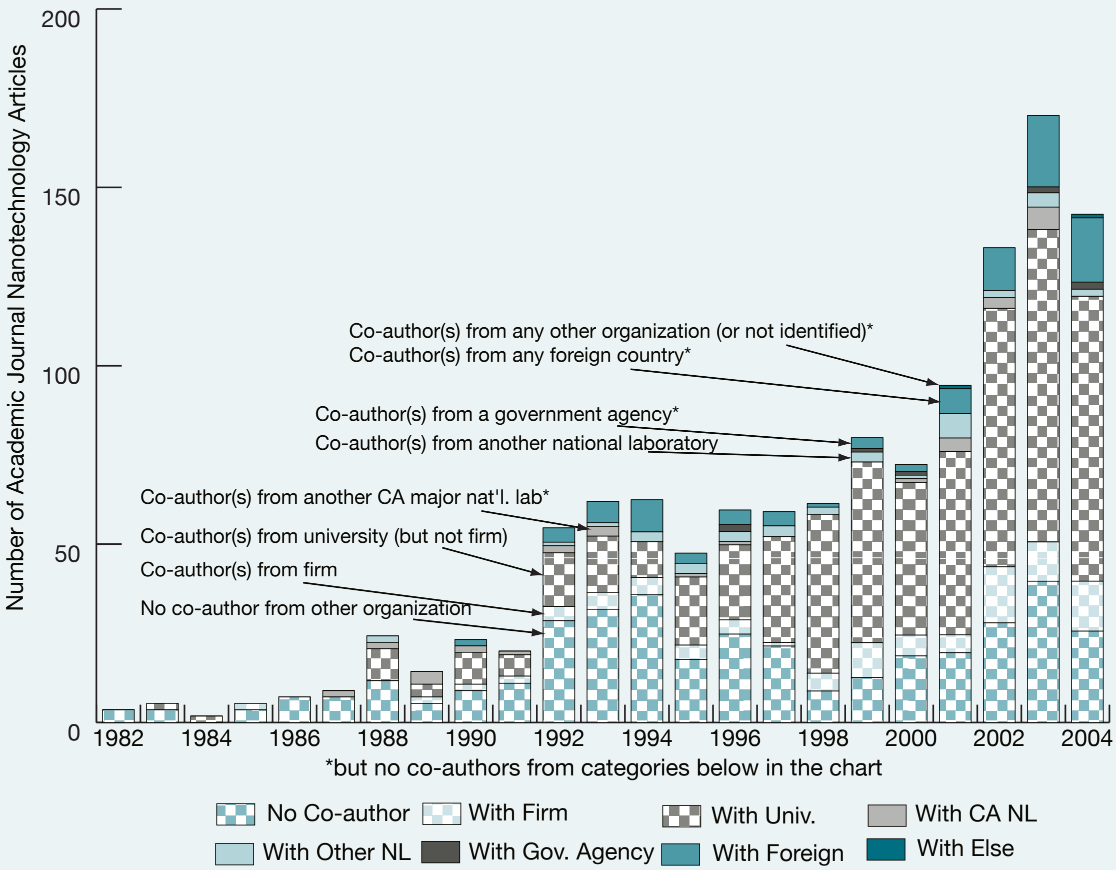


Figure 1.2. Knowledge Flows: Co-Authorship of Nanotechnology Articles by California's Six Major National Laboratories, 1982-2004

* Zucker and Darby are both professors at UCLA, Research Associates of the National Bureau of Economic Research, and fellows of the California Council on Science and Technology. California's six major national laboratories are defined as Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories/California (Sandia National Laboratories in New Mexico treated as a separate, not included lab), Stanford Linear Accelerator Center, NASA Ames Research Center, and Jet Propulsion Laboratory.

\+ See, Zucker, Darby, and Jeff Armstrong, "Geographically Localized Knowledge: Spillovers or Markets?", Economic Inquiry, January 1998, 36: 65-86; Zucker and Darby, "Capturing Technological Opportunity Via Japan's Star Scientists: Evidence from Japanese Firms' Biotech Patents and Products," Journal of Technology Transfer, January 2001, 26: 37-58; Zucker, Darby, and Armstrong, "Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology," Management Science, January 2002, 48: 138-153.

Figure 1.2. provides measures of publication and co-authorship patterns of California's major national laboratories for articles identified as relevant to nanoscale science and technology ("nanotechnology" hereafter) from 1982 through 2004. Nanotechnology has been identified by the federal government as a major technological driver for industry formation and transformation in the next several decades, so it is particularly interesting to examine the national lab's contributions. It is also the only area for which data are readily available to construct such measures.§ Some 69% of all nanotechnology articles with an author in one of California's six major national labs are co-authored with one or more authors outside of that lab, including 8% of all articles with firms, 47% with universities but not firms. Co-authors on the other 14% of all articles are 6% from government (including other national labs) and 8% from foreign countries.

Figure 1.3 focuses on articles co-authored with any authors from firms or with authors from universities if none are from firms. Articles with co-authors from a firm indicate direct transfer of tacit knowledge to firms. Since university professors often collaborate with or start firms, co-authorships with university co-authors may be significant sources of indirect impact of the national labs on commercial development.

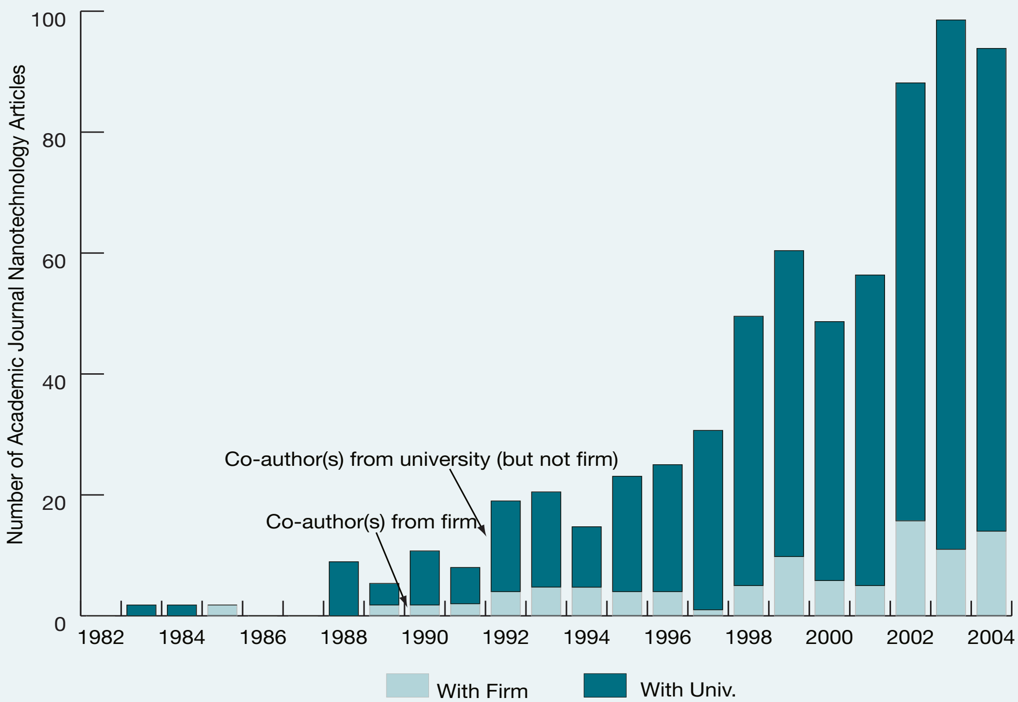
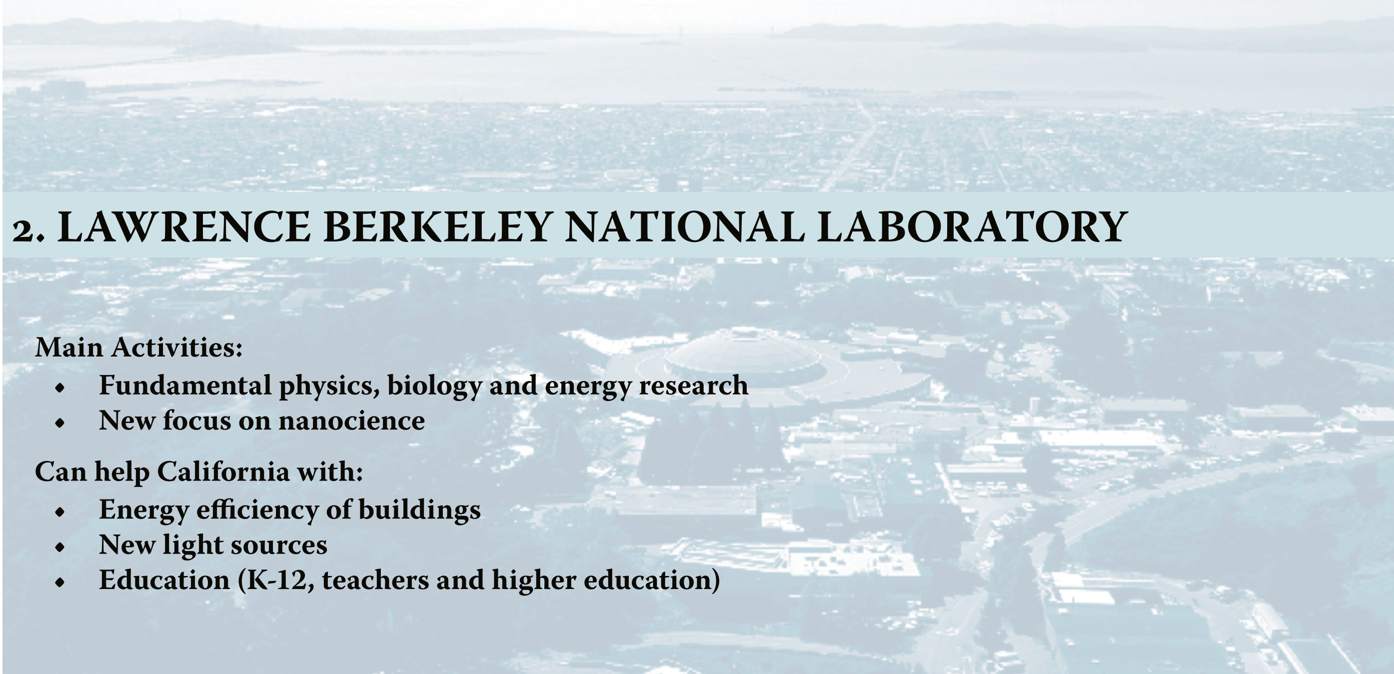


Figure 1.3. Firm and University Co-Authorship of Nanotechnology Articles by California's Six Major Laboratories, 1982-2004

§ These data are available as a by-product of our work building NanoBank.org under support of the National Science Foundation. "Nanotechnology articles" are identified as relevant to nanoscale science and technology by a boolean search of the titles and abstracts in our flat-file version of the Thomson ISI Web of Science™ database for the appearance of one or more terms in a list of nano and 379 other terms (but excluding appearances as measurement terms) which frequently appear in articles in the Virtual Journal of Nanotechnology and/or in glossaries of nanotech terms. Because abstracts enter the database beginning in 1991 or thereafter (depending on the journal), the number of articles for which abstracts are unavailable have been weighted by the ratio of the number of articles identified for those articles for which full information is available to the number of those same articles which would have been identified if only the titles had been used. The 1991 weight is used for years before 1991. In order to count each article only once, a hierarchy was created: If there was any co-author from a firm, the article was counted as co-authored with a firm. If there was no co-author from a firm, but one or more from a university, the articles was counted as co-authored with a university; and likewise reading across the figure's legend.



2. LAWRENCE BERKELEY NATIONAL LABORATORY

Main Activities:

- **Fundamental physics, biology and energy research**
- **New focus on nanocience**

Can help California with:

- **Energy efficiency of buildings**
- **New light sources**
- **Education (K-12, teachers and higher education)**

2.1 INTRODUCTION TO BERKELEY LAB

For almost 75 years, Lawrence Berkeley National Laboratory has conducted important research in science and engineering. Located on a 200-acre site in the hills above the University of California's Berkeley campus, Berkeley Lab holds the distinction of being the oldest of the Department of Energy's national laboratories. Berkeley Lab is managed by the University of California, operating with an annual budget of more than $500 million (FY2004) and a staff of about 3,800 employees, including more than 500 students.

Berkeley Lab conducts unclassified research across a wide range of scientific disciplines, with key efforts in fundamental physics and chemistry; quantitative biology; nanoscience; new energy systems and environmental solutions; and the use of integrated computing as a tool for discovery. It receives its support primarily from DOE's Office of Science, but also works with other federal agencies as well as with industry and state governments.

Berkeley Lab was founded in 1931 by Ernest Orlando Lawrence, winner of the 1939 Nobel Prize in physics for his invention of the cyclotron, a circular particle accelerator that opened the door to high-energy physics and understanding the nature of atoms. Lawrence believed that scientific research is best done through teams of individuals with different fields of expertise, working together. His teamwork concept is a Berkeley Lab legacy that has yielded rich dividends in basic knowledge and applied technology, and a profusion of awards. Over its history, ten Nobel Laureates have worked at the lab. One of those ten is Steven Chu, the lab's current director.

2.2. HISTORY OF BERKELEY LAB[10]

Early History

In the 1930s, the laboratory (then called the UC Radiation Laboratory) pioneered the use of cyclotrons to "smash" atoms together to understand their components and how matter could be modified for useful purposes. This work included understanding the nature of neutrons; the creation of new radioisotopes for medical treatment (the laboratory worked closely with the University of California Hospital in San Francisco, later UC San Francisco); and eventually the creation of artificial elements such as plutonium. The lab became one of the world's top physics research centers. During this period, the lab received its funding from the state of California and private philanthropies.

[10] This report's brief history of Berkeley Lab draws from Judith Goldhaber, editor, *Lawrence and His Laboratory: A Historian's View of the Lawrence Years*, 1981, http://www.lbl.gov/Science-Articles/Research-Review/Magazine/1981/index.html.

Contributions during World War II

In August 1939, Albert Einstein, at the behest of his friend and fellow scientist, Leo Szilard, sent a letter to President Franklin Roosevelt describing the possibility of an atomic bomb and warning of Germany's interest in the field. Roosevelt ordered what became the Manhattan Project, and in the 1940s, with government funding, Lawrence and his team at Berkeley made three major contributions to the bomb project: Lawrence pioneered the first successful technique for separating bomb-grade uranium out of general uranium; Glenn Seaborg and his colleagues at the lab discovered plutonium, the second material that can be used in atomic bombs; and Lawrence personally recommended a Berkeley colleague, J. Robert Oppenheimer, to lead the project to design, test, and build the first nuclear weapons. Oppenheimer recommended a remote site at Los Alamos, New Mexico, for a new secret weapons laboratory. He modeled his new center on the interdisciplinary team approach developed at Berkeley. The University of California was asked to manage the new laboratory at Los Alamos, and today it still runs that facility.

During World War II, Lawrence also helped to create an important new organizational model for government-funded R&D. The centers at Berkeley and Los Alamos (along with Caltech's Jet Propulsion Laboratory, described later in this report) pioneered the idea of a laboratory owned and funded by the federal government but staffed with university scientists and managed by a university contractor. Sandia National Laboratories pioneered the analogous idea of a government engineering laboratory run by industrial contractors. Up until World War II, civil servants staffed government laboratories, and, as noted earlier in this report, civil servants continue to staff and manage most federal laboratories today, including all Department of Defense laboratories and all NASA R&D centers except JPL. But Lawrence showed that when a project needed to tap the best research scientists and engineers that the nation's universities and companies could offer, then contractor-operated laboratories worked very well. They could recruit these talented individuals and organize them into effective interdisciplinary teams. The government-owned, contractor-operated laboratory was born.

The Post-War Science Laboratory

After World War II, the laboratory at Berkeley continued as a major federally funded research center. In the late 1940s, the new Atomic Energy Commission (AEC) — which took over responsibility for nuclear activities — decided to continue funding two types of R&D facilities: the nuclear weapons laboratories (Los Alamos, Sandia, and later Livermore), which had both classified and unclassified work; and a set of nuclear science laboratories that originally conducted both classified and unclassified research but eventually focused almost entirely on unclassified work. The Berkeley laboratory remained one of the leading science laboratories, and its early post-war classified R&D on applied nuclear projects gradually moved to its field station in Livermore, which eventually became the separate Livermore laboratory. Meanwhile, the Berkeley laboratory continued its largely unclassified work on nuclear physics. Eventually, California received a second science laboratory funded by the AEC and its successor agency, the Department of Energy: the Stanford Linear Accelerator Center (SLAC), which is discussed later in this report.

In the 1950s, the Berkeley Radiation Laboratory continued to develop both advanced particle accelerators to learn more about the nature of atoms and new "detectors" to record data from these experiments. Among the findings was the discovery of the "anti-proton" and hence antimatter. During this same decade, the physicists also began working with IBM. It took seven physicists two years to "train" two IBM computers to analyze data from these experiments. In the process, the laboratory acquired another major technical competence: high-performance computing. Today, Berkeley Lab continues to be a major center for high-performance computing.

QUICK FACTS ABOUT LAWRENCE BERKELEY NATIONAL LABORATORY

Full name: Ernest Orlando Lawrence Berkeley National Laboratory
Nicknames: Berkeley Lab, LBNL, LBL
Location: Berkeley, in the hills above UC Berkeley
Year established: 1931
Type of laboratory: government-owned/contractor-operated
Management: operated by the University of California for the U.S. Department of Energy
Director: Steven Chu
Number of employees: approximately 3,800, including more than 500 students
FY 2004 budget: $500 million
Web site: www.lbl.gov
Main activities:

- Interdisciplinary research in physics, chemistry, materials science, energy, biology and genomics, and advanced computing
- Growing research activities in nanoscience and nanotechnology

National user facilities (all available to California researchers):

- Advanced Light Source (for probing the details of materials)
- Energy Sciences Network
- National Center for Electron Microscopy
- National Energy Research Scientific Computing Center
- Molecular Foundry (opening in 2006)

Examples of technological and economic contributions to California:

- Lab-developed technologies licensed to start–up companies in areas such as nanotechnology, drug discovery, solar energy, and water purification
- Collaborative research projects that aid companies such as Intel, IBM

Examples of educational contributions to California:

- Extensive collaborations with professors at UC Berkeley and other California universities
- Approximately 500 undergraduate and graduate students working at the lab at any one time, plus up to 500 guest students working on specific projects

Examples of assistance to state and local government agencies in California:

- Extensive assistance to the California Energy Commission

Ernest Lawrence died in August 1958, and in time the Radiation Laboratory became Lawrence Berkeley Laboratory — and later Lawrence Berkeley National Laboratory, or Berkeley Lab for short.

In the 1960s, leadership in particle accelerators passed to new laboratories that had more physical room for larger and larger atom smashers. Berkeley Lab scientists continued to play a key role in the design of these new machines, including the large new linear accelerator at Stanford. Meanwhile, Berkeley's small machines continued to do good research in physics, and the lab expanded work in other areas such as biology and materials science. In the 1970s, DOE asked the laboratory to take on new missions in the critical areas of non-nuclear energy development and efficiency. Berkeley Lab had become a "multi-purpose laboratory," capable of applying its scientific and engineering capabilities to new as well as continuing priorities.

The lab's official history, edited by Judith Goldhaber, makes an important point about the laboratory's organizational flexibility and adaptability during this era:

> The laboratory's main principle of adaptation has been the creation of interdisciplinary teams that dissolve ordinary institutional boundaries in order to develop a machine, a research project, or a research program. It was on this principle that Lawrence established his laboratory. To demonstrate the wide promise of his machine and its products to his patrons, [Lawrence] recruited biologists, physicians, and chemists as well as physicists and engineers to work on and around the cyclotron. After the war he reaffirmed the principle by promoting hybrids like … bioorganic chemistry. Materials research, the first big interdisciplinary program initiated after Lawrence's death, drew on institutional mechanisms already firmly in place. The divisions of energy and environment and earth sciences are new variations on the successful principle of growth through diversification into interdisciplinary research programs.[11]

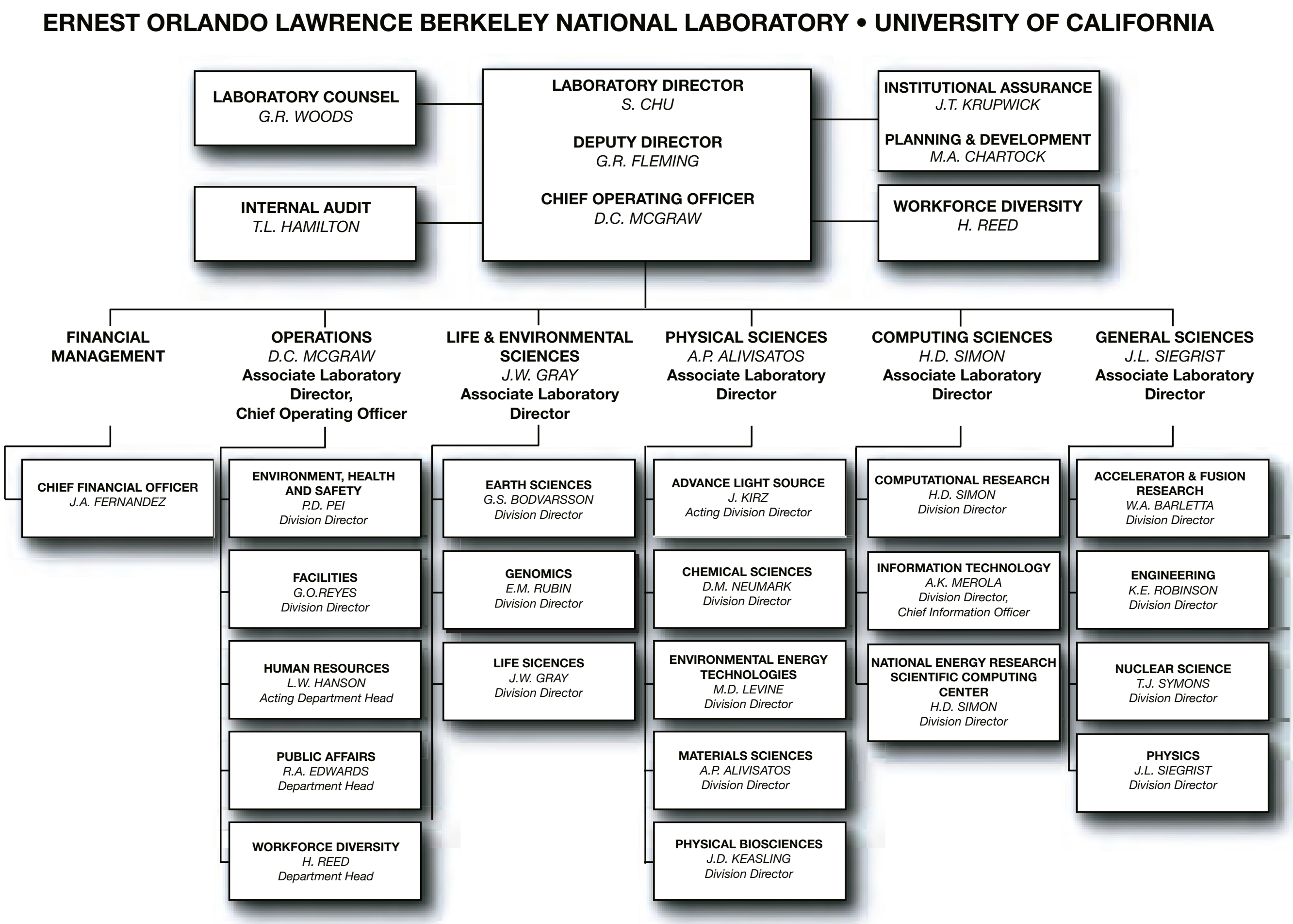


Figure 2.1. Organizational Chart for Berkeley Lab

[11] Judith Goldhaber, editor, *Lawrence and His Laboratory: A Historian's View of the Lawrence Years,* 1981.

2.3. MAJOR PROGRAMS, FACILITIES, AND INITIATIVES

Programs and Facilities

Today, Lawrence Berkeley National Laboratory has large programs in materials research (using advanced small accelerators), energy and environment, supercomputing, and continued work in physics, chemistry, and biology. It also has several major new research directions.

Berkeley Lab has over a dozen scientific divisions. As shown in the organizational chart, they are divided into four main groups:

- Life and Environmental Sciences
- Physical Sciences
- Computing Sciences
- General Sciences

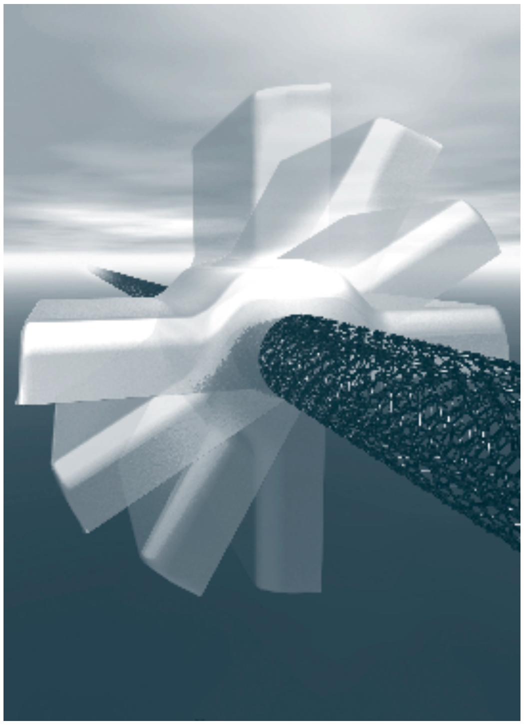
Below are examples of Berkeley Lab research and following is a list of the major user facilities at Berkeley Lab — facilities available to lab scientists as well as to university and company researchers in California.

Major New Initiatives

Four new research initiatives illustrate the directions in which Berkeley Lab is moving. They also reflect the lab's continuing expertise in fundamental physics, biology, and energy.

- ***Nanoscience research*** continues to grow at Berkeley Lab, in part because the Advanced Light Source (ALS) and the National Center for Electron Microscopy have some of the world's most powerful microscopes. The new Molecular Foundry will also play a central role in this research.
- ***Protein crystallography*** work at the Advanced Light Source is expanding, in part because of grants from the Howard Hughes Medical Institute. Proteins are central to biological processes, and biomedical researchers would like to design new medicines that can bind to particular proteins, so as either to block disease or promote healthy functions. But proteins are incredibly complex and hard to characterize. The new ALS project is a major initiative to deal with this problem.
- ***Solar-to-chemical energy*** is an initiative to mimic photosynthesis by using sunlight to create new materials that can be used as fuels. In effect, this project aims to "grow" new fuels in factory-like settings and thus create new materials to help replace oil. This project, a new initiative under Berkeley Lab Director Chu, involves researchers from many parts of the lab: energy, biology, nanotechnology, and computational science.
- ***The Supernova/Acceleration Probe (SNAP) satellite observatory*** is a planned satellite to examine supernovas in order to understand how the universe has expanded over the past 10 billion years. For years, physicists using particle accelerators have helped astronomers understand the elementary particles that made up the early universe and even now are affecting it. Many of today's efforts focus on the mysterious "dark energy" — the unseen force that scientists speculate is responsible for the continuing rapid expansion of the universe. The SNAP satellite, if funded, will provide precise measures of the effects of this unseen but powerful force. This is important fundamental science in which California scientists are leaders.

EXAMPLES OF BERKELEY LAB RESEARCH



Computer simulation of a nanomotor spinning on a carbon nanotube. In 2004, a Berkeley Lab team led by physicist Alex Zettl won a prestigious R&D 100 award for this work from *R&D Magazine*. Potential applications include biological and environmental sensors, electronic products, airbags, and blood pressure monitors.

Pictures of the "Berkeley Lamp," a highly energy efficient table lamp developed at Berkeley Lab with funding from the California Energy Commission's Public Interest Energy Research (PIER) program and from the U.S. Department of Energy. The lamp is currently available for sale.

NATIONAL USER FACILITIES AT BERKELEY LAB

- Advanced Light Source (ALS). The ALS is a large machine that generates intense X-rays to explore the properties of materials, analyze samples for trace elements, probe the structure of atoms and molecules, study biological specimens, investigate chemical reactions, and manufacture microscopic machines. In effect, it is very powerful imaging tool to look deep into a living cell and see the molecules that make up the cell wall or probe the surface of a silicon chip — atom by atom.
- National Center for Electron Microscopy, which uses beams of electrons to study the details of materials. It is particularly useful in research in nanotechnology and microelectronics.
- National Energy Research Scientific Computing Center (NERSC), a major supercomputer center used by researchers throughout DOE's science programs. The center is used for creating models and simulations of many things, including biological systems, energy systems, and basic physical and chemical properties.
- Molecular Foundry. This new facility will open in 2006, and is one of five Nanoscale Science Research Centers that DOE is creating. Research at this $85 million facility will focus on making nanoscale devices, including wires, electronic devices, plastics, and biological materials. It should help, for example, with the manufacture of new kinds of solar energy panels and new types of low-energy light-emitting diodes for lighting.

2.4. CONTRIBUTIONS TO CALIFORNIA

Technological and Economic Contributions

First, Berkeley Lab makes significant economic contributions through the jobs it provides and the procurement money that it spends in California. Some details on these and other lab contributions to California are available in Appendix B.

Second, Berkeley Lab has an active technology transfer program that has benefited California companies and workers.[12] As a federal facility, the lab works with companies from all over the country. But as a laboratory based in California, it is not surprising that it works closely with many California companies, both large and small. There are two main types of cooperation with industry: industry-laboratory cooperative research and licensing of lab technologies.

The cooperative projects themselves can take several forms:

- ***Cooperative research and development agreements (CRADAs).*** Under a CRADA, a company contributes funds and personnel to a joint project and a federal laboratory contributes personnel, facilities, and possibly intellectual property.
- ***Other cooperative mechanisms.*** These include Personnel Exchanges, Memoranda of Understanding, Technology Maturation projects, and Technical Assistance Agreements.
- ***Work for others.*** A company may sponsor Berkeley Lab scientists to conduct research on a specified issue if there are researchers with the appropriate capabilities and interest in the project. The unique facilities and specialized staff expertise at Berkeley Lab provide research opportunities that may not be available anywhere else.

Berkeley Lab has an active technology transfer program that has benefited California companies and workers.

Licenses of lab-developed patents and software can go to either existing companies or to new start-up firms. Berkeley Lab helps create new jobs by licensing technologies that become the basis for startup companies. One important point is that both Lawrence Berkeley National Laboratory and Lawrence Livermore National Laboratory have biotechnology tools to license as well as the more familiar inventions in physics, energy, and related fields. As mentioned earlier, Berkeley Lab has a long history of exploring how small amounts of radioactive materials can be used for medical diagnoses and treatment. And the human genome project — the effort to map all genes on human chromosomes — actually started in Department of Energy labs before largely moving to the National Institutes of Health. DOE labs had the computer facilities and skilled biologists to begin the ambitious project.

Technologies developed at Berkeley Lab have led to the creation of over 18 start-up companies with a combined market capitalization over $2 billion.

Technologies developed at Berkeley Lab have led to the creation of over 18 start-up companies with a combined market capitalization over $2 billion. For example, Symyx Technologies, Inc. is based on a Berkeley Lab license. It began as a start-up and is now a publicly traded company with a market capitalization of over $900 million and over 275 employees, many of which are high-paying skilled jobs.

[12] Detailed information on Berkeley Lab's technology transfer program and its accomplishments is available at: http://www.lbl.gov/Tech-Transfer/index.html.

Contributions to Education and Academic Research

Berkeley Lab makes two types of contributions to education in California:

- Programs for kindergarten through community college (K-14) students and teachers.
- Formal and informal research collaborations with faculty, undergraduates, and graduate students from both the University of California and other California universities.

Berkeley Lab's Center for Science and Engineering Education (CSEE) manages the student and teacher programs. CSEE runs three types of programs:

- ***Outreach programs*** in which Berkeley Lab researchers offer tours for school children and mentoring and volunteer activities in the schools.
- ***Student opportunities***, which include internships for high school students and college students, including community college students.
- ***Teacher opportunities***, which include teacher professional development programs at the lab for science and mathematics teachers, curriculum development, and classroom resources. One such program, called the Laboratory Science Teacher Professional Development Program (LSTPD), enables teachers in K-12 schools and community colleges to spend four to eight weeks at Berkeley Lab during the summer and to continue to work with the lab or another DOE laboratory for a total of three years. Berkeley Lab also offers a Faculty and Student Teams (FaST) program to assist faculty members from colleges and universities with limited prior research capabilities with their own professional development and with preparing their students for careers in science, engineering, computer science, and technology.

Berkeley Lab's research collaborations with university professors and graduate students are extensive. As one would predict, collaborations with UC Berkeley are particularly close, but the lab also has extensive ties with professors and graduate students throughout the state.

In 2004, 571 individuals from the University of California worked with Berkeley Lab: 212 faculty members who had joint appointments at the lab, 343 graduate student research assistants, seven student assistants, and nine visiting postdoctoral fellows. In addition, that year Berkeley Lab had 62 resident postdoctoral fellows and 214 visiting postdoctoral fellows from other universities, many of them from California schools. This report's Appendix B provides additional details. The following text box lists some recent examples of Berkeley Lab's contributions to California industry.

In 2004, 571 individuals from the University of California worked with Berkeley Lab.

Assistance to State and Local Government

Berkeley Lab has a long tradition of working with state and local government agencies in California, particularly in the energy field.

Berkeley Lab has long worked with the California Energy Commission (CEC). The lab has provided technical advice to the commission and conducted research funded by the commission's Public Interest Energy Research (PIER) Program. Recently, in 2004, the CEC funded a new operation at Berkeley Lab, the Demand Response Research Center (DRRC). Demand response facilitates the quick, automatic reduction of energy use in buildings, industrial facilities, and homes in response to a rising price in the cost of power or an emergency on the electric grid.

For example, when electricity prices rise, large commercial users can implement a preplanned program of reducing certain electrical loads of their choice.

The lab has also been a leader in energy-efficiency technologies, including the development of new energy-efficient lighting — resulting in both the "Berkeley Lamp," a very efficient fluorescent light, and new low-power light-emitting diodes. This work has led to two formal research agreements on lighting technology with the publicly owned Sacramento Municipal Utility District (SMUD) and one with the Richmond Office of the U.S. Postal Service.

EXAMPLES OF BERKELEY LAB'S CONTRIBUTIONS TO CALIFORNIA INDUSTRY

Examples of joint research projects with major California companies performed under cooperative research and development agreements (CRADAs):

- Applied Materials: particle-free wafer processing
- Chiron: high throughput assay for screening novel anti-cancer compounds
- General Atomics: medical accelerator technology
- Hewlett-Packard: light emission processes and dopants in solid state light sources
- Intel: identification of semiconductor contaminants
- Kaiser Foundation Hospital: information infrastructure for distributed health care imaging
- Lumileds Lighting: efficiency improvement of solid state light emitting materials
- Seagate Technology: nanometer characterization and design of molecular lubrication the head-disk interface in computer hard disk drives
- General Nanotechnology LLC: tools for integrated circuit mask repairs
- Gene Logic: analysis of gene expression data
- Adelphi Technologies: neutron source technology for industrial radiography
- Catalytics Advanced Technologies: catalysts for petrochemical processing
- Fiber Network Engineering: thermal management tools for optical networks

Examples of California start-ups based on Berkeley Lab licenses:

- Nanomix: products from nanoscale materials and components, including sensors and hydrogen storage systems to power fuel cells
- Nanosys: products such as nanowires, nanotubes, quantum dots, flexible electronics, solar cells, and coatings
- Syrrx: structural proteomics (the process of generating protein structures from genetics information) for drug discovery
- Quantum Dot: quantum dot fluorescent probes to label and measure biological systems, such as living cells
- VSOM: optical microscopy for biological applications
- WaterHealth International: portable low-power water disinfection units
- Xradia: nanofabrication of x-ray imaging technologies
- Symyx: high-throughput materials discovery

Examples of licenses to established California companies:

- Affymetrix: computational gene modeling software
- Avigen: potential gene therapy for Parkinson's disease
- Gatan: CCD camera for transmission electron microscopes
- Genentech, Chiron, and others: software for automated macromolecular crystallography
- Syrrx and Novartis Genomics Institute: robotics for nanovolume protein crystallography
- Digirad: portable gamma camera for medical imaging
- Fairchild Imaging: CCDs for night-vision goggles and other purposes

2.5. OPPORTUNITIES AND CHALLENGES

California has an opportunity to get even more benefits from Berkeley Lab, but there are also challenges.

Perhaps the most important opportunities are in the energy area. For example, Berkeley Lab's expertise in energy conservation for buildings could be used further by state agencies to cut their own electrical and heating costs.

In addition to opportunities, Berkeley Lab faces two long-term challenges, both of which state policy might help address. First, the lab will need new buildings, both to replace existing laboratories and to provide new facilities for new areas of research. It is hard to recruit and retain the best researchers if the physical facilities are in bad shape. But DOE funding for new buildings is limited.

Negotiating cooperative projects is difficult and time-consuming, each state agency has different procurement rules and state law often prohibits agencies from paying in advance for research services.

Second, Berkeley Lab — and in fact all federal laboratories in California — face administrative difficulties that limit the work they can do for California state agencies. Right now, negotiating cooperative projects is difficult and time-consuming, in part because each state agency has different procurement rules and in part because state law often prohibits agencies from paying in advance for research services, while federal law requires such payments. The last section of this report will explore this issue in more detail and will suggest steps that might reduce these problems. This last section will also recommend other steps that the federal labs and state government might take together to increase the benefits that state agencies can get from these laboratories.

3. LAWRENCE LIVERMORE NATIONAL LABORATORY

Main activities:

- **Nuclear weapons**
- **Homeland security**
- **Energy and environmental research**
- **Genomics, bio, material and computational science, astrophysics**

Can help California with:

- **Homeland security and disaster mitigation**
- **Hydrogen fuel technology**
- **Air quality improvement**
- **Groundwater cleanup**
- **Education (K-12, teachers and higher education)**

3.1. INTRODUCTION TO LIVERMORE

Lawrence Livermore National Laboratory (LLNL or Livermore) is a Department of Energy national security laboratory with responsibility for ensuring that the nation's nuclear weapons remain safe, secure, and reliable. LLNL also works to prevent the spread and use of nuclear and other weapons of mass destruction and to strengthen homeland security. The laboratory has capabilities in conventional defense, energy, environment, biosciences, and basic science. Research programs in these areas enhance the competencies needed for the laboratory's national security mission.

Equally important for California, these broad research programs also create valuable unclassified science and technology. Ernest Orlando Lawrence, who helped create Livermore as well as Berkeley Lab, argued that hiring top scientists and engineers to carry out cutting-edge research and work in multidisciplinary teams was the best way to ensure the nation's scientific and technological leadership. Being a world leader in areas such as physics, lasers, advanced computing, and genomics is vital for national security work, but it also leads to unclassified research and expertise that makes the laboratory a significant resource for California industry and government. LLNL has an active technology transfer program that has helped California companies, offers valuable educational programs, and provides technical assistance to several California state agencies.

The University of California operates Lawrence Livermore National Laboratory, on behalf of the Department of Energy's National Nuclear Security Administration (NNSA). As of April 2004, LLNL had 6,946 full-time employees, including 2,765 scientists and engineers (1,237 with Ph.D. degrees). Part-time employees, temporary hires, students, and contract employees brought the total workforce to over 8,000. In federal fiscal year 2005 the lab has a budget of $1.7 billion. The largest part of that budget supports "stockpile stewardship" — the DOE program to maintain the safety, security, and reliability of the nation's nuclear weapons.

LLNL's sponsors include — in decreasing order of support — the Department of Energy, the Department of Defense, the Department of Homeland Security, the intelligence community, the National Institutes of Health, NASA, and others, including industry and other federal, state, and local agencies.

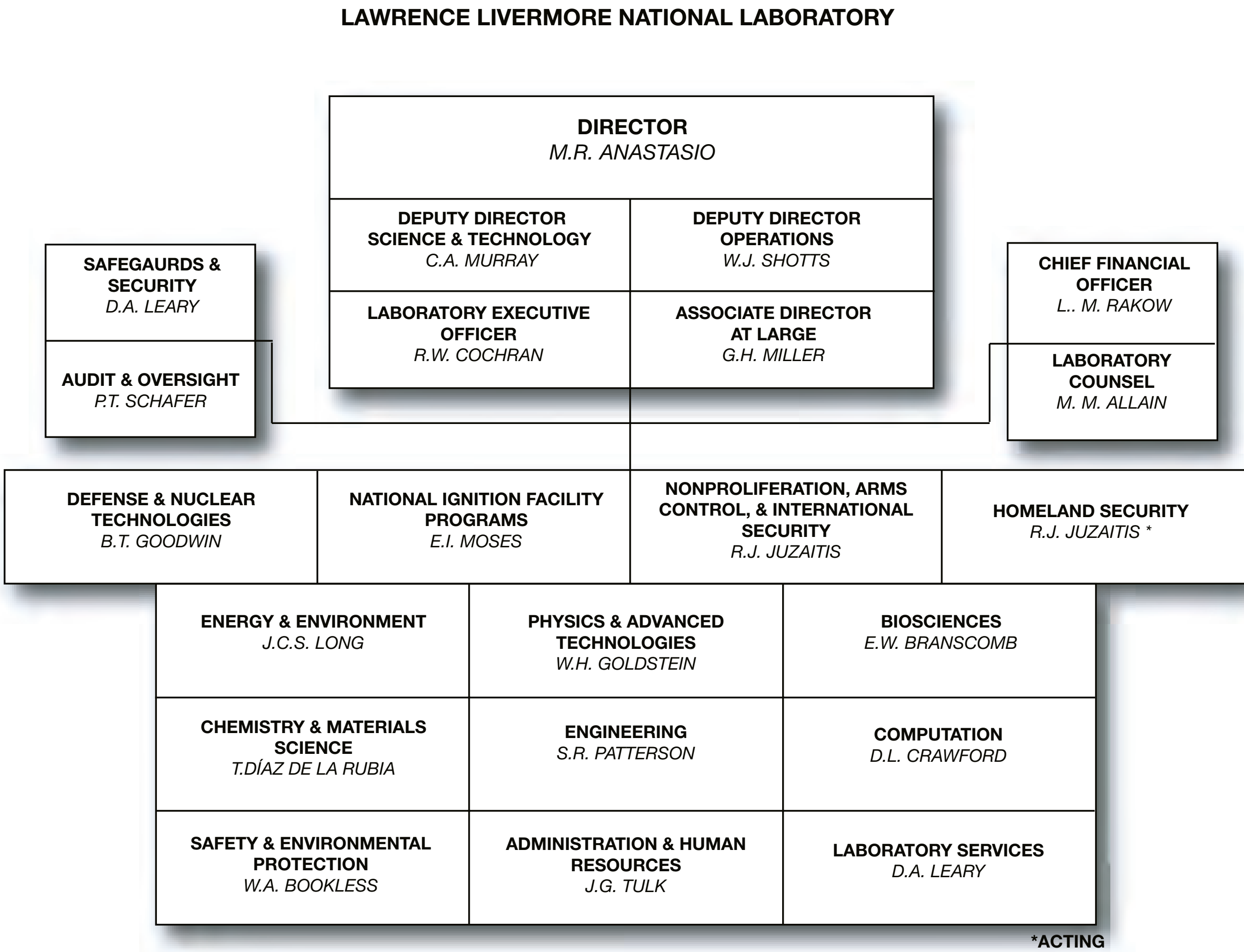


Figure 3.1. Organizational Chart of Lawrence Livermore National Laboratory

3.2. HISTORY OF LAWRENCE LIVERMORE NATIONAL LABORATORY

Early History

Livermore was established in 1952, on the site of an old U.S. Navy air station.[13] In the late 1940s and early 1950s, Lawrence's Berkeley Radiation Laboratory (later renamed Lawrence Berkeley National Laboratory) conducted some experiments on the site. In 1952, Lawrence and his colleague Edward Teller succeeded in persuading the federal government to create a second nuclear weapons design center in addition to the original one at Los Alamos. They chose the Livermore site for the new facility. Eventually, Livermore separated from Berkeley Lab and became a separate organization.

[13] The following brief history of Livermore Lab draws on "Making History, Making a Difference," available at http://www.llnl.gov/llnl/about/make_history.jsp, and "Fifty Years of Accomplishments," available at http://www.llnl.gov/accomplishments/.

QUICK FACTS ABOUT LAWRENCE LIVERMORE NATIONAL LABORATORY

Full name: Lawrence Livermore National Laboratory
Nicknames: LLNL or Livermore Lab
Location: Livermore
Year established: 1952
Type of laboratory: government-owned/contractor-operated
Management: operated by the University of California for the Department of Energy's National Nuclear Security Administration
Director: Michael R. Anastasio
Number of employees: 8,700
FY 2005 budget: $1.7 billion
Web site: www.llnl.gov
Main activities:

- National security: stewardship of the nuclear weapon stockpile
- National security: strengthening homeland security and countering weapons of mass destruction
- Energy and environment
- Other science (genomics, biosciences, computational science, astrophysics, chemistry and materials science)

Key facilities:

- National Ignition Facility
- Supercomputing facilities
- Contained Firing Facility (Site 300)
- National Atmospheric Release Advisory Center
- Center for Accelerator Mass Spectrometry
- Forensic Science Center
- Jupiter Facility (lasers for studying properties of materials)

Examples of technological and economic contributions to California:

- Participation in DOE-Intel project to develop equipment for the next generation of computer chips
- Licensing of micropulse radar technology to 16 companies
- Developing innovative subsurface cleanup technologies
- Helping California farmers to fight Newcastle poultry disease and a soybean disease

Examples of educational contributions to California:

- Pioneering summer program to offer courses and research opportunities for California science and math teachers
- Several research institutes with ties to California universities
- Multiple programs for kindergarten through postdoctoral fellowships

Examples of assistance to state and local government agencies in California:

- Groundwater cleanup assistance
- Air quality assessment and monitoring
- Hydrogen fuel technology
- Homeland security assistance

Weapons Research, Counter-Proliferation, and Homeland Security

In the late 1950s, Livermore made its first major breakthrough: the design of a nuclear warhead for missiles that could be launched from highly survivable submarines. Later it developed other warheads, including compact ones. This work on nuclear weapons has continued to the present. Today, the federal government no longer designs or tests nuclear weapons but does have extensive programs to keep existing weapons safe, reliable, and secure.

Livermore continues to play an important role in monitoring any new nuclear tests, and it has used its expertise in detecting weapons activities to help counter the proliferation of other weapons of mass destruction

Since the late 1950s, Livermore also has contributed to nuclear arms control by providing technical analysis and developing treaty monitoring capabilities. The laboratory helped develop and deploy equipment to monitor both atmospheric and underground nuclear explosions, including a worldwide network of seismic monitoring stations to detect underground blasts. This technical capability created confidence that the U.S. could indeed detect nuclear tests. That confidence contributed to President Kennedy's decision in 1963 to sign the Limited Test Ban Treaty with the Soviet Union, a treaty that banned nuclear weapons testing in the atmosphere, underwater, or in space.

Livermore continues to play an important role in monitoring any new nuclear tests, and it has used its expertise in detecting weapons activities to help counter the proliferation of other weapons of mass destruction and, more recently, with equipment and policies for counter-terrorism and homeland security.

Biology and Environmental Science

In the 1960s, the laboratory created its bioscience and environmental programs, an outgrowth of early work analyzing the biological effects of radiation. Biotechnology developments at Livermore and Los Alamos, such as chromosome markers and high-speed cell sorters, enabled the Department of Energy to launch the Human Genome Initiative in 1987. Later, the National Institutes of Health (NIH) and British scientists partnered with the DOE initiative, creating the international endeavor that in 2000 completed sequencing the human genome. DOE's Joint Genome Institute (JGI) opened the Production Genomics Center (PGF) in 1999 in Walnut Creek, which merged the sequencing efforts of Livermore, Los Alamos, and Berkeley Lab and sequenced human chromosomes 5, 16, and 19.[14] Livermore's expertise in genomics now contributes to the development of biological agent detectors and technologies for disease prevention.

Environmental programs at Livermore have led to other capabilities: the development of novel groundwater remediation technologies now in use at Superfund sites; models that contribute to understanding the human impact on global climate change; and the creation of the National Atmospheric Release Advisory Capacity (NARAC), which provides important information after the release of radioactive or toxic materials, such as during the Three Mile Island accident in 1979, the Chernobyl disaster in 1986, or local California emergencies such as a chemical release in Richmond and a tire fire in Tracy.

[14] The University of California manages the PGF for DOE. Today, Oak Ridge National Laboratory in Tennessee, Pacific Northwest National Laboratory in Washington State, and the Stanford Human Genome Center also participate in the JGI. For detailed information on the Institute, see: http://www.jgi.doe.gov.

Lasers and Supercomputing

In the 1970s, Livermore began a laser research program, and the laboratory has been a leader in laser science and technology ever since. LLNL has been home to a succession of the world's most powerful lasers, from the Shiva laser completed in 1978 to Nova in the 1980s to 1997 groundbreaking for the National Ignition Facility (NIF). The lasers are used for two main purposes: creating small thermonuclear explosions, miniature versions of hydrogen bomb explosions that can be used to better understand explosions in weapons; and for research in "inertial confinement fusion," a technology that one day may create abundant, safe, and low-polluting energy.

In the late 1980s, Livermore researchers began to explore the feasibility of using multiple parallel computer processors for scientific computing. Livermore had long been active in computing, and the need for ever more powerful simulations for nuclear weapons design has guided industry's development of supercomputers. Livermore had often been home to "serial number one" of new computers, and had helped industry make prototype machines ready for a wider range of interests. The move towards parallel processing was a major next step in scientific computing, allowing much more powerful simulations of nuclear weapons and other physical events. That advancement soon became particularly important for the nation's nuclear weapons program. These resources have also been used for unclassified fundamental science, and their use through unclassified research collaborations will be expanded in the near future.

Stockpile Stewardship Program

After the demise of the Soviet Union and the end of the Cold War, the United States and a non-Soviet Russia began to reduce their nuclear stockpiles and worked together to reduce the likelihood that nuclear weapons technologies would spread to other countries. As part of their commitment to nonproliferation, the two countries and other nations ceased nuclear testing.

On August 11, 1995, President Clinton announced that the U.S. would pursue a Comprehensive Nuclear Test Ban Treaty — a treaty to prohibit all nuclear tests. At the same time, he reaffirmed the importance of retaining a safe and reliable U.S. nuclear weapons stockpile, which would be reduced in size. On September 25, 1995, the president directed the Department of Energy and the Department of Defense to take steps to create what became known as the Stockpile Stewardship Program — a program to use computer simulations and non-nuclear testing as a basis for maintaining an aging nuclear stockpile and to make necessary refurbishments and upgrades. The U.S. Senate has not ratified the Test Ban Treaty, but both the Clinton and Bush administrations have maintained the halt to nuclear testing.

Lawrence Livermore National Laboratory is home to essential components of the Stockpile Stewardship Program, including advanced supercomputers that are part of the Advanced Simulation and Computing (ASC) Program and the National Ignition Facility (NIF), which will be used for fusion physics experiments. The ASC Program computers at Livermore, developed in partnership with IBM, continue to set world records. ASC Purple, a classified system capable of performing 100 trillion floating-point operations per second, will play a key role in the Stockpile Stewardship Program. It is currently being installed in the laboratory's new 253,000 square foot Terascale Facility. BlueGene/L, another machine that is the world's fastest supercomputer but with a more experimental architecture, is also being installed in the Terascale Facility. It will perform 360 trillion floating-point operations per second. Computation is now a mainstream method in theoretical science at LLNL. Three of the top thirteen ranked supercomputers in the Top 500 Supercomputer Sites list from June 2005 are at Livermore; one of the top ten is used only for unclassified research.

The National Ignition Facility's laser capabilities will be crucial to the Stockpile Stewardship Program because it is the only facility that can create the conditions of extreme temperature and pressure — conditions that exist only in stars or in exploding nuclear weapons — that are relevant to understanding the operation of our modern nuclear weapons. In addition, NIF is the only facility that can create fusion ignition and thermonuclear burn in the laboratory. Nuclear fusion is the process that our modern nuclear weapons use to achieve their immense explosive power. The understanding of these conditions and the data provided by NIF will allow our nuclear stewards to assess and certify the aging stockpile without actual nuclear tests using supercomputer modeling tools.

3.3. MAJOR PROGRAMS, FACILITIES, AND INITIATIVES

Major Missions, Programs, and Facilities

Today, Livermore has four main missions and a set of scientific and engineering programs and facilities to help it carry out those missions. The four missions are:

- ***National security — stockpile stewardship***. Livermore's main mission today is to maintain the nuclear weapons stockpile, provide assurance of weapon safety and reliability, and certify performance — all in the absence of nuclear testing. The laboratory is part of DOE's integrated program of weapons monitoring, assessment (validated by simulations and experiments), and refurbishment of weapons components.
- ***National security — strengthening homeland security and countering weapons of mass destruction.*** Livermore applies its expertise in nuclear weapons and in the physical and life sciences to develop advanced technologies, systems, and operational capacities to prevent and detect the spread and use of nuclear, biological, and chemical weapons, and to respond to the threatened use or actual use of such weapons. For example, the laboratory is helping to develop advanced, portable devices for real-time detection of nuclear materials and biological agents.
- ***National security — in a global context.*** Emerging threats to global security are broader than military conflict and terrorism. Livermore pursues breakthrough scientific and technological advances to address growing sources of global insecurity and meet pressing needs for environmental quality, clean energy, improved risk assessment capabilities, better water management, and improved human health.
- ***National security — sustaining international leadership in science and technology.*** Livermore contributes to the advance of science in several important fields: bioscience, biotechnology, and genomics; physics and astrophysics; laser science and technology; computational science; and materials science and nanotechnology.

To carry out these missions, Livermore maintains scientific and engineering competence in a wide range of scientific and engineering fields — including physics and nuclear materials, advanced lasers, high-performance scientific computing, materials science, and engineering development. Following in Ernest Orlando Lawrence's tradition, Lawrence Livermore National Laboratory's central competence is its ability to organize its scientists and engineers into multidisciplinary, integrated teams to solve complicated scientific and technical problems.

Livermore has several major facilities to help with this work. The text box on the next page lists these key facilities.

MAJOR FACILITIES AT LAWRENCE LIVERMORE NATIONAL LABORATORY

- ***National Ignition Facility (NIF),*** a stadium-sized 192-beam laser facility currently under construction, providing a unique capability for investigating both weapons physics and possible laser-based commercial fusion energy.
- ***Supercomputing facilities,*** Livermore now has some of the world's most powerful supercomputers, able to conduct highly advanced computer simulations of real-world events. Some of this supercomputing capability is used for classified research for the purpose of understanding aging nuclear weapons without having to actually conduct nuclear explosions. Some of this supercomputing capability is also available for unclassified scientific research, such as for global change models.
- ***Contained Firing Facility,*** for non-nuclear explosion experiments to help understand the safety and reliability of aging nuclear weapons.
- ***National Atmospheric Release Advisory Center,*** which provides atmospheric plume predictions in time for emergency response to the release of radioactive or other hazardous materials.
- ***Center for Accelerator Mass Spectrometry,*** the most versatile system in the world for accelerator-based measurements of isotropic abundance.
- ***Forensic Science Center,*** a laboratory with exceptional chemical and forensic analysis capabilities to counter terrorism using chemical, nuclear, biological, and high-explosives agents.
- ***Jupiter Facility,*** a user facility with a variety of special lasers that can be used to study the properties of materials.

Key Initiatives

The previous section mentioned Livermore's two main initiatives for carrying out its responsibilities under the Stockpile Stewardship Program: the acquisition of new supercomputers and the completion and use of the National Ignition Facility.

Livermore also has major initiatives in homeland security. Lawrence Livermore National Laboratory's Homeland Security Organization continues to provide support to the Department of Homeland Security to help meet the challenges of weapons-of-mass-destruction proliferation and terrorism. Over the past several years, for example, Livermore has developed advanced technologies such as real-time, portable detectors of nuclear materials and biological agents. These technologies have either been used in the field or show great promise for future implementation. Since September 11, 2001, Livermore has performed over one million assays for the U.S. Government in support of its efforts against bioterrorism.

Since September 11, 2001, Livermore has performed over one million assays for the U.S. Government in support of its efforts against bioterrorism.

Livermore is also pursuing a wide range of programs and initiatives to address growing sources of global insecurity. For example, it is engaged in improving the quality and resolution of global and regional climate models, developing healthcare technologies and technologies to improve water quality, and advancing fusion science as a possible source of clean energy.

3.4. CONTRIBUTIONS TO CALIFORNIA

At Livermore, the federal government has hired some of the world's leading scientists and engineers and has given those researchers the facilities needed to carry out cutting-edge research in fields such as physics, lasers, advanced computing, and genomics. Being world leaders in these fields is vital for national security. But these capabilities are also a major asset for California's industry and state and local governments, because much of the basic scientific and technological research carried out by Livermore scientists and engineers is unclassified. To be sure, many specific applications of that underlying research will become part of classified weapons programs. But, the underlying scientific knowledge itself and even many of the new technological inventions are not secret.

Livermore's expertise and technology can help and has helped California in three main areas: technology and expertise for California industry; educational activities, including joint work with university researchers and a highly respected teacher training program; and technical assistance to state agencies. The next section of this chapter provides more details, including several case studies presented below and in the accompanying text boxes.[15]

Technological and Economic Contributions

First, Livermore makes significant economic contributions through the jobs it provides and the procurement money that it spends in California. The laboratory has over 8,000 employees, and the annual payroll is over $660 million. About a third of the annual budget is spent on procurements, with over $260 million (more than 40% of the total) spent in California. Much of its procurement goes to small businesses, small disadvantaged businesses, and women-owned businesses. Further details on these and other laboratory contributions to California are available in the Appendix.

Second, federal law encourages government laboratories such as Livermore to share their unclassified expertise and technologies with U.S. companies and state and local governments.

As one of several Department of Energy national laboratories, Livermore — like its sister facility, Berkeley Lab — can license unclassified technologies to California firms. About 25% of the laboratory's active patent and copyright licenses are with California companies.

On average, over 90 patents per year are issued for LLNL inventions...LLNL's technology transfer program is consistently one of the top performers among all DOE national laboratories in terms of license royalty income.

On average, over 90 patents per year are issued for LLNL inventions. Since 1978, Livermore researchers have won 106 of *R&D Magazine's* prestigious R&D 100 awards. LLNL-developed technologies are the basis of over 50 start-up companies (two thirds of which are in California), with annual revenues of over $230 million. In a recent example, a California start-up company licensed BioAMS patents developed at Livermore's Center for Accelerator Mass Spectrometry; this came about through LLNL's relationship with UC Davis.

LLNL's technology transfer program is consistently one of the top performers among all DOE national laboratories in terms of license royalty income. For the past three years, LLNL has been first among all DOE national laboratories in the important category of "earned royalties," which is that portion of royalties that is based on a percentage of licensee's sales. Earned royalties, therefore, is a measure of a tech transfer program's success at working with licensees to make real products and services available in the marketplace.

---

[15] With the exception of the text box on K-12 teacher education, the information in this section of the report draws heavily on case studies prepared by Dr. Robin L. Newmark of LLNL. The text box on teacher education comes from Stan Hitomi, an experienced science teacher now working at LLNL as part of their teacher training program. The contributions of Dr. Newmark and Mr. Hitomi are gratefully acknowledged.

Also like Berkeley Lab, Livermore undertakes joint work with companies in three main ways:

- ***Cooperative research and development agreements (CRADAs).*** Under a CRADA, a company contributes funds and personnel to a joint project and a federal laboratory contributes personnel, facilities, and possibly intellectual property.
- ***Other cooperative mechanisms.*** These include Personnel Exchanges, Memoranda of Understanding, Technology Maturation projects, and Technical Assistance Agreements.
- ***Work for others.*** A company may sponsor Livermore scientists to conduct research on a specified issue if there are researchers with the appropriate capabilities and interest in the project. The unique equipment and specialized staff expertise at Lawrence Livermore National Laboratory provide research opportunities that may not be available anywhere else.

California's high-technology companies and start-ups are in an excellent position to take advantage of Livermore technology, and the text box below lists several examples where they have either licensed LLNL patents or engaged in joint work with laboratory researchers to create new technologies. Both agriculture and electronics have benefited from this work.

LIVERMORE AND CALIFORNIA: INDUSTRY, HEALTH, AND AGRICULTURE

- Semiconductors. High-volume manufacturing of computer chips with 30 nanometer feature size is a goal of Intel Corporation for 2009. Through use of Extreme Ultraviolet Lithography (EUVL), Intel and other chip manufacturers expect to extend the benefits of Moore's Law into the next decade. EUVL has been developed through a research partnership in which an industrial consortium invested over $26 million in work at Livermore, Lawrence Berkeley, and Sandia National Laboratories. Livermore's contributions to developing EUVL stem from expertise in laser technologies (e.g., precision optics and metrology). Future commercial products arising from EUVL will help sustain Livermore's leadership in high-performance scientific computing and other fields.
- Other industrial technologies. LLNL-developed technologies are the basis of more than 50 start-up companies earning more than $230 million annually. About two-thirds of these firms are in California. One laboratory invention, the micropower impulse radar, has already led to 16 licenses for diverse applications, including sensors for homeland security applications. Other licensee products range from medical diagnostics, flow cytometers, and a clinical radiation treatment planning system to laser and optics technologies. In addition, laboratory-developed software is being used by commercial entities through more than 200 licenses.
- Detecting agricultural diseases. A rapid nucleic acid test developed by LLNL and UC Davis colleagues saved California ranchers from having to destroy thousands of chickens during an outbreak of Newcastle disease, a devastating poultry virus. The screening technique reduced the time necessary to identify the disease in birds from 6-12 days to just four hours. This allows for rapid control of the virus through certification of disease-free birds and quick isolation of diseased birds. Livermore researchers have also developed rapid tests for hoof-and-mouth disease, West Nile Virus, and different types of Salmonella. Capabilities to identify the unique signatures of naturally occurring pathogens and rapidly detect them in food, plants, and animals stem from the laboratory's efforts in genomics and detector development to fight bioterrorism.
- Combating soybean disease. Recently, DOE's Joint Genome Institute in Walnut Creek — which includes scientists from Livermore — has determined the genetic makeup of a devastating soybean disease responsible for more than $1 billion in crop damage in 2003. A biotechnology firm in Santa Clara, California, has utilized this genetic information to develop probes for use in further research to combat the disease.

Contributions to Education and Academic Research

Lawrence Livermore National Laboratory contributes to California education in two important ways. First, Livermore scientists work with university professors and graduate students on joint research projects, to the mutual benefit of both groups and often in ways that help California.

University-level contributions. As a University of California-managed laboratory, Livermore has close ties with UC campuses. Students and faculty at UC campuses currently participate in more than 500 ongoing research collaborations with Livermore staff. These mutually beneficial interactions provide UC researchers with access to unique facilities. Research institutes at Lawrence Livermore National Laboratory's — the Institute for Geophysics and Planetary Physics, the Seaborg Institute, the Institute for Scientific Computation Research, the Institute for Laser Science and Applications, and the Physical Bioscience Institute — provide focal points for university collaborations. Livermore's Center for Accelerator Mass Spectrometry is the world's most versatile and productive facility of its type. Currently, more than 70 academic and research organizations access the center through collaborative research projects, including 23 faculty researchers at UC campuses, the University of Southern California, and Stanford. In 1963, UC Davis' Department of Applied Science was established as a joint organization with LLNL to develop a graduate degree training program for Livermore employees; this program has since evolved into the Student-Employee Graduate Research Fellowship (SEGRF) Program, providing graduate students from all University of California campuses a four-year fellowship to complete their dissertation. Since its beginning, the program has awarded 337 Ph.D. degrees, nearly half of whom have been hired by the laboratory. Livermore is also assisting in the establishment of UC Merced. Lawrence Livermore National Laboratory plans to have a close affiliation with this new campus, and the university's research will be aligned with LLNL's in a number of areas.

Collaborations with LLNL in high-technology areas also strengthen research programs on University of California campuses. Notably, Livermore was an important partner in two center awards that UC won from the federal National Science Foundation: the Center for Adaptive Optics at UC Santa Cruz, and the Center for Biophotonic Science and Technology at UC Davis. Given the size and expected ten-year duration of these awards, the centers will establish nodes of exceptional scientific productivity. In addition, the National Institutes of Health designated the UC Davis Cancer Center as a National Cancer Institute. The center's partnership with Lawrence Livermore National Laboratory was a key factor in the award.

These joint projects are important examples of what this report's introduction calls "research clusters" — multi-organizational concentrations of expertise, knowledge creation, and education that give California true "critical mass" and world leadership in key fields of science and technology.

K-14 contributions. Second, in addition to these university-level collaborations in research and graduate education, Livermore also has active programs to assist education from kindergarten through the community college level. These programs benefit both students and teachers. Altogether, LLNL spends over \$8.5 million a year on educational outreach programs that engage more than 10,000 students and teachers each year.

More than 500 teachers participate annually in the laboratory's programs to help K-14 educators improve their teaching of science. These programs are offered at the UC Edward Teller Education Center (ETEC) on the Lawrence Livermore National Laboratory campus and at other locations throughout California's Central Valley. ETEC is sponsored by Livermore, the UC Office of the President, UC Davis, and UC Merced. The following text box provides additional information on a key component of this program, the Teacher Research Academy.

LIVERMORE AND CALIFORNIA: TEACHER RESEARCH ACADEMY

In addition to short courses in areas such as computers, Livermore's education program now includes a **Teacher Research Academy** that gives California science teachers hands-on experience with cutting edge research. The academy provides four "levels" of training. Many teachers take the Level 1 courses, and some of these move into the additional activities.

- Level 1 consists of three-day summer courses on new fields of science, such as biotechnology. Livermore scientists teach these short courses both at the Teller Center, adjacent to the laboratory, and at other sites in California.
- Level 2 courses last five days and focus on current scientific instrumentation, giving teachers new and exciting ways to carry out classroom experiments.
- Levels 3 and 4 are particularly notable. A limited number of interested K-14 teachers work in one of Livermore's unclassified research laboratories, as interns who participate in actual laboratory science. Level 3 is a weeklong "pre-internship" course, an orientation session on LLNL's rules and culture. Level 4 is a research internship. Teachers participate in research, contribute to a research paper, and learn more about how to teach their students to conduct actual research projects. Research topics so far include biotechnology, biophotonics (using lasers in biological research), environmental science, and physics/astronomy. Livermore hopes to add engineering internships next. After teachers complete a summer internship, the program will loan them research equipment so that they and their students can conduct experiments in the classroom.

This expanded program is now in its third year and shows great promise as a way to enhance science teaching. Experience so far suggests that hands-on research experiences help excite good teachers and play a role in keeping them in teaching. During the summer of 2005, about 100 teachers participated altogether, most in Level 1 and 2 courses. Nine teachers participated in Level 4 research internships, six at the laboratory itself and three in corporate laboratories that have joined the Livermore program. Funding, currently modest, comes from the laboratory, UC, and corporate contributors.

For K-12 students, the laboratory offers school tours for fourth and fifth grade classes, hands-on science programs offered at Bay Area schools, a Science on Saturday lecture series, conferences to encourage middle school girls in math and science, and science education programs in partnership with local school districts. LLNL is also the major organizing sponsor of the annual Tri-Valley Science & Engineering Fair, which is affiliated with the Intel International Science and Engineering Fair.

Assistance to State and Local Government

Livermore has a long tradition of providing technical assistance to California state agencies. Contributions to agriculture have already been discussed. In addition, Livermore has also long provided assistance in environmental science, physical infrastructure, and energy. Expertise in atmospheric, hydrological, and geophysical sciences — an outgrowth of earlier nuclear weapons testing activities — provides the basis for this work on California energy and environmental issues. A small LLNL program supports work in the public interest, under which state or local governments can request technical assistance where the laboratory has unique expertise. Examples of such work include investigating the cause of rock falls in Yosemite National Park and assistance from the Forensics Science Center in specific criminal investigations. More recently, the laboratory has also provided assistance for homeland security in California. The next text box summarizes some examples of these contributions.

LIVERMORE AND CALIFORNIA: ASSISTANCE TO STATE AND LOCAL GOVERNMENT

- **Water**. Water is a critical resource for California. The laboratory's capabilities to simulate and trace (using isotopes) the movement of groundwater, manage large databases, and remediate contaminated groundwater have all been applied to issues within the state. For example, LLNL is conducting a U.S. Bureau of Reclamation-sponsored study to assess and determine the quantity, quality, and feasibility of using groundwater resources within the Salton Sea Basin. Using its unique capabilities in isotope hydrology, the laboratory has tracked the flow of groundwater for the Orange County Water District to assess the feasibility of supplementing water supplies with treated wastewater. In addition, Livermore researchers helped the state and federal governments understand the threat posed by leaking underground fuel tanks and the gasoline additive Methyl Tertiary Butyl Ether (MTBE). More recently, LLNL has assisted the state in its evaluation of other fuel additives.
- **Air quality**. The laboratory also applies its expertise in measurement and computer simulation to address air quality issues in the state. Atmospheric modeling capabilities range from global-climate scale to regional impacts of climate change to real-time assessments of the consequences of a release of hazardous substances. In a recent example, California's Air Resources Board requested a Livermore scientist's assistance in providing responses to comments that were received on a climate change regulatory package that establishes carbon dioxide emission standards. High-resolution models have also been run to assess the impact of climate change on California's water resources. The laboratory's Center for Accelerator Mass Spectrometry, which is able to detect chemical signatures from minute samples, has been used to study the impact on California's air quality of pollution originating locally and as far away as Asia.
- **Infrastructure**. Applying long-standing expertise in seismology and engineering, laboratory researchers have addressed critical infrastructure vulnerabilities in earthquake-prone California. For example, scientists from LLNL and UC Berkeley performed computer simulations of the San Francisco/Oakland Bay Bridge to determine how it would respond to an earthquake along the Hayward Fault (the seismic motions had been earlier calculated at Livermore). These simulations are large and complex, requiring advanced numerical techniques, enormous computational power, and the coupling of earth sciences and engineering know-how. In a similar effort, LLNL researchers combined laboratory measurements of soil strength, finite element modeling of topography, and analysis of recorded small earthquakes to understand the collapse of the Highway 14 and I-5 interchanges in the Northridge Earthquake of 1994.
- **Renewable energy**. LLNL is working to enhance the effectiveness of California's renewable energy portfolio. Laboratory staff coupled geochemistry with engineering to produce a technology for extracting silica from geothermal fluids, which increases the efficiency of geothermal energy production and yields a marketable silica by-product. The creation of a resource-mapping tool that integrates criteria for wind resources potential with avian habitat characteristics will enhance wind power resource management in the state. In the mid-1990s, researchers from Livermore, Sandia National Laboratories, and other groups designed and tested an optimized hydrogen-fueled internal combustion engine (ICE) for a hybrid concept vehicle as a transition technology to hydrogen-fueled light duty vehicles. Ford Motor Company is currently testing its hydrogen ICE hybrid vehicle and will make it available to California for the state's Hydrogen Highway Initiative. Current energy modeling work includes studying the impact of hydrogen distribution and production methods for California's Hydrogen Highway.
- **California's security**. The laboratory is engaged in a variety of projects to assess and support California homeland security requirements. Livermore conducts threat characterization activities, has fielded radiological and biological detectors for use at ports and border crossings; and supports emergency operational needs. Some of the state and local agencies that Livermore works with include San Francisco area agencies, San Francisco International Airport, Orange County regional jurisdictions, the California National Guard, the California Highway Patrol, transit agencies, and agencies dealing with port and border security. In addition, the laboratory conducts studies of critical California infrastructure components to identify vulnerabilities and provide technical recommendations for enhancing their safety and security. LLNL has a memorandum of understanding with UC Santa Barbara and the Naval Postgraduate School to further homeland defense research.

3.5. OPPORTUNITIES AND CHALLENGES

The discussion above illustrates how Lawrence Livermore National Laboratory already has a wide range of beneficial linkages to California industry, education, and government. The primary opportunity is to build for the future on these current ties. Two particular possibilities deserve attention.

First, Livermore's Teacher Research Academy illustrates how LLNL and other major federal laboratories in California are helping to train and excite K-14 science and mathematics teachers. At a time when California needs high-quality science and math teachers to prepare young people for an increasingly knowledge-based economy, these laboratory programs are a real asset to the state. The programs remain relatively small, but it appears that researchers at Livermore and other laboratories are more than willing to provide more courses and research experiences, if resources can be found. Livermore's experience also shows that private companies are often willing to participate in this kind of program. State support for a larger public-private partnership in teacher training might generate large benefits for California's schools and economy.

Second, both Livermore and Sandia/California (which the next section of this report will discuss) have significant capabilities in homeland security, particularly technologies for detecting and identifying terrorist weapons and for planning and analyzing threats. As the state of California and local governments increase their homeland security spending and try to figure out the best way to spend these limited resources, Livermore and Sandia are important assets. Officials in Sacramento may want to consider how the laboratories can help them carry out their important homeland security activities.

Streamlined contracting rules would make it easier to provide even more technical assistance to the state.

The obstacles to greater cooperation between Lawrence Livermore National Laboratory and California state agencies are the same ones discussed in the earlier section about Berkeley Lab: funding constraints and state contracting processes. Livermore has much greater experience than other federal laboratories in California in working with state agencies, but streamlined contracting rules would make it easier to provide even more technical assistance to the state.

4. THE CALIFORNIA DIVISION OF SANDIA NATIONAL LABORATORIES

Main activities:

- **Nuclear weapons**
- **Homeland security and disaster mitigation**
- **Energy research**
- **Chemical, information, biological, and microsystems science and engineering**

Can help California with:

- **Homeland security**
- **Hydrogen fuel technology**
- **Air quality improvement**
- **Education (K-12, teachers and higher education)**

4.1. INTRODUCTION TO SANDIA/CALIFORNIA

The Sandia National Laboratories division at Livermore, California, is a Department of Energy (DOE) facility. Its mission includes protecting the nation from terrorist threats, providing solutions to energy problems, and ensuring the safety and effectiveness of the nuclear weapons stockpile. Sandia/California is a leader in developing new technologies and engineering solutions for the critical challenges confronting the nation. It also has been a good neighbor to the state of California for almost fifty years and works closely with state agencies and businesses, as well as the federal government, to address issues of particular interest to the citizens of California. Examples include the Sandia-managed San Diego Border Research and Technology Center and Sandia's work on port security with the Ports of Los Angeles and Long Beach. Sandia/California also provides many educational programs at all levels that engage the educational community and contributes to California's rich technological environment.

Since opening in 1956, Sandia/California has been active in California's technical community. Sandia innovations introduced into industry — such as clean rooms for semiconductor manufacturing — have had an enormous impact on commercial processes. As a division of Sandia National Laboratories, Sandia/California is able to draw on a long tradition of national service and the full resources of a much larger laboratory family that includes a major site in New Mexico.

Sandia innovations introduced into industry — such as clean rooms for semiconductor manufacturing — have had an enormous impact on commercial processes.

Sandia National Laboratories is one of DOE's large multi-program national laboratories, founded in 1949 in Albuquerque, New Mexico. It has expertise in science, engineering, and technology, and in using a systems approach to create solutions to complex problems. Sandia's original emphasis on engineering — turning the nuclear explosive packages created by Los Alamos National Laboratory and Lawrence Livermore National Laboratory into deployable weapons — expanded into new areas as national security requirements changed. Today, with no nuclear testing, Sandia's weapons work focuses on ensuring that the nuclear stockpile is safe, secure, and reliable through advanced modeling and simulation coupled with laboratory and field testing.

Since September 11, 2001, Sandia has expanded its homeland security and disaster preparedness programs. Sandia/California has played a leadership role in marshalling the resources of the New Mexico and California laboratories to support the nationwide security effort with appropriate technologies to detect or deter a variety of possible threats, with much of its work focused on needs in California.

Much of Sandia's fundamental research is unclassified, and the California laboratory encourages active collaborations with both universities and industry. Some of Sandia/California's facilities exemplify the kind of investment made in the California laboratory and are described later in this chapter. One notable example is the Combustion Research Facility (CRF), which is improving the efficiency and environmental quality of automobile engines and industrial burners. Partnerships and projects involving California companies are also discussed in this chapter.

The economic impact of Sandia/California is considerable. The California division employs 1,350 of Sandia's 10,500 people. Of the California workforce, about 400 hold Ph.D. or master's degrees. The fiscal year 2004 budget for the California division was $233 million, its yearly payroll is close to $86 million, and it typically spends more than $40 million a year on procurements within California.

Miriam John is vice president of Sandia/California and chief executive of the California facility. She also leads Sandia's Homeland Security Management Unit, which encompasses programs and staff at both the New Mexico and California sites. Figure 4.1. is an organizational chart for Sandia/California.

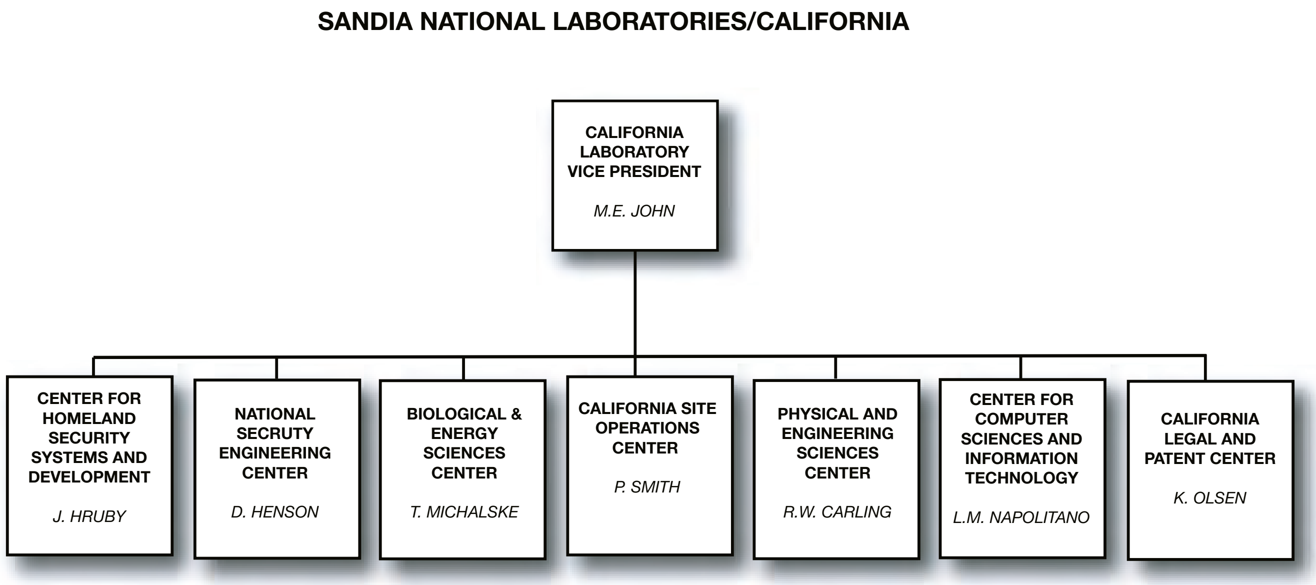


Figure 4.1. Organizational Chart for Sandia/California

QUICK FACTS ABOUT SANDIA/CALIFORNIA

Full name: California Division of Sandia National Laboratories
Nickname: Sandia/California
Location: Livermore
Year established: 1956
Type of laboratory: government-owned/contractor-operated
Management: operated by Lockheed Martin for the Department of Energy's National Nuclear Security Administration
Director: Miriam John
Workforce: 1,350
FY 2004 budget: $233 million
Web site: www.ca.sandia.gov
Main activities:

- Nuclear weapons (stockpile stewardship and transformation)
- Homeland security
- Energy research
- Chemical, information, biological, and microsystems science and engineering

National user facility:

- Combustion Research Facility (est. 1980). The Combustion Research Facility (CRF) is an Office of Science user facility for broad-based research in energy science and technology. In 2005, the CRF hosted 142 users and 826 visitors.

Examples of technological and economic contributions to California:

- DOE-Intel project to develop equipment for next-generation computer chips
- Hydrogen storage technologies

Examples of educational contributions to California:

- "Go Figure Math Challenge" for K-12 students
- Strategic Universities Partnership Council & University Fellowships
- "Family Science Nights"
- Three regional "Science Bowls" for high school students
- Internship "Institutes" offer student opportunities in advanced computing, homeland security, engineering, modeling and simulation, and other disciplines

Examples of assistance to state and local government agencies in California:

- Operation Safe Commerce at the Ports of Los Angeles and Long Beach
- Advanced detection equipment and emergency response systems and planning for San Francisco International Airport
- Partnership with Livermore Police Department: Rapidly Deployable Chemical Detection System (RDCD)
- San Diego Border Research and Technology Center

4.2. HISTORY OF SANDIA/CALIFORNIA[16]

Sandia National Laboratories grew out of a World War II division of Los Alamos and became a separate laboratory in 1949. Sandia's main site is in Albuquerque, New Mexico, which is close to Los Alamos.

Sandia's precursor was Z Division, created in 1945 as the engineering design, testing, and assembly arm of the wartime Los Alamos Laboratory. The division soon moved to Sandia Base in Albuquerque, New Mexico, to be near an airfield and work closely with the military. In 1948, Z Division's growth prompted its designation as Sandia Laboratory, a separate branch of Los Alamos. But the growth continued, and the Atomic Energy Commission — the predecessor to today's Department of Energy — began to look for an industrial firm to manage the engineering facility. In May of 1949, President Truman asked the American Telephone and Telegraph Company (AT&T) to manage Sandia. Western Electric, AT&T's manufacturing arm, accepted the management role on a no-profit, no-fee basis. On November 1, 1949, Sandia Corporation, a wholly owned subsidiary of Western Electric, began managing the facility. Sandia was designated a multi-program national laboratory in 1979. In 1993, Martin Marietta took over Sandia's management contract, and two years later merged with Lockheed to become Lockheed Martin.

In 1956, Sandia opened its second laboratory in Livermore, California, across the street from Lawrence Livermore National Laboratory. From the late 1950s through the early 1990s, the two laboratories worked closely to design, test, and assemble reliable weapons. Since 1993, when President Clinton ended U.S. nuclear testing and established the Stockpile Stewardship Program, Sandia/California and LLNL have focused on keeping the America's nuclear weapons safe, secure, and reliable, using non-nuclear tests, computer simulations, and upgraded components to certify and refurbish the nuclear stockpile. They have continued that strong partnership into meeting the challenges of homeland security.

Since its creation, Sandia/California has developed expertise in many areas of science and engineering and applied those skills to energy and environment, homeland security, and nonproliferation. For example, it has developed particular expertise in energy research, including cleaner forms of combustion and, more recently, storage of hydrogen fuels.

4.3. MAJOR PROGRAMS, FACILITIES, AND INITIATIVES

Programs and Facilities

Sandia/California has mission responsibilities in four key areas:

- ***Nuclear weapons.*** Sandia's primary mission is ensuring that the U.S. nuclear arsenal is safe, secure, and reliable, and can fully support U.S. deterrence policy. Sandia/California and LLNL are jointly responsible for the upkeep and certification of five of the nine nuclear weapon types in the U.S. stockpile. Sandia plays a major role in DOE's Advanced Strategic Computing Program, carrying out three-dimensional advanced computer modeling and simulation research to help maintain safe and reliable weapons in this era of no nuclear testing.
- ***Energy.*** Sandia/California is home to an internationally recognized center in the science of combustion, including how to burn fuels more efficiently and with less pollution. The Combustion Research Facility is a major DOE user facility and makes its diagnostic capabilities and resources available to U.S. industry and academia.

[16] The following description of Sandia's history is drawn from its Web pages, particularly from the history section that can be found at http://www.sandia.gov/about/history/. Sandia/California's Web site is http://www.ca.sandia.gov/casite/index.html.

The division has expertise in hydrogen storage and has recently initiated new programs with both the Department of Energy (metal hydrides) and GM (hydride storage and fuel cell system engineering).

- ***Homeland security.*** Sandia/California has homeland security programs in borders and transportation security, radiological and nuclear countermeasures, chemical and biological countermeasures, cyber security, and systems analysis. The division works closely with LLNL and the Department of Homeland Security as well as state and regional government entities. Recently, Sandia/California has established a Weapons of Mass Destruction Decision Analysis Center to help emergency response agencies practice and improve their response plans for terrorist incidents.
- ***Science & technology.*** Science and technology is an essential mission at Sandia/California and includes research and development in computation, biology, infrastructure, and microtechnologies. Sandia/California has a strong record in innovation, chemistry, materials science, and intellectual property, registering 27% of all Sandia patents issued over the last five years.

To carry out these four missions, Sandia/California has built scientific and technological capabilities in several key areas, including the following:

- ***Bioscience and biotechnology.*** Biotechnology and bioscience are expected to be as important to future national security concerns as physics was for the past 60 years. At Sandia, traditional strengths in systems design and engineering physics, information sciences, and engineering are being leveraged with bioscience expertise to address the complex problems of "systems biology." The focus is on elucidating the structure, function, dynamics, and interactions of proteins that are important in producing and/or mitigating the physiological effects of a chemical or biological attack. Sensors and diagnostics for rapid detection and identification of bioagents, bioremediation and decontamination, and bio-derived fuels are other application areas.
- ***Chem/bio program.*** Well before 2001, Sandia was working on technologies and systems to address the threat of chemical or biological agents. The events of 2001 increased awareness of the potential threat. Sandia scientists, engineers, and technologies played a significant role in the response to the October 2001 anthrax episodes. Technical assistance in decontamination and interior dispersion of biological agents facilitated the eradication of anthrax in key federal and commercial buildings. Research and development into chemical and biological defense continues with efforts to develop and field preparedness and response capabilities.
- ***Systems analysis.*** Deployment of effective homeland security measures requires detailed understanding of the net benefits of alternatives and continuous assessment of technology readiness for insertion into deployed systems. Understanding requires detailed analytical, simulation, and assessment capabilities. Application of these capabilities to address key technical, programmatic, and policy-related decisions constitutes systems analysis. Systems analysis examines alternative architectures for both defensive and responsive systems to provide requirements for technology development and to assess the performance of prototypes and test systems for continued improvement in performance as larger-scale systems are deployed.
- ***Distributed information systems and information protection.*** Capabilities at Sandia/California span multiple computer science and information technology disciplines. Activities include computational science and mathematics research, high-performance computing, visualization systems research and development,

problem solving environments, information security research and operations, desktop computer support, videoconferencing solutions and desktop collaboration technologies, and network operations. Most of the computer science work is supported by the National Nuclear Security Administration's Advanced Simulation and Computing program, which insures the integrity of the nation's nuclear stockpile, and other federal agencies and Department of Energy offices.

- ***Materials and engineering sciences.*** Sandia/California's Physical and Engineering Sciences Center has three primary areas of expertise: materials science, engineering science, and microsystems science and technology. The center is engaged in research and development on a wide variety of topics to support the national security missions of Sandia. Examples of current topics are hydrogen storage, micro-electro-mechanical systems (MEMS), radiation detection materials and systems, and nanoscale science and technology. Customers include many offices within DOE, including the National Nuclear Security Administration, Office of Science, Energy Efficiency and Renewable Energy, and Nuclear Non-proliferation. The center also works with the Department of Homeland Security, the Department of Defense, and a number of industrial customers.

To help support these activities, Sandia has a number of major facilities and centers. They include both facilities at the California site and additional facilities in New Mexico that the California division can draw upon. The following two text boxes provide information on two important Sandia operations. The first — the Combustion Research Facility — is located at Sandia/California and works particularly closely with California state agencies. The second — the National Infrastructure Simulation and Analysis Center — is located in New Mexico, and illustrates how California, as well as other states, can draw upon equipment and expert groups throughout the overall Sandia complex.

THE NATIONAL INFRASTRUCTURE SIMULATION AND ANALYSIS CENTER

The National Infrastructure Simulation and Analysis Center (NISAC) is a partnership between Sandia National Laboratories and Los Alamos National Laboratory that provides advanced modeling and simulation capabilities for the analysis of critical infrastructures such as highways, electrical lines, and natural gas pipelines and their interdependencies, vulnerabilities, and complexities. Their analysis includes technical, economic, and national security implications of infrastructure protection, mitigation, response, and recovery operations.

NISAC recently applied its capabilities to conducting analyses of infrastructure impacts due to Hurricanes Katrina and Rita. It completed 17 reports for the Department of Homeland Security (DHS), including two Katrina pre-event reports, one Ophelia pre-event report, four Rita pre-event reports, and 10 Katrina post-event reports. NISAC also is looking at scenarios around the nation to identify possible events with the potential for severe consequences.

Sandia earlier demonstrated the value of such information with its analysis of the Northridge Earthquake. On January 17, 1994, the Northridge Earthquake occurred in Los Angeles at a magnitude of 6.7, killing 60 and injuring more than 7,000. It resulted in billions of dollars in damage. Sandia's Infrastructure Surety Department used the Northridge data to create a model for improving emergency response and disaster recovery to these large-scale events. By identifying infrastructure interdependencies, they were able to determine how these elements would affect the restoration of infrastructure and critical services as well as establishing priorities and pointing to improvements in response.

SANDIA/CALIFORNIA'S COMBUSTION RESEARCH FACILITY (CRF)

The Combustion Research Facility is the Department of Energy's premier site for broad-based research in combustion and energy-related science and technology. A DOE "user facility," the CRF provides unique collaborative research opportunities for university, industry, and government scientists and engineers.

The CRF's work focuses on developing the science base needed to develop cleaner, more efficient transportation, power generation, and industrial processes. Researchers have made great strides in understanding complex chemical reactions at the molecular level — knowledge that is critical to new and improved energy technologies. By understanding the incremental steps in soot formation, for example, researchers and engine designers are working to significantly limit the amount of soot formed in the first place.

In addition to its fundamental combustion research, the Combustion Research Facility also conducts research on the following:

- Alternative fuels
- Advanced, low-polluting engine concepts, including hydrogen-fueled internal combustion engines
- Improving and reducing the environmental impact of diesel combustion

Sandia has been named a Department of Energy "Center of Excellence" in conducting research on metal hydride-based hydrogen storage, which Governor Schwarzenegger recognized in a recent news release (see http://www.schwarzenegger.com/news.asp?id=1526). A key objective is to develop materials capable of storing hydrogen safely and economically on board a vehicle that can be operated for at least 300 miles before refueling.

In addition to contributing to the nation's energy security, technologies developed at the Combustion Research Facility are being used to develop devices for the rapid detection of chemical and biological warfare agents.

Several Combustion Research Facility managers and a former director have participated in various organizations and projects designed to help California, including:

- California Council on Science and Technology
- Governor's Hydrogen Highway Initiative
- California Air Resources Board
- California Environmental Protection Agency

Major New Initiatives

Two major initiatives underway at Sandia/California are expanded homeland security activities and hydrogen fuel research.

The way in which Sandia/California is carrying out these two new initiatives is also important. Both reflect the way that Sandia/California and other federal laboratories now undertake research and technology deployment — with an emphasis on science and technology partnerships. Tapping the expertise of multiple science and technology organizations can expand research, as well as speed the transfer of the resulting knowledge and technology.

In homeland security and disaster preparedness, Sandia/California's expanded activities include additional research and development in such areas as biological and chemical sensors. Sandia/California has expanded its partnerships with state and local agencies and with private companies. The work here emphasizes two priorities: (1) partnerships using current technologies to help state and local officials prepare now for possible emergencies and (2) work with private firms to commercialize new technologies as rapidly as possible.

Sandia's hydrogen program supports President Bush's and Governor Schwarzenegger's long-term vision for commercially viable hydrogen-powered vehicles. These activities are carried out by multidisciplinary teams of scientists and engineers located at Sandia's sites in Livermore and Albuquerque. The work is done in close partnership with industry, government, and university research institutions worldwide. Sandia's most important contribution centers on hydrogen storage using metal hydrides. Sandia also conducts research in direct support of U.S. industry partners. In January 2005, the Department of Energy Metal Hydride Center of Excellence opened at Sandia/California to meet or exceed FreedomCAR 2010 hydrogen storage goals. Sandia/California is the lead laboratory among 15 partner organizations (seven universities, five national laboratories, and three industries). Additionally, General Motors and Sandia have embarked on a four-year program to develop a hydrogen storage system utilizing a complex metal hydride.

Sandia's hydrogen program supports President Bush's and Governor Schwarzenegger's long-term vision for commercially viable hydrogen-powered vehicles.

4.4. CONTRIBUTIONS TO CALIFORNIA

Technological and Economic Contributions

For almost 50 years, Sandia/California has made significant economic contributions through the jobs it provides and the purchasing of goods and services in California. As mentioned earlier, the fiscal year 2004 budget for the California division was $233 million, its yearly payroll was close to $86 million, and it typically spends more than $40 million a year on procurements within California. Further details on these and other contributions to the California economy are available in the appendix.

The value of a national laboratory in a state goes far beyond the payroll and direct economic activity it generates. Participation in technology partnerships and technology spin-offs contribute to the technology base of the region and bring advanced technologies into the commercial setting. Sandia/California has a robust technology licensing program that in 2004 had 1,090 active licenses, many with California companies. It also has authority to enter into the same types of technology partnerships as do other DOE laboratories: cooperative research and development agreements, work-for-others agreements, and facilities agreements — all of which enable California companies and others to get access to its unique facilities and expertise.

Sandia/California works with California industry in several key areas:

- ***Energy and combustion research.*** The work of the CRF includes industrial partnerships for internal combustion engine design, conventional and alternative fuels formulation, hydrogen materials (metal hydrides), and hydrogen storage containers. Additionally, the CRF has recently developed industrial partnerships in high-energy fiber lasers.
- ***Semiconductors.*** The extreme ultraviolet lithography (EUVL) project that Sandia/California, Lawrence Livermore National Laboratory, and Lawrence Berkeley National Laboratory jointly conducted with Intel and other semiconductor companies demonstrated a next-generation technique for producing computer chips with ever smaller circuit lines. Sandia played a central role in this award-winning project, providing, among other things, integration, assembly, and operation of a fully functional prototype machine, the Engineering Test Stand (ETS).

- ***Biosciences.*** Since 1999, Sandia/California has made a substantial investment in biology, hiring several dozen researchers in the biological sciences and partnering them with chemists, material scientists, microtechnologists, and engineers. The investment is in support of Sandia's missions in national security, primarily biological weapons defense and energy security. The work has strong ties to California. In addition to joint programs with neighboring LLNL and nearby LBNL, strong collaborations exist between Sandia staff and researchers at UC Berkeley, UC San Francisco, Stanford University, and the Scripps Research Institute in San Diego. Technologies being developed are licensed for commercial use to biotechnology firms throughout the state.
- ***Telemedicine.*** Sandia has conducted research and development in telemedicine technology that led Sandia researchers to two primary conclusions: (1) telemedicine, combined with other health-care information technologies, has the power to enable fundamental transformations in modern health-care delivery, and (2) the nation needs to cultivate a new systems-oriented science of health-care delivery to guide these transformations so that costs can be contained, access to care guaranteed, and quality of care maintained or improved even as demand for care rapidly increases. California, with its extensive information infrastructure, strong technology base, and rich array of medical expertise, can drive this transformation. Sandia, with its background in health-care systems, economic and policy analysis, and cutting-edge microsystems engineering resources, would be a strong partner in any such effort.
- ***Microsystems and microfabrication.*** By leveraging its microsystems and microfabrication capabilities, Sandia/California has attracted industrial partners, especially in the field of chemical and biological species detection. Industrial partnerships include development of laboratory instruments (such as liquid chromatography), first responder hand-held microfluidic analysis systems, devices for real-time analysis of municipal water sources, and various microfluidic components (such as valves, fittings, pumps, and power supplies). Some of the partnerships are based on licenses of Sandia/California's intellectual property.

As a particular example of work with industry, Sandia partnered in 1999 with Reaction Design, a San Diego company, to commercialize its CHEMKIN software for simulating chemical reaction flow for the automotive, power generation, and chemicals/materials industries. This software is now in use at over 150 commercial companies that apply the software to design more efficient and more environmentally friendly chemical processes. For example, the leading manufacturers of gas turbines for distributed power generation use CHEMKIN to reduce nitrogen oxides emissions to meet California's stringent standards while maintaining high performance requirements of end-users. Reaction Design has grown to 15 employees and recently opened an office in Japan.

Sandia also has a special mechanism for employees who wish to leave to work in entrepreneurial companies. As described in the following text box, this process does not provide a leave of absence — employees leave Sandia. But they are guaranteed re-employment within two years, which provides a type of safety net that makes entrepreneurship less risky professionally.

ENTREPRENEURIAL SEPARATION TO TRANSFER TECHNOLOGY (ESTT)

One of Sandia National Laboratories' mechanisms available for the transfer of technology to the commercial sector is Entrepreneurial Separation to Transfer Technology (ESTT). Under this mechanism, employees terminate their employment at Sandia for the purpose of starting a small, technology-based business or helping expand such a small technology-based business. This termination of employment is not considered a leave of absence. However, employees leaving Sandia under this program have an option to return to employment at Sandia within two years. They are guaranteed to be re-hired into similar positions at Sandia if they choose to return before the end of their approved length of separation. To participate in the program, employees must obtain approvals based in part on the sufficiency of the benefits to Sandia. If a license to use Sandia intellectual property is necessary to operate the proposed business, participation also will depend on the development of a sound business plan and successful negotiation of license terms.

Since it was begun in 1994, more than 23 Sandians have used the ESTT program to create four start-up companies and expand seven additional companies in California. The California start-up companies are SiTek, Eksigent, Hy-Energy LLC, and Sky+ Ltd. The California companies that Sandians helped expand are Reaction Design, Axsun Technologies, Livermore Software Technology Corporation, MEMX, E20 Communications, S&R Precision Machining, and W5 Networks, Inc.

Ten Sandians left to start-up Eksigent Technologies in Livermore, California. Eksigent was formed in 2000 to commercialize the EKPump technology discovered by its founders. Prior to May 2000, Eksigent's technical personnel led development of portable chemical analysis systems at Sandia National Laboratories, including breakthrough technologies that form the basis of Eksigent's extensive suite of microfluidic technologies. In August 2001, Eksigent signed a license agreement with Sandia to secure rights to some of Sandia's microfluidics technology for use in many applications in chemical analysis, biotechnology, proteomics, drug discovery, MEMS, and microelectronics. More information about Eksigent can be found at http://www.eksigent.com.

Entrepreneurs leaving Sandia can also receive business coaching and assistance from Technology Ventures Corporation (TVC), established by Lockheed Martin when awarded the contract to operate Sandia National Laboratories. TVC assists start-up companies with market research, business plan preparation, and angel and venture capital acquisition. In addition, valuable year-round training in all aspects of small business development and management is available to entrepreneurs. TVC has an office in Livermore.

Contributions to Education and Academic Research

Sandia/California contributes to education and academic research in California through research collaborations with several of the state's universities, Sandia-funded graduate research fellowships, a vigorous internship program, and outreach mentoring and volunteer activities in local K-12 schools.

Higher education. Sandia's principal staffing goal is to attract high-quality staff to meet its critical skills requirements. To this end, it has a vigorous set of student programs that support 200–300 students each year. This effort also augments Sandia's research and helps students succeed in their academic careers. The programs are aligned with Sandia's hiring needs to attract top talent. California's outstanding universities allow Sandia recruiters to find and hire some of their best and brightest students, and these institutions appreciate that Sandia encourages the students to complete their education before accepting employment at Sandia.

As part of its programs, Sandia/California operates a number of institutes for students and faculty and intern programs, including:

- The Center for Cyber Defenders Institute (CCD) has trained over 100 interns in cyber security. Twenty-one of those interns are now employed as Sandians. In its early years, the CCD was instrumental in training students in this area prior to universities offering similar programs. Sandia has partnered with universities as they have gained expertise and enhanced their programs.
- The Embedded Reasoning Institute provides research opportunities in computer science, physical science, and engineering.
- The Microsystems Partnerships Program provides research opportunities in design, fabrication, and testing of microsystems, microelectronics, and advanced sensors.
- The Homeland Security Institute gives interns an opportunity to work with Sandia researchers in critical areas such as chemical and biological countermeasures, critical infrastructure surety, and explosive detection technology.
- Engineering Sciences exposes students to the national laboratory environment and encourages them to pursue careers in scientific fields critical to the DOE mission.
- National Security Electrical and Mechanical Engineering offers students hands-on experience with real-world engineering challenges.
- Computer Science Research fosters collaborations between universities and Sandia to solve problems in computational science and mathematics.
- Advanced Computing Research allows students an opportunity to conduct research in three-dimensional modeling and simulation.

Sandia also has diversity outreach activities. They include:

- Supporting targeted fellowships such as the National Physical Sciences Consortium (NPSC) and the National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM), and Sandia's own One Year on Campus (OYOC) program, a master's degree program for minority students in approved technical or mission-related programs.
- Targeted recruiting, specific to underrepresented student groups.
- Service on the Berkeley Edge committee each year. Berkeley Edge is a UC Berkeley Ph.D. program that helps to identify, recruit, and retain talented minority students in science, mathematics, and engineering. Recently, Sandia has hired several interns and one full-time employee as a result of this effort.

In 2002, Sandia/California's Strategic University Partnerships Council (SUPC) began strengthening interactions and partnerships with Stanford University, UC Berkeley, and UC Davis to improve Sandia's visibility at these institutions, improve recruiting effectiveness, and identify opportunities for joint research and development. Sandia has established graduate research fellowships and aggressive recruiting efforts at all three campuses. Joint collaborations in targeted research areas have increased significantly. For example, Sandia is continuing an affiliation with Stanford University's Center for International Security and Cooperation (CISAC).

In addition, Sandia has an on-going collaboration with UC Berkeley in its Berkeley Sensor and Actuator Center (BSAC). At UC Davis, two Sandians are collaborating with Enrique Lavernia, dean of the School of Engineering, on specialized materials development. Also at UC Davis, a formal seminar exchange has been established between the university and Sandia. This brings engineering and science professors to Sandia and Sandia scientists and engineers to the campus each semester. At a recent joint UC Davis/National Laboratory Board meeting, Dean Lavernia cited Sandia's formal Action Plan Annual Report as an "example of an excellent collaboration between the university and a national laboratory."

These programs benefit Sandia and the school. Sandia has the opportunity to cultivate and nurture potential future employees, while academic institutions gain unique and valuable learning opportunities for students and faculty. As a result of their Sandia internship, many undergraduates decide to continue their education by pursuing advanced degrees. In addition, extensive joint research collaborations produce leading-edge, world-class research that benefits both institutions and the nation.

K-12 contributions. On the K-12 side, Sandia sponsors a variety of science and mathematics programs. For example, Sandia supports Go-Figure, an annual math challenge offered in the Bay Area to identify mathematically talented 7–12 grade students and develop their skill and enthusiasm in math. The top 60 students are honored at a banquet attended by Sandians, teachers, and parents. These students are tracked, and many are hired for internships and encouraged to pursue advanced degrees. Another program sponsored by Sandia is Family Science Night, an evening of hands-on science activities held at local elementary schools. Children and their parents work together to conduct inquiry-based, age-appropriate science activities.

Sandia employees actively participate in community outreach endeavors aimed at sharing the science of Sandia. For instance, the Science Discovery Center provides science kits, hands-on activities, and materials, which are available to be checked out by any Sandian as they work with schools in the community.

Sandia facilitates three Regional Science Bowls each year (one in conjunction with Lawrence Berkeley National Laboratory), involving a competition between high schools in the San Francisco Bay Area. The event offers students who excel in math and science, and the teachers who have prepared them, a forum through which they receive national recognition for their talent and hard work.

The Sandia Women's Committee sponsors an annual Math and Science Awards banquet each year to honor local high school juniors for their academic achievements in math and science. Awards are presented by the Sandia/California vice president and attended by Sandia women scientists and engineers who act as hosts for the awardees during the evening. Designed to encourage young women to pursue technical careers, Sandians share their personal stories regarding their paths to a technical career. They encourage the young winners to follow their dreams and explore all options.

Assistance to State and Local Government

New technologies to meet new challenges will be needed by California and other states to deal with problems that might not have been recognized only a short time ago. As an engineering laboratory, Sandia/California has the vision and competence to recognize changing conditions and emerging technologies in order to design new devices and systems to meet evolving national and local needs.

Sandia supported both education and state government by participating in the development of the 2002 version of the California Master Plan for Education. Laboratory representatives played key roles in developing the "Forecasting and Planning" section. In the report, recommendations were made for the state to develop coordinated planning models to aid in the decision processes around the allocation of limited resources to meet current and emerging educational needs.

SANDIA/CALIFORNIA'S CONTRIBUTIONS TO CALIFORNIA'S SECURITY

Sandia has significant partnerships with organizations, agencies, and companies in California as they address the challenges of homeland security and disaster preparedness. These efforts have led to changes in operations, modifications of policies, introduction of new technologies, and new business opportunities in the homeland security marketplace.

- **California Highway Patrol, U.S. Customs and Border Patrol, and local law enforcement:** Sandia manages the San Diego Border Research and Technology Center for the U.S. National Institute of Justice. It provides technical assistance to law enforcement and evaluation of new technologies for drug interdiction, reduction of border crime, and counter-terrorism along the U.S.-Mexico border. Accomplishments include the use of precision location technology that is based on the global positioning system by the border patrol from aerial platforms to interdict illegal border crossings and the use of remote video monitoring to reduce border crime.
- **Southern California Edison (SCE) and U.S. Bureau of Reclamation:** Sandia evaluated the preparedness of SCE's grid management system and the Bureau of Reclamation's western waterways and dams against cyber and other attacks on its critical information systems. These evaluations have led to the re-engineering of the control systems of federal dams in California (Shasta Dam among them) as well as the SCE Power Management System to harden them against internal and external cyber threats.
- **Ports of Los Angeles (LA) and Long Beach (LB):** Sandia is the program manager for the ports' Operation Safe Commerce (OSC) activities. An initiative of the Department of Homeland Security's port security program, OSC focused on the largest domestic ports and integrated new detection technologies with risk assessments and modifications to security operations. Sandia's work with LA/LB has enabled the ports to introduce technologies that reduce the likelihood of smuggling of weapons of mass destruction without interfering with efficient operation of cargo and logistics facilities.
- **Bomb Disposal Operations:** Sandia has helped Riverside and Alameda Counties, along with bomb disposal units at the state level, to understand and use a patented technology for the nondestructive disablement of unexploded ordnance. Disposal units can defuse/disable bombs while preserving the materials for forensic evaluation and eventual prosecution.
- **San Francisco International Airport (SFO):** In a long-term partnership, Sandia and SFO have jointly developed models, introduced detection technologies, performed exercises, and modified response procedures to mitigate the risk and consequences of chemical and biological attacks. The work is now codified in a bio-terrorism preparedness manual issued by the Transportation Security Administration for use at airports nationwide.
- **Alameda/Contra Costa Public Health:** Using simulations for an interagency bio-terrorism exercise, Sandia helped local public health agencies refine and extend their bio-terrorism preparedness planning and response protocols. The exercises use models to represent the spread of diseases and pathogens and allow decision makers to affect the outcome of the simulated attack. As a result, Alameda's Public Health Department changed its plan for distribution of antibiotics and for public notification of an attack.
- **San Diego Public Health and U.S. Navy (San Diego):** Sandia, along with its partners from Lawrence Livermore National Laboratory, have helped the San Diego area integrate its civilian and military bio-terrorism response plans. Extensive modeling, analysis, and assessments have helped public health departments coordinate their early warning, laboratory analysis, notification, and prophylaxis distribution procedures.

SANDIA/CALIFORNIA'S CONTRIBUTIONS: THE "MICROCHEMLAB"

Some sensor technologies that Sandia/California has developed and is sharing with government officials in California have applications beyond counter-terrorism. For example, one major technical achievement is a small, portable device called "microChemlab" (or "µChemlab"). Two prototypes are pictured below. The device is a miniaturized chemical laboratory that separates biological and chemical molecules and then uses an ultraviolet laser diode to visualize the separated molecules as they emerge. On-board data processing identifies molecules of interest.

As Sandia technologies approach market-ready status, the lab often seeks business partnerships with industry, universities and other federal agencies. In 2004, Sandia entered into an agreement with Tenix Investments and CH2M Hill to develop an unattended water safety system based on Sandia's µChemLab technology.

Current prototypes have uses in detecting possible biological and chemical terrorism substances. The demonstration unit has been used to detect biotoxins such as ricin, staphylococcal enterotoxin B, and botulinum toxin, and it is being applied to identify viruses and bacteria using protein fingerprinting. Parallel analysis channels provide highly accurate chemical detection of very small amounts. For California, one obvious and important application will be to analyze water samples and assure the safety of drinking water against both natural and intentional contamination. Sandia/California is working with two companies (Tenix, Ltd., and CH2M Hill) to develop an unattended water safety analyzer for use in public water systems, with Sandia's microChemLab serving as the base technology. Sandia works closely with the Contra Costa Water District on this project.

The technology also has important potential uses beyond homeland security, particularly in medicine and agriculture. Sandia has begun to use the microChemLab system to analyze saliva and blood samples for key indicators of disease or other medical distress in humans. Agricultural applications have particular California relevance. The system could be used as a protein identification and quantification tool to characterize crop quality or evaluate animal health. Sandia is now exploring possible industrial partnerships in California to commercialize the technology.

Sandia brought its considerable experience in developing such decision and planning models for military, health care, and homeland security applications to inform the discussions and frame the recommendations.

Since the terrorist attacks of September 11, 2001, and the anthrax attacks of October 2001, Sandia has greatly expanded its homeland security work with state and local agencies in California. Sandia's activities in California are quite varied and range from assistance to border patrol officers, to security protection for the Ports of Los Angeles and Long Beach, to a pioneering bio-terrorism preparedness program at the San Francisco International Airport. These projects are described in the text box on the previous page. The box following the project descriptions discusses a revolutionary new hand-held device to detect both biological and chemical agents. It is useful for not only homeland security, but also potentially in water management, medicine, and agriculture.

Sandia's activities in California range from assistance to Border Patrol officers, to security protection for the Ports of Los Angeles and Long Beach, to a pioneering bio-terrorism preparedness program at San Francisco International Airport.

4.5. OPPORTUNITIES AND CHALLENGES

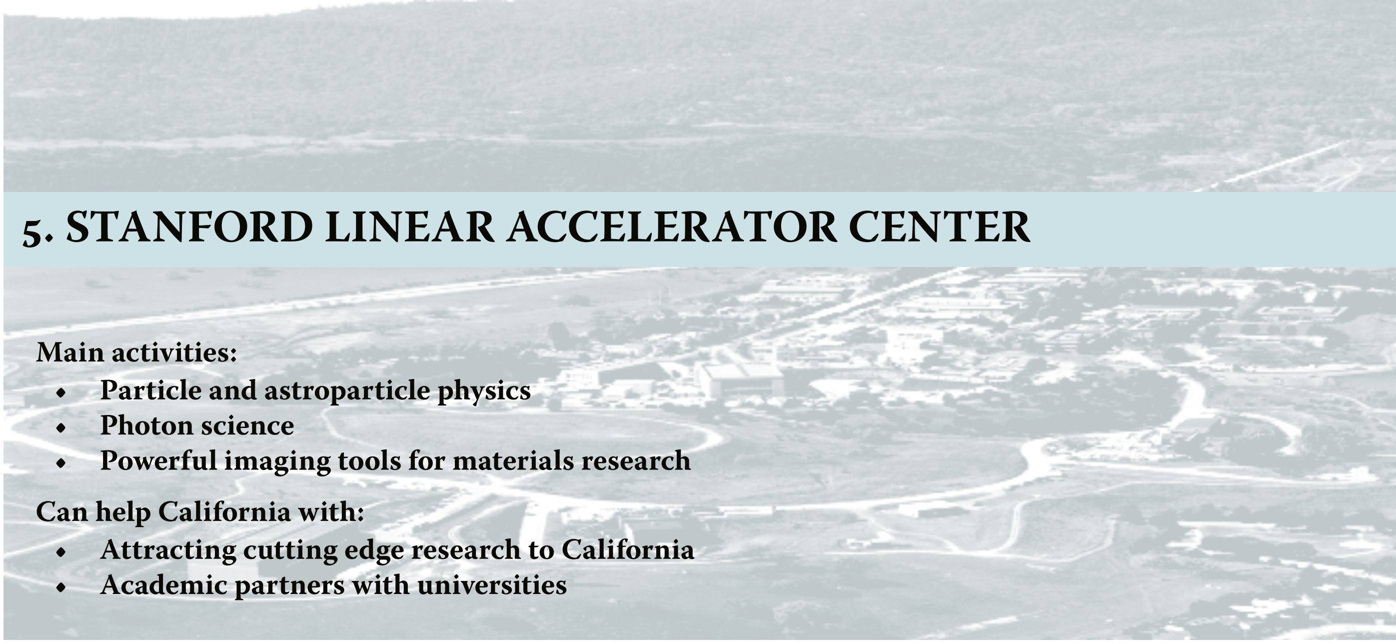
Sandia's California division has worked successfully with many California companies. It is also greatly expanding its assistance to state and local agencies involved in homeland security. As an engineering laboratory, it has the potential to help California agencies and companies develop new sensors and other devices for homeland security.

Two challenges stand in the way, however. As mentioned in the Berkeley Lab and Livermore chapters of this report, Department of Energy regulations require that its laboratories collect fees for joint research before commencing any joint projects with companies or state and local agencies. For companies, this is usually not a problem. But California state procurement rules generally provide that state agencies can only pay for contract work after that work has been performed. These state rules can be a barrier to efforts by Sandia and other laboratories to provide assistance to state agencies.

Second, the process of commercializing a technology that will be sold to law-enforcement agencies is complex. The process requires bringing together a wide range of parties with different needs and different backgrounds: technology developers at the laboratories; local police, fire, and medical personnel; state and federal officials who help fund local purchases of new equipment; and of course the companies that one hopes will define markets, refine technologies, and actually produce commercial versions of devices such as Sandia's microChemlab.

California homeland security officials might play an important role in convening meetings of these various groups and possibly providing either seed grants for further technology development or early procurement contracts to provide an incentive for companies to manufacture these devices.

Since its inception, Sandia/California has been an engaged partner with the state in building California's future, and will continue to be a partner in assisting California with evolving challenges. The resources of a major engineering laboratory can be leveraged with creativity and vision to assist the citizens of California in many dimensions of their daily lives.



5. STANFORD LINEAR ACCELERATOR CENTER

Main activities:
- **Particle and astroparticle physics**
- **Photon science**
- **Powerful imaging tools for materials research**

Can help California with:
- **Attracting cutting edge research to California**
- **Academic partners with universities**

5.1. INTRODUCTION TO STANFORD LINEAR ACCELERATOR CENTER

The Stanford Linear Accelerator Center (SLAC) is a major research laboratory, owned by the U.S. Department of Energy and operated by Stanford University. Established in 1962, its mission is to design, construct, and operate state-of-the-art electron accelerators. At the heart of SLAC is a three-kilometer (two-mile) long linear particle accelerator and related facilities. This machine accelerates electrons to very high speeds and energy levels for two key purposes:

- The original purpose of this and other accelerators is to smash the electrons in targets. The resulting collisions briefly break atomic particles apart and provide clues about the building blocks of atoms. Interestingly, these experiments can also shed light on what particles were created during the Big Bang, the huge explosion that created the universe billions of years ago. Experiments at SLAC can help explain why the universe has some kinds of matter and not other kinds.
- The fast-moving electrons generated within the linear accelerator can also be used to produce intense beams of x-rays, which scientists can then use to take extraordinarily clear pictures of atoms and molecules in electronic materials, human proteins, and chemical reactions. These "x-ray light sources" are powerful tools for researchers and industry.

The Stanford Linear Accelerator Center's work thus runs the gamut from very fundamental investigations into the nature of matter — research with no immediate applications but of vast interest to scientists — to studies of materials and cells that have applications in electronics, nanotechnology, medicine, and energy. SLAC's work is unclassified, and most of its funding comes from the Department of Energy's Office of Science.

SLAC has its own staff of physics, engineers, and computer scientists, and is also a national user facility available to researchers from universities, laboratories, and companies in the U.S. and around the world. SLAC's work has been recognized with many awards and honors, including three Nobel Prizes in physics. The Stanford Linear Accelerator Center's director is Jonathan Dorfan. Figure 5.1. provides an organizational chart.

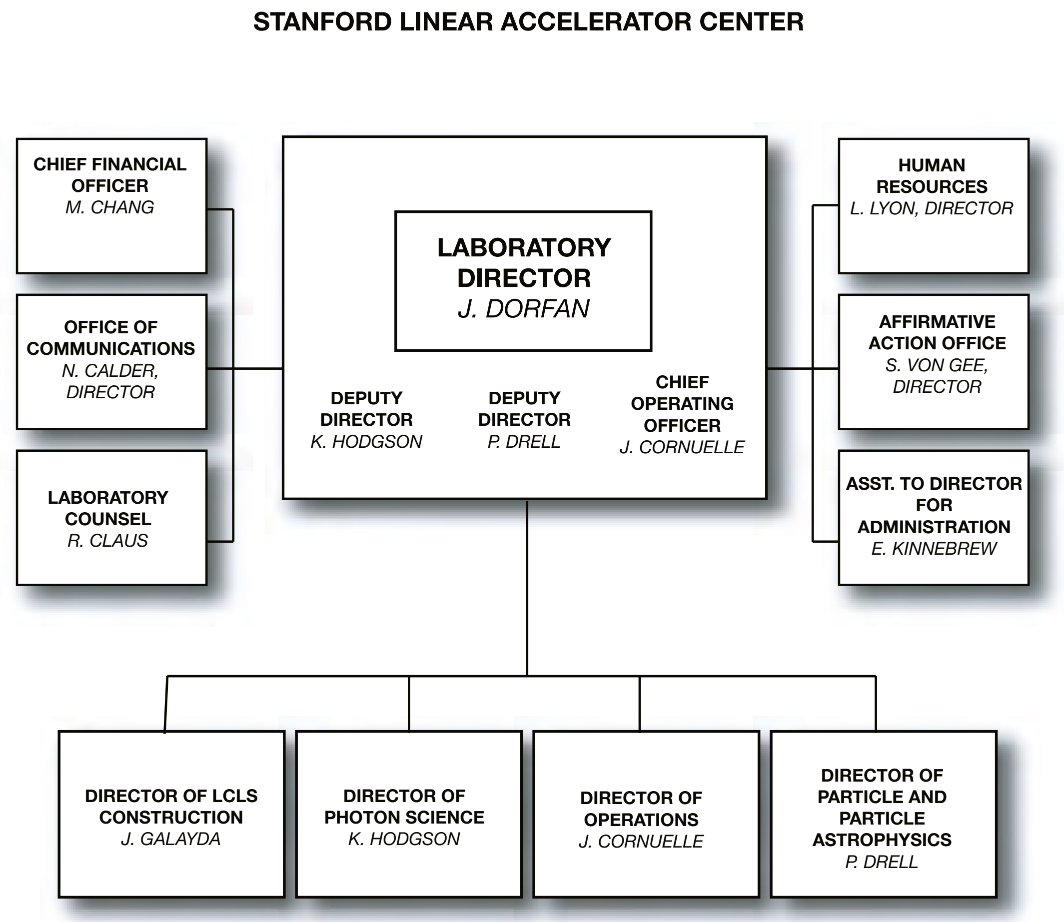


Figure 5.1. Organizational Chart of the Stanford Linear Accelerator Center

5.2. HISTORY OF THE STANFORD LINEAR ACCELERATOR CENTER

Research on the Fundamental Nature of Matter

SLAC is one of two large particle accelerators built in the 1960s by the U.S. Government to increase understanding of the nature of atoms and matter.[17] As discussed earlier in this report, America's history of particle accelerators and particle physics began in California, when Ernest Lawrence created what became Berkeley Lab. Of course, Berkeley Lab continues to have important accelerators, most recently its Advanced Light Source. But by the late 1950s, scientists also needed bigger accelerators than what could be built on the limited amount of land available to Berkeley Lab. SLAC was designed to meet these needs. Construction began in 1962 and finished in 1966.

SLAC's initial work focused on the first of its two current activities: colliding subatomic particles to better understand the nature of atoms and matter. The new machine quickly led to important discoveries. As one article has pointed out, "Early experiments led to Nobel Prize-winning work that showed, for example, that elemental particles that compose the atomic nucleus — the proton and neutron — were themselves composed of even smaller, more fundamental objects called quarks." [18]

[17] The other accelerator built in the 1960s is at the Fermi National Accelerator Laboratory ("Fermilab"), outside of Chicago. It and SLAC are both continuing to do important scientific research.

[18] Yvonne Daley, "Shining a Light on the Invisible World, Stanford Today, July/August 1997, available at: http://www.stanford.edu/dept/news/stanfordtoday/ed/9707/9707smf.html.

QUICK FACTS ABOUT THE STANFORD LINEAR ACCELERATOR CENTER

Full name: Stanford Linear Accelerator Center
Nickname: SLAC
Location: Menlo Park, near the Stanford University Campus
Year established: 1962
Type of laboratory: government-owned/contractor-operated
Management: operated by Stanford University for the U.S. Department of Energy
Director: Jonathan Dorfan
Number of employees: 1,520
FY 2005 budget: approximately $250 million
Web site: www.slac.stanford.edu
Main activities:

- Particle and astroparticle physics
- Photon science (science of light)

National user facilities (available to California researchers):

- Stanford Synchrotron Radiation Laboratory
- Linac Coherent Light Source (under construction)

Example of technological and economic contributions to California:

- Electronics and biological research at the Synchrotron Radiation Laboratory

Examples of educational contributions to California:

- Research collaborations with researchers from California universities

As this physics research continued over the years, SLAC scientists became increasingly interested in a separate but related research question. While particle physicists had investigated the smallest particles, astronomers and astrophysicists had wondered what occurred at the instant of the Big Bang, the moment that created our universe, and how that momentous event had shaped the nature of the universe. One particular question intrigued SLAC scientists: why did matter win out over antimatter in the first few milliseconds following the Big Bang? Evidence suggests that at the very beginning, both matter and antimatter were abundant, suggesting that they could have annihilated each other almost immediately and destroyed the universe barely after it began. Yet, clearly matter and the universe are here. Why?

In the 1990s, the Department of Energy funded the construction of an additional target facility at SLAC, called the "B Factory." This large "detector" is designed to look for evidence, after particles collide, of short-lived subatomic particles known as B mesons that provide clues about matter and antimatter. The B Factory opened in 1998 and today continues it research. An electrical accident at the end of 2004 led to a five-month shutdown and additional safety upgrades, but in April 2005 the B Factory went back on line. It continues its investigations into matter and antimatter.

Another major development at SLAC came in 2003, when physicist Fred Kavli and his Kavli Foundation gave $7.5 million to Stanford to establish an institute to advance research in astrophysics, high-energy physics, and cosmology. The Kavli Institute for Particle Astrophysics and Cosmology is a collaboration between SLAC and Stanford University's physics and applied physics departments. And it will focus on a range of important questions about the universe: What powered the Big Bang? What is the role of unseen "dark matter" in binding the universe together? How do black holes work?

X-rays for Materials Research

In 1973, SLAC began what it called the Stanford Synchrotron Radiation Project, later renamed the Stanford Synchrotron Radiation Laboratory (SSRL). A synchrotron is a circular particle accelerator, and today they are particularly suited to the creation of x-rays used in taking pictures of atoms and molecules. With funding from the Department of Energy, SLAC added the synchrotron to the existing three-kilometer long Stanford Linear Accelerator. The main machine accelerates electrons to a high energy level, and then the synchrotron further boosts the energy level and then uses the electrons to create x-rays. In turn, those x-rays can be used like a super microscope and camera. The SSRL is a national user facility, available to researchers from universities, other government laboratories, and industry. Semiconductor companies, for example, use it to look for impurities in silicon wafers. Biomedical researchers use it to look at the nature of proteins.

> *Semiconductor companies, for example, use SLAC to look for impurities in silicon wafers. Biomedical researchers look at the nature of proteins.*

This year, SLAC is beginning construction of an even more powerful x-ray source, the Linac Coherent Light Source (LCLS). (For physicists, x-rays are a form of light, the term "coherent" refers to highly structured laser light, and "linac" is another term for linear accelerator. The work done at such a facility is called "photon science," named after the particles that make up light.) LCLS will act like a lightning-fast strobe light, able to take freeze-frame snapshots of atoms and molecules — essentially x-ray motion pictures. Funding comes mainly from the Department of Energy, with some additional money from the National Institutes of Health (NIH). SLAC is leading the project, and other partners include Lawrence Livermore National Laboratory and UCLA. Project completion is expected in 2008, with the first experiments in 2009.

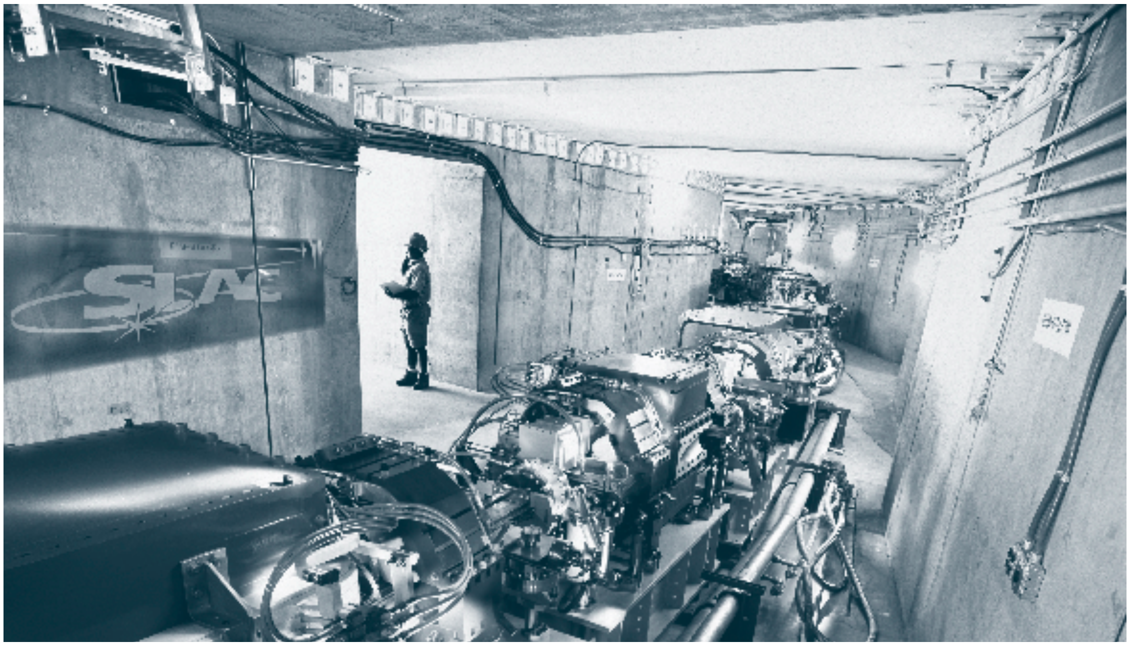
5.3. MAJOR PROGRAMS, FACILITIES, AND INITIATIVES

Programs and Facilities

As discussed above, SLAC's programs are now divided into two groups, with the following names:

- ***Particle and astroparticle physics.*** According to SLAC, the mission here is to make discoveries in particle and astroparticle physics to redefine humanity's understanding of what the universe is made of and the forces that control it.
- ***Photon science.*** The mission is to make discoveries in photon science at the frontiers of the ultrasmall and ultrafast in a wide spectrum of physical and life sciences. This is a growing mission at SLAC and one with important benefits for California industry.

SLAC's facilities consist of the main three-kilometer linear accelerator, plus the synchrotron light facility to generate x-rays and a set of detectors for particle physics experiments. Powerful magnets accelerate particles down the length of the accelerator and then shoot them into the synchrotron and detectors. In the photograph at the beginning of the chapter, the linear accelerator itself is visible as the long line running from the upper right corner down to the center. The other facilities are in the buildings in the center, at the end the accelerator, and in the lower left corner of the photograph.



The Stanford Synchrotron Radiation Laboratory (SSRL) accelerator. (Courtesy: SLAC)

In addition to the particle accelerator and related facilities, SLAC also has an extensive computer complex. Physics experiments generate enormous amounts of data, and SLAC is a pioneer in handling huge data sets and making them available over the Internet.

Initiatives

The most important new initiative at SLAC is the Linac Coherent Light Source, discussed earlier. SLAC provides the following description of this new machine:

The Linac Coherent Light Source (LCLS) is a revolutionary new machine for the production of hard x-rays. The x-rays are emitted in the form of a laser beam, with a brightness that is 10 billion times greater than that of any existing x-ray source on earth. X-rays are already our most widely used and essential tool for studying and understanding the arrangement of atoms in materials such as metals, semiconductors, ceramics, polymers, catalysts, and plastics, and in biological molecules. The structural knowledge obtained with x-rays holds the key to understanding the properties of matter such as mechanical strength, magnetism, transport of electrical currents and light, energy storage, and catalysis. Likewise, in biology much of what we know about structure and function on a molecular level comes from x-ray studies. Such knowledge forms the basis for the development of new materials and molecules and the enhancement of their properties, which in turn will advance technology, fuel our economy, and improve our quality of life. LCLS will bring a completely new dimension to the use of x-rays to study matter through its unique properties never before available.

In general, the shorter the wavelength of the light used, the smaller the sample one can see with it. Visible light has a wavelength that is far too large to resolve single molecules. When a large ocean wave rolls over a small stone the waves are not perturbed enough to detect that the stone is there. However, the same small stone can have a large effect on small ripples. To see an atom, a very short wavelength is needed. Today, scientists often use the x-rays produced by a synchrotron light source to study how their atomic structures affect the properties of materials (for example, ferromagnetic nanostructures in electronic devices, the binding of contaminants to soil particles, and the active sites of biomolecules that bind drugs). But the synchrotron light sources cannot produce ultra-short pulses, so they cannot resolve the ultra-fast motions of atoms during chemical reactions. LCLS is a revolutionary advance within the synchrotron radiation world, since it produces the x-rays associated with synchrotron light sources, and these x-rays are produced in ultra-short, ultra-intense pulses.[19]

5.4. CONTRIBUTIONS TO CALIFORNIA

Technological and Economic Contributions

First, the Stanford Linear Accelerator Center makes significant economic contributions through the jobs it provides and the procurement money that it spends in California. Second, while SLAC's work in particle physics and astroparticle physics is pure basic scientific research, and is not intended to generate immediate practical benefits, the x-ray program has proven applications. The x-rays generated by the synchrotron light sources are powerful imaging tools, able to look deeply into materials and analyze their composition. So far, researchers have used the existing synchrotron light facility for a variety of valuable projects. These are some examples:[20]

- ***Medicine.*** Researchers examine human proteins, including so-called "parasite proteins" that attach themselves to healthy cells and trigger cancers, viruses, and mutations. Some of this work has focused particularly on parasite proteins associated with breast cancer. Other biomedical researchers use the SLAC facility to investigate how muscles contract, how protease inhibitors can help people infected by HIV, and how the structure of bone mass is affected by osteoporosis.
- ***Environmental science.*** Researchers learn how plants such as water hyacinths, Indian mustard, and rabbit-foot grass clean up the environment by removing toxic materials. This research may help create new ways to clean up toxic waste sites and nuclear sites. For example, research at SLAC has shown which plants can absorb selenium, a dangerous heavy metal deposited in bay marshes by oil refineries.
- ***Electronics.*** Researchers from the semiconductor industry use the facility to look at the surface of silicon wafers, to detect and remove microscopic specks of metals that could slow down computer memory.

Contributions to Education and Academic Research

The Stanford Linear Accelerator Center contributes to university education and academic research in two major ways. First, SLAC is part of Stanford University, and its senior researchers are also Stanford faculty members. Close ties with the University's departments of physic and applied physics means that many Stanford graduate students, and also some undergraduates, benefit by becoming part of SLAC research projects. Second, SLAC is a national user facility, enabling physicists, material scientists, biologists, and others to conduct cutting-edge research. While people come from all over the world to conduct research at SLAC, the fact that the facility is in California makes it particularly convenient for California researchers.

[19] Stanford Linear Accelerator Center, "LCLS: A New Era of Science," http://www-ssrl.slac.stanford.edu/lcls/science.html. A more detailed brochure on the LCLS is available at: http://www-ssrl.slac.stanford.edu/lcls/downloads/lcls_brochure_print_opt.pdf.

[20] These examples are drawn from Yvonne Daley, "Shining a Light on the Invisible World, Stanford Today, July/August 1997, http://www.stanford.edu/dept/news/stanfordtoday/ed/9707/9707smf.html.

It is hard to measure and document the how valuable this world-class research is and will be to California's long term industrial innovation and economic success. But a larger benefit may exist beyond the specific projects that academic and industrial researchers conduct at SLAC, Berkeley Lab, and the other federal laboratories in the state.

As discussed in the introduction to this report, the presence of so many world-class research centers throughout California — in the federal laboratories as well as the state's universities and industrial R&D centers — provide a critical mass of bright people, a set of research clusters in which bright people learn from each other and which, in turn, helps California attract and retain new generations of bright scientists and engineers. For many graduate students and researchers, places such as SLAC make California the place to be. Some of those people, whether in universities, laboratories, or companies, will go on to create new inventions and create new start-ups. The exact role of SLAC or any other federal research laboratory in California's "innovation ecosystem" is hard to measure. But their role in attracting and nurturing world-class people is undoubtedly a major asset for California and its future. Future work by the California Council on Science and Technology will try to provide additional details on these networks of people and their contributions to the state.

For many graduate students and researchers, places such as SLAC make California the place to be.

5.5. OPPORTUNITIES AND CHALLENGES

Even in a time of federal budget deficits and intense competition for federal funds, SLAC's budget has been rising, a testament to the quality of its work and projects. In particular, DOE has provided funds for the new Linac Coherent Light Source, a facility that offers new opportunities for California.

SLAC will make this powerful new imaging tool available to researchers throughout the state, and it promises to make contributions to electronics, nanotechnology, biotechnology, environmental science, and other fields.

6. NASA AMES RESEARCH CENTER

Main activities:

- **Space science missions**
- **Astrobiology**
- **Space robotics**
- **Aviation and aeronautics**
- **Bio-info-nano technologies**

Can help California with:

- **Aircraft remote sensing of the environment**
- **Partnerships with small business**
- **Education (K-12, teachers and higher education)**

6.1. INTRODUCTION TO NASA AMES

The NASA Ames Research Center is one of NASA's ten field installations. Located at Moffett Field, near Sunnyvale and Mountain View, the center was founded on December 20, 1939, as an aircraft research laboratory for the National Advisory Committee for Aeronautics (NACA), and in 1958 it became part of the then-new National Aeronautics and Space Administration.

Ames has seen major changes over the past two decades and in effect has reinvented itself. The center saw its original role in aeronautics shrink, and it was buffeted as NASA's programs and budgets went through some turmoil. Today, Ames still plays an important role in aeronautics research, but it also conducts scientific and engineering research in support of a broad range of NASA missions. It is NASA's lead center for supercomputing, and also conducts research and technology development in intelligent systems and robotics, fundamental space biology (also called astrobiology), nanotechnology, thermal protection systems (such as the protective tiles on the space shuttle), and human factors research. To strengthen its capabilities, it has developed a new set of research partnerships, including a major research collaboration with the University of California. Recently, it announced another major partnership with Google, one that will focus on large-scale data management and computing. Ames also has extensive programs in technology transfer and education, providing additional benefits to California.

Ames is a "government-owned, government-operated" federal laboratory, meaning that its core employees are federal civil servants.[21] In addition, it hires contractors and, as mentioned, has growing research partnerships with universities and other organizations. The director is G. Scott Hubbard. Figure 6.1. is an organizational chart for the center.

6.2. HISTORY OF NASA AMES[22]

In 1939 Congress approved a request by the National Advisory Committee (NACA), the government's aircraft R&D agency, for a second research laboratory to complement its original facility in Langley, Virginia. The new laboratory was located on the West Coast, so it could work closely with the growing aircraft industry in California and Washington State. The NACA

[21] The Jet Propulsion Laboratory, discussed later in this report, is the only NASA field center that is run by a contractor. All other NASA centers, including Ames, are staffed by federal civil servants.

[22] The following history section is drawn from Ames Web sites and from NASA, *Orders of Magnitude: A History of the NACA and NASA, 1915-1990*, http://www.hq.nasa.gov/office/pao/History/SP-4406/cover.html.

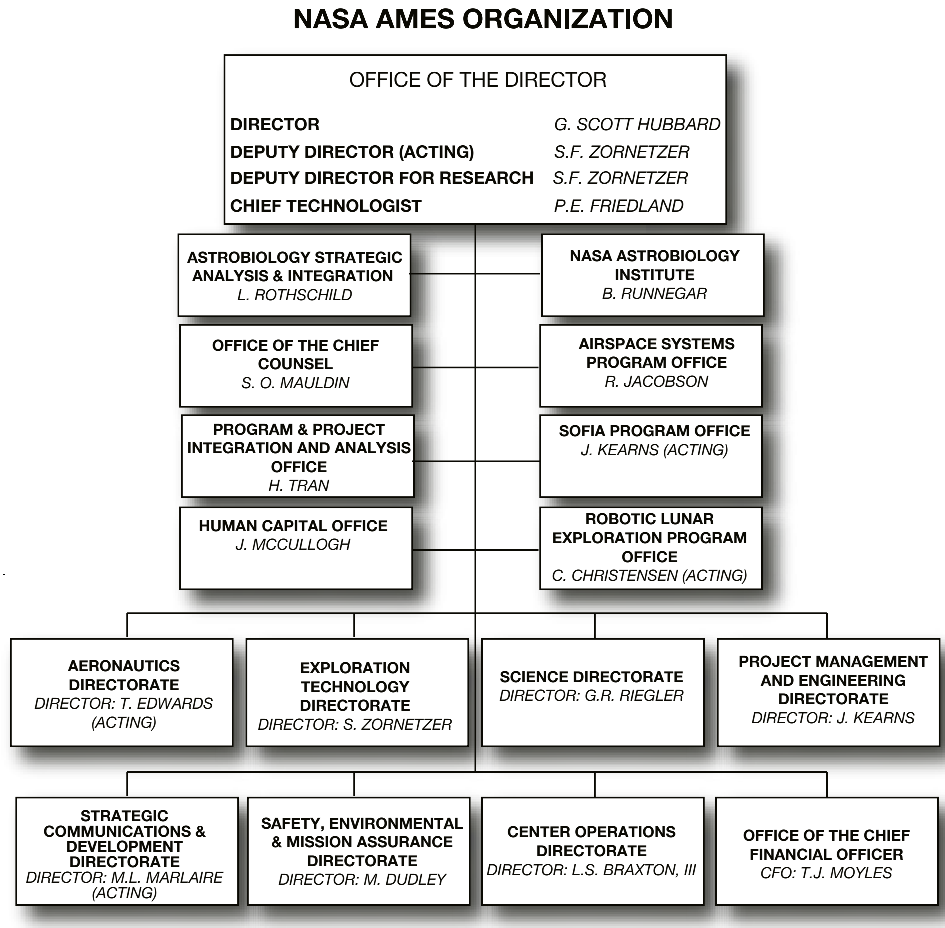


Figure 6.1. Organizational Chart for the NASA Ames Research Center

conducted research to help the military as well as the commercial aircraft industry, and the agency placed the new laboratory on the site of the Sunnyvale Naval Air Station, later named Naval Air Station Moffett Field. The new laboratory was named for the then-chairman of the NACA, Joseph S. Ames. In 1958, Congress created NASA, dissolved the NACA, and moved Ames and other NACA facilities into the new space agency.

Ames pioneered new aircraft technology through the construction and use of wind tunnels, research aircraft, and methods of theoretical aerodynamics.

During its first decades, Ames pioneered new aircraft technology through the construction and use of wind tunnels, research aircraft, and methods of theoretical aerodynamics. Later, the center's aeronautics work expanded into computational fluid dynamics (the mathematics of movement through air and water), simulation technology, computers, air traffic management research, tilt rotorcraft, life sciences, and spacecraft technology. Some of Ames' contributions include the swept-back wing concept that is used on all high-speed aircraft today; the blunt body concept, which is used on spacecraft such as the shuttle to prevent incineration upon planetary reentry; the management of the Pioneer spacecraft, which was the first human-made object to leave the solar system; the life detection experiment on the Viking spacecrafts to Mars, the first two spacecraft to perform experiments on another planet; and the Lunar Prospector mission, which discovered water at the poles of the Moon.

QUICK FACTS ABOUT THE NASA AMES RESEARCH CENTER

Full name: Ames Research Center
Nicknames: Ames or ARC
Location: Moffett Field, California, near Sunnyvale
Year established: 1939
Type of laboratory: government-owned/government-operated (a civil service laboratory)
Management: owned and operated by NASA
Director: G. Scott Hubbard
Number of employees: 1,458
FY 2004 budget: $904 million
Web site: www.nasa.gov/centers/ames/home/index.html
Main activities:

- Science: astrobiology
- Science missions (SOFIA, Kepler, Space Station Biological Research Project)
- Technology for science and exploration (information technology, intelligent/adaptive systems, lunar robotic exploration, thermal protection systems, and nanotechnology and bio-info-nano fusion)
- Aviation and aeronautics (particularly air traffic and space management tools)
- Education

User facilities:

- Three wind tunnels
- Supercomputer
- Flight simulators
- Arc jet facilities
- Collapsed Structure Facility

Examples of technological and economic contributions to California:

- High Dependability Computing Consortium
- Aircraft remote sensing help for wine-makers in Napa and Sonoma Counties during the 1990s phylloxera infestation

Examples of educational contributions to California:

- NASA Exploration Center and other programs for K-12 students and teachers
- University Affiliated Research Center (partnership with the University of California)

Example of contributions to state and local government:

- Assistance to California's Blue Ribbon Task Force on Nanotechnology

By the 1980s, aircraft design was changing. Aircraft designers no longer used wind tunnels as much as before and instead relied increasingly on computer models. Ames still has three major wind tunnels, and they are still occasionally used. For example, in 2003 Ames tests helped the Jet Propulsion Laboratory select a parachute design for the two Mars Exploration Rovers, Spirit and Opportunity, that successfully landed on the red planet in 2004. And Ames conducted tests on a scale model of the redesigned space shuttle after the Columbia tragedy. But wind tunnel research no longer was the major activity at Ames.

Instead, the center built on other capabilities and shifted its focus to other areas of importance to NASA, including those that support President Bush's Vision for U.S. Space Exploration (the Moon-Mars Initiative), announced in January 2004. Today, Ames focuses on five major sets of activities, described in the next section. It also has developed some innovative ways to carry out those missions, with a particular focus on innovative research partnerships with companies and universities.

In 1994, the Navy closed Naval Air Station Moffett Field, and the base was turned over to Ames. Ames is currently refurbishing historic buildings on the site and using some of this area for the new NASA Research Park, which is also described later in this chapter.

6.3. MAJOR PROGRAMS, FACILITIES, AND INITIATIVES

Programs, Facilities, and Program Initiatives

Today, Ames focuses on the following five sets of programs:

Science: astrobiology. Ames manages the NASA Astrobiology Institute (NAI), an organization that involves scientists from both NASA and universities and focuses on the study of life in the universe. The institute asks such questions as: How do habitable worlds form and how do they evolve? How did living systems emerge? How can we recognize other biospheres?

Science missions. Ames is the lead NASA center for two important science missions:

- *Stratospheric Observatory for Infrared Astronomy (SOFIA).* SOFIA is an airborne telescope, embedded in a 747 aircraft that can fly above most of the atmosphere and thus take images with minimal atmospheric distortion. When it starts flying, probably in 2006, it will be the world's largest airborne observatory and will make observations that are impossible for even the largest and highest ground-based telescopes. The telescope will study several subjects, including star birth and death; the formation of new solar systems; identification of complex molecules in space; planets, comets and asteroids in our solar system; nebulae and dust in galaxies; and black holes at the center of galaxies. The SOFIA project is jointly funded by NASA and the German Aerospace Center (DLR), and managed for Ames by the University Space Research Association.
- *Kepler mission.* Ames is the lead science center for the upcoming Kepler mission, an unmanned observatory that will circle the sun looking for earth-like planets in other solar systems. Since the first planets were discovered around other stars, scientists have wanted to find earth-like planets and see if they contain water and possibly life. Kepler will be the first telescope specifically designed for that mission.

The NASA Astrobiology Institute asks such questions as: How do habitable worlds form and how do they evolve? How did living systems emerge? How can we recognize other biospheres?

Technology for science and exploration. Ames is a major technology and technology development center for NASA, and is currently conducting work in five major areas:

- *Information technology.* Ames' role in supercomputing is an outgrowth of its aeronautics work, since one early use of supercomputers was to model aircraft and spacecraft movement through the atmosphere. Later work expanded into hurricane track prediction, models of global ocean circulation, and the physics of supernova denotations. In October 2004, Ames unveiled its newest supercomputer, named Columbia after the space shuttle orbiter lost in 2003. Ames, SGI Corporation, and Intel developed the new supercomputer. Columbia is one of the fastest computers in the world today and particularly well suited for modeling and simulation, including modeling complex biological systems. Other Ames information technology work beyond supercomputing includes work on autonomous systems, such as the Mars rovers, and human factors research.
- *Intelligent/adaptive systems*. NASA's research in intelligent/adaptive systems is centered at Ames. This technical area focuses on NASA's need for autonomous systems and robotics, intelligent system health management for spacecraft, collaborative and assistant systems for mission operations and NASA astronauts, and robust engineering for advanced software systems. Ames provided the technologies for the Mars Exploration Rovers robotic planning system, and the collaborative tools for the scientists studying the results from that mission. Advanced monitoring software for the Earth Observing 1 (EO-1) satellite has been flown to test out artificial intelligence technologies to maintain and manage the health of spacecraft. Recently, a voice-interface system for the International Space Station (ISS) was flight tested by ISS astronauts.
- *Robotic Lunar Exploration Program*. Recently, NASA has expanded Ames' work in intelligent/adaptive systems by making Ames the agency's lead center for the Robotic Lunar Exploration Program (RLEP). This program will undertake a series of robotic lunar exploration missions that will help prepare for later long duration human operations, leading ultimately to a sustained presence on the Moon. The program is a key part of President Bush's Moon-Mars Initiative. The new program will specifically help identify sites for exploration, place infrastructure to be used by future human missions, assess the possibility of using the Moon's resources to support human missions, refine technologies needed for later human missions, and prepare for human scientific activities on the Moon.
- *Thermal protection systems*. For 40 years, NASA has used the Ames Arc Jet Complex — a research facility for simulating the high temperatures of entry into a planet's atmosphere — to test thermal protection systems (heat shields, heat-resistant tiles, etc.) for every human spaceflight program and every planetary exploration program, including Apollo, the space shuttle, Viking and other missions that landed on Mars, and the Galileo mission to Jupiter.
- *Nanotechnology and bio-info-nano fusion*. Nanotechnology efforts at Ames began in 1996 and have grown into the current Center for Nanotechnology. At Ames, the study of nanotechnology works towards the development of ever smaller and more powerful sensors and information storage devices — especially miniaturized instruments that can go on future spacecraft. Ames now has a major new cross-disciplinary "bio-info-nano" or "BIN" initiative underway to combine nanotechnology, biology, and information technology in innovative ways. This work ranges from miniaturized bio-sensors that might one day look for life on Mars to the new field of bio-

nanotechnology, which applies biology to engineering objectives through, for example, the use of proteins as templates for the production of nanoscale electronic circuits. As discussed later in this section, Ames is working closely with the University of California on this initiative. Related to this initiative is the work of the Ames Genome Research Facility, which is developing a nanopore-based system that will be able easily to sequence single molecules of nucleic acid, DNA, or RNA.

Aviation and aeronautics. While wind tunnel work at Ames is now modest compared with past decades, the center continues to have a major program in new technologies and software to improve air traffic management and control. Working with the Federal Aviation Administration and private companies, Ames is developing techniques for moving ever-increasing numbers of aircraft safety through America's crowded airspace. Computer simulation of both air traffic and individual aircraft aids this effort.

Education. NASA in general and Ames in particular put a high priority on education programs, particularly to assist science and mathematics teachers and to excite children about science, engineering, and space. More details are provided below, in the section on contributions by Ames to education.

Innovative Collaborations

In the 1990s, Ames faced not only changing missions but also two other challenges common to many federal laboratories: it sometimes had difficulty hiring good technical professionals at government pay levels, and it faced new areas of science and technology that were exciting but also so complex as to be beyond the ability of any one laboratory to master. Ames decided that it needed more partnerships with universities and companies in order to carry out its missions, and it also believed that new partnerships would benefit universities and companies.

Ames had long had partnerships with other NASA field centers and with aerospace and computer contractors, including a long and successful collaboration with the computer company SGI.

But in the late 1990s, Ames and NASA headquarters in Washington also saw other opportunities, which led to three sets of related collaborative activities: a new NASA Research Park on the grounds of the old Naval Air Station Moffett Field, new research and education partnerships with universities and community colleges, and a continuation of existing partnership programs with companies.

NASA Research Park. Leaders at Ames and NASA particularly saw a new and perhaps unique opportunity: the ability to use buildings and land at the old Naval Air Station Moffett Field to create a research park next to Ames. Universities and companies that wanted to work with Ames would be invited to locate facilities in the research park, and along with conducting their own activities (such as offering university courses or conducting their own research) these universities and companies could also expand research partnerships with Ames, sometimes through NASA-funded collaborations.

The following text box lists some of the partners now at the NASA Research Park.

The goal here is to create a shared-use R&D campus for government, academia, non-profits, and industry. Universities, other non-profits, and companies large and small may lease office space if their activities at least in part support NASA's research, education, and outreach missions. Early partners included the University of California, Carnegie Mellon University,

ORGANIZATIONS CURRENTLY PARTICIPATING IN THE NASA AMES RESEARCH PARK

Educational and governmental organizations:

- University of California, led by UC Santa Cruz
- Carnegie Mellon University, which has a satellite campus at Ames and offers master's degree programs
- San Jose State University
- Foothill-De Anza Community College District
- Space Technology Center
- National Center for Equal Opportunity in Higher Education
- Women in Science, Technology, Engineering, and Mathematics
- Inland North Space Alliance
- Kentucky Science and Technology Corporation

Industrial partners:

- Apprion: security and operational optimization
- Arachi: comprehensive dynamic motion technology
- BluPoint Global: distribution of digital media
- Changene: bone density
- Conceptlabs: technology assessment
- Defouw Engineering: biomedical devices
- DMJM Technology: architectural and engineering services
- E4exchange: mental health scenario planning
- Fireball Information Technology: support services for combating wildfires
- Google: large-scale data management, massively distributed computing, nanotechnology
- Honeybee Robotics: robotic creations
- IISC: computer neuro networks
- InformArt/GaryAir: soft computing and intelligent mechanisms
- Intelligen Tek, Inc.: human-machine interface technology
- Intrinsyx Technologies: software, systems, space technologies
- ION America: fuel cells
- Jivalti: research library
- Jumping Beans, Inc.: distributed computing integration
- LB&B Associates: jet fuel
- NXAR Technologies: software development for knowledge network systems
- Ozen Engineering, Inc.: software utilization services
- Photozig: integrated photographic technology
- Pregati Synergestic Research, Inc.: computer software R&D
- Tibion: muscle augmentation technology
- UAV Collaborative: advanced unmanned aerial vehicles
- Venezia, Inc.: maintenance and construction
- Western Disaster Center: technology for natural and man-made disasters

San Jose State University, the Foothill-De Anza Community College District, and several small start-up companies working on NASA-related products.

A major development came in September 2005, when Ames and Google announced that Google will build a large research complex in the NASA Research Park and that researchers from the two organizations will collaborate in areas such as large-scale data management, massively distributed computing, and nanotechnology. Google will contribute its expertise in data management, and Google will gain access to NASA's space data, imagery, and supercomputer expertise. Google already uses satellite images in its Google Maps service and Google Earth software.[23]

New university partnerships. The presence of these organizations at the Moffett Field site makes it easier for Ames to enter into research collaborations with these organizations — partnerships that bring valuable expertise and specialists to NASA. Ames is now looking to build collaborations in astrobiology, information technology, nanotechnology, and biotechnology.

In September 2005, Ames and Google announced that Google will build a large research complex in the NASA Research Park.

Several new university partnerships illustrate the new collaborative approach that Ames is undertaking with partners who are already located in the NASA Research Park.

First, in September 2003, the University of California, represented by UC Santa Cruz, signed a 10-year, $330 million contract with NASA to establish a University Affiliated Research Center (UARC) at Ames. San Jose State University is also a participant. This is a first-of-its-kind contract for NASA and a further example of the new kind of research partnership that Ames is creating. A statement from UC Santa Cruz summarizes the rationale for the new partnership.

> "NASA officials said the UARC will provide a unique combination of research and educational capabilities to meet NASA's mission requirements and to develop future human resources in technology and science… Overall, the UARC will provide long-term continuity of top-tier research talent focused on NASA's growing multidisciplinary mission needs." [24]

UC Santa Cruz researchers working at Moffett Field are currently carrying out research tasks for the University Affiliated Research Center in three areas: aerospace systems, information technology and computer science, and nanotechnology.

In perhaps the most important single development to date in the NASA Research Park (NRP), the University of California has budgeted funds for the 2010 construction of a new state-of-the-art building for the Bio-Info-Nano Research and Development Institute (BIN-RDI). Led by UC Santa Cruz, the $65 million facility will feature highly specialized "lablets" for industry and government research and shared educational facilities. It will be a leader in bio-info-nano convergent science and technology development, and will be a catalyst for bringing together education, business, science, and technology. The BIN-RDI will also provide short-term tenant laboratories for small companies and startups. It will foster leading-edge science, while enhancing California's competitive advantage in both the technological and business arenas.

Second, NASA has entered into a long-term relationship with Carnegie Mellon University (CMU), a leading research center in fields such as robotics and computer science. CMU, based in Pittsburgh, has now established a west coast campus within the NASA Research Park. As part of that campus, CMU professors and students now work with Ames researchers on computing and other topics. In addition, NASA now funds a High Dependability Computing

[23] Michael Bazeley, "Company to Build Complex Near Ames Center," *San Jose Mercury News*, September 29, 2005.

[24] UC Santa Cruz, "UCSC launches bold new collaboration with NASA," September 22, 2003, http://currents.ucsc.edu/03-04/09-22/nasa.html.

THE NASA/CARNEGIE MELLON UNIVERSITY (CMU) HIGH DEPENDABILITY COMPUTING CONSORTIUM (HDCC)

Dependable systems technology is necessary to ensure that the software we create meets the ever more challenging requirements of continuous operation, safety critical reliability, high integrity and high security. These have long been requirements of aerospace and defense systems. Now, equally challenging requirements are being placed on commercial and e-business systems, as well as the embedded systems that increasingly provide the infrastructure for our daily lives.

A number of major information technology companies have signed a memorandum of understanding to work together on issues involving systems where dependability is crucial, such as:

- Air traffic control
- Internet communication
- Electric power production and transmission
- Space exploration
- Highway safety
- Health care

Companies that have signed a memorandum of understanding and joined the consortium include:

- Adobe Systems, Inc.
- Cisco Systems
- Compaq Computer Corporation
- Five Nine Solutions, Inc.
- Hewlett-Packard Corporation
- IBM Corporation
- ILOG, Inc.
- Marimba, Inc.
- Microsoft Corporation
- Novell, Inc.
- Oracle Corporation
- SGI, Inc
- Siebel Systems, Inc.
- Sun Microsystems, Inc.
- Sybase, Inc.

Source: http://www.hdcc.cs.cmu.edu/about.html

Consortium led by Carnegie Mellon University and involving 25 companies. The following text box describes the High Dependability Computing Consortium.

Third, the NASA Research Park (NRP) provides a neutral site where NASA's university partners can partner with each other. In 2000, California's three public higher education institutions — the University of California, the California State University System, and California Community College System — established a partnership to deliver science, technology, engineering and mathematics education on-site in the NRP. This group has already secured over $5 million in grants to further their programs. Similarly, a partnership among Stanford University, San Jose State, Utah State, Cal Poly and Santa Clara Universities and the Aerospace Corporation led to the creation of the Space Technology Center, which focuses on very small satellite R&D and education.

Other collaborations. Ames also continues more traditional forms of collaboration with companies and universities, including licenses of Ames technologies, cooperative R&D through Space Act Agreements, memoranda of understanding with universities, and contracts with small firms under NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) programs. The next text box lists several of these recent collaborations between Ames and industrial and academic partners.

OTHER RECENT AMES PARTNERSHIPS

- Caneus (infusion): $1.2 million infusion to the Center for Nanotechnology (CNT) for R&D funding for Carbon Nanotube Gas-Sensor
- Lockheed Martin (Reimbursable Space Act Agreement): to evaluate the aerodynamic stability and performance for Lockheed's baseline vehicle geometry using Ames state-of the-art optimization techniques, and to improve the stability and aero-thermal performance at multiple design conditions
- University of California Davis (MOU): to assist UC Davis in upgrading, refurbishing and performing research at the Air Forces Sacramento Air Logistics Center
- NXAR (license): license of Netmark, an object-relational database management system, that will be commercialized by NXAR into a suite of business information applications
- Flight Explorer (license): will incorporate NASA's Air Traffic Management Tool (FACET) into its commercial product line
- Bectrasys Corp (license) of PostDoc; a multi-user, web-based application for storage and retrieval of documents
- NanoConduction (Space Act Agreement/License): a collaboration to develop better cooling systems for microelectronics
- Xerox (license): license of Netmark, an object-relational database management system, which resulted in a new product

6.4. CONTRIBUTIONS TO CALIFORNIA

Technological and Economic Contributions

General economic impact. First, NASA Ames makes significant economic contributions through the jobs it provides and the procurement money that it spends in California. In fiscal year 2004, Ames had a total budget of $904 million and a total workforce of 1,458 (including both civil servants and contractors). That staff included 338 Ph.D.'s and an additional 265 individuals with master's degrees. Procurements in fiscal year 2004 totaled $485 million, much of that spent in California.

Budgets, employment, and procurements at Ames will all shrink over the next few years, as NASA reduces existing programs to pay for President Bush's Moon-Mars Initiative. However, Ames will remain a significant laboratory with significant economic contributions to California.

Further details of Ames' contributions to California are available in the Appendix. In addition, Ames' recently commissioned economic impact study provides additional details.[25]

Technology partnerships. Second, Ames has an extensive technology partnerships program, which involves several kinds of partnering options for companies:

- ***Space Act agreements.*** These contracts are similar to the Cooperative Research and Development Agreements (CRADAs) and work-for-others agreements offered by DOE laboratories and other federal agencies, except that NASA has its own separate legal authority for joint projects. These agreements can either be non-reimbursable, in which NASA and the company each pay for their own part of a joint project, or reimbursable, in which the company reimburses NASA for its participation. NASA provides data, facilities, or services to the paying entity.

[25] Bay Area Economics, *Economic Benefits Study: NASA Ames Research Center and NASA Research Park,* July 9, 2004.

- ***Licensing agreements.*** Like other federal laboratories, Ames can license its patented inventions to other parties.
- ***Software licenses.*** Ames also can license software programs.
- ***Other agreements.*** These include contracts and cooperative agreements under which NASA may provide funds, services, equipment, information, or intellectual property in order to carry out a NASA objective.
- ***Small Business Innovation Research Program (SBIR) awards and Small Business Technology Transfer Program (STTR) awards.*** Small businesses conducting R&D in technical areas of interest to NASA may apply for SBIR awards. STTR awards go to small firms partnering with universities in fields of interest to NASA.

AMES ASSISTANCE TO THE WINE INDUSTRY IN NAPA AND SONOMA COUNTIES

Beginning in late 1980's, California wine growers were faced with destruction of their vines by infestation of a root louse named phylloxera (biotype B). The louse kills vines by feeding on their roots. There is no way to eradicate the pest, and infested areas must eventually be replanted on a phylloxera-resistant or tolerant rootstock. The infestation was present in eight California counties, and was particularly severe in Napa and Sonoma Counties where thousands of acres of premiere vineyards have already been destroyed or are scheduled for future replacement.

From 1993 through 1995, NASA Ames (through its Ecosystem Science and Technology Branch) collaborated with industry and university partners to develop and transfer data from remote sensing (airborne photography) and associated computer analyses as a tool for vineyard managers to use in addressing the phylloxera problem. NASA's partners on this project included the University of California Cooperative Extension (Napa County), the University of California, Davis (Entomology Department.), California State University, Chico (School of Agriculture) and the Robert Mondavi Winery. Staff from each organization brought unique expertise to the project, working together in the field, laboratory and computer room. The work was co-funded by NASA's Office of Advanced Concepts and Technology and the Robert Mondavi Winery. Project results are being made available to the wine industry, commercial remote sensing product vendors, agricultural community and general public through invited oral presentations and written reports.

During the 1993 growing season, field data and data from NASA Ames ER-2 aircraft (shown below) were collected from Napa Valley test sites with special sensors designed to study earth resources, including plant stress manifested as reductions in vegetation canopy density. Infestations were detectable in this remotely sensed imagery, even in the early stage when phylloxera were underground eating vine roots but the above ground plant still appeared healthy.

By using remote sensing and associated analysis techniques, growers could attain earlier knowledge on the infestation's rate of spread, and the rate of decline for affected vines. In short, growers had a much better idea of which vineyards were in trouble at particular times and when they needed replacement. The information that Ames provided allowed for more informed replanting decisions, helping California wineries retain market share.

Source: http://geo.arc.nasa.gov/sge/grapes/grapes.html

NASA Ames ER-2 aircraft from above

Ames is most active in the licensing, other agreements, and SBIR areas. For example, in fiscal year 2004, Ames made 30 SBIR phase I awards (the first level of SBIR awards), of which nine went to California companies. Since 1990, several dozen new commercial products have resulted either from these partnerships, mostly by small companies. Many of these companies come from either California or other western states.

California agriculture. In addition to these partnerships with individual companies, Ames also has occasionally made important general contributions to another part of California's economy: agriculture. For many years, Ames operated remote-sensing aircraft that could detect, among other things, the presence of certain agricultural diseases. One notable example of help from Ames aircraft came in Napa and Sonoma Counties in the 1990s, when many vineyards became infected with a disease caused by the louse phylloxera. How Ames helped agricultural officials and growers manage the infestation is the subject of the text box on the previous page.

Contributions to Education and Academic Research

Education programs. Ames has extensive programs to help train science and mathematics teachers, to excite children about science and technology, and to provide internships and fellowships for undergraduate and graduate students. The next text box lists the main programs for teachers and students. Some of these programs are NASA-wide, with Ames participating along with other NASA centers, and some of them are specific to Ames. In general, the emphasis here is more on providing materials, internships, and fellowships for students rather than on providing formal teacher-training programs.

Academic research collaborations. An earlier section of this chapter has discussed the research collaborations that Ames has developed with universities and colleges, particularly the University of California and Carnegie Mellon University. As Ames continues to move towards what one could call a partnership-oriented strategy for research, it is likely that Ames will continue and expand these research partnerships — to the benefit of universities with operations in California.

Contributions to State and Local Government

At times, Ames has provided valuable technical assistance to state and local officials in California. The earlier text box discussed one example: providing important data to help state and wine industry officials effectively manage the phylloxera infestation. Another example is a recent agreement between Ames and Salinas Valley Memorial Hospital to work together on medical imaging technologies.

In addition, Ames is making policy contributions to California, particularly through its role as a convener and catalyst for policy discussions about the state's high-tech future. One example is the role of Ames and its director, Scott Hubbard, in the Blue Ribbon Task Force on Nanotechnology, a group of high-profile volunteers from academia, government laboratories, industry, and the venture capital community that has met since the fall of 2004 to discuss the steps state government and industry can take to ensure that California is well positioned to take advantage of future economic opportunities in nanotechnology. Ames has offered its facilities to host meetings, and has volunteered to help organize and facilitate the discussions. This task force is not an official state committee but rather a group of interested volunteers. The willingness of Ames and its director to host the group has been very helpful. Ames sees its participation as both a public service and as a possible way to build additional research

NASA AMES EDUCATION PROGRAMS

Primary and Secondary Education

- NASA Exploration Center (a science center at Ames)
- Ames Exploration Encounter (a science field program for students in grades 4-6)
- NASA Quest Project (Internet-based tools for teachers and students)
- NASA Robotics Education (robotics materials and competitions)
- NASA Student Involvement Program (high school students participate in NASA research)
- Summer High School Apprenticeship Research Program (for under-represented high school juniors and seniors)
- Student Space and Biology Research Program (high school seniors work at Ames)
- Ames Educator Resource Center (provides instructional materials for teachers)
- SOFIA's Education Program (materials for teachers and students, plus opportunities for 75 teachers to fly aboard the aircraft observatory)
- JASON Teacher Workshops
- Industry Initiatives for Science and Math Education (summer research experiences in industry for teachers)
- RoboCamp-West (a robotics camp offered by Carnegie Mellon University and Ames)
- Student Resource Center (Web sites with photographs, and earth and space data)

Post-Secondary Education

- Foothill-DeAnza Community College District Internship and Training Programs
- Education Associates Program (work/study opportunities for university students)
- Minority University Research and Education Program (provides grants to minority institutions and internships for students)
- NASA Scholars (a summer program for students from minority institutions)
- Student Career Experience/Cooperative Education Program (paid work experiences for undergraduates and graduate students)
- Undergraduate Student Research Program (provides on-site mentored research experiences)
- Graduate Student Researchers Program (provides competitively-awarded graduate fellowships)
- Harriet G. Jenkins Pre-Doctoral Fellowship Program (provides fellowships and research experiences for Ph.D. students in NASA-related disciplines)
- Resident Research Associates Program (guest investigators at NASA centers)
- NASA Faculty Fellowship Program (provides summer research opportunities for college faculty)

collaborations, informal and formal, with California nanotechnology researchers — a step that certainly cannot hurt Ames' continuing efforts to develop nanotechnologies useful to NASA.

6.5. OPPORTUNITIES AND CHALLENGES

Over the past decade, Ames has gone through major changes to update its mission and to create research partnerships to bolster its ability to develop new and complex technologies for NASA. But the last two years have posed even further challenges: a major shift in NASA's priorities towards the new Moon-Mars Initiative and away from traditional activities such as aeronautics, continuing tight NASA budgets, a NASA trend (now abated) to shift programs and funding from NASA centers to aerospace contractors, and most recently a new accounting system within the space agency. Ames has responded not only with shifts in its internal programs but also with buyouts for civil service employees and some layoffs for contract personnel. It has not been an easy time.

Now, however, NASA budgets and programs have stabilized somewhat, and Ames is succeeding in putting its new initiatives and research collaborations into place, including the major partnership with the University of California. The continuing emphasis that Ames places on research partnerships bodes well for California, both because of opportunities for new NASA funds to California universities and companies but also because of the longer-term promise that the new fields Ames is helping to nurture, including nanotechnology, will one day generate new companies, jobs, and wealth. Ames is weaving itself, for the best of NASA reasons, further into California's research clusters.

7. JET PROPULSION LABORATORY

Main activities:

- **Robotic spacecraft**
- **Earth-orbiting observatories**
- **Deep space communications**

Can help California with:

- **Remote sensing of natural resources**
- **Climate information**
- **Information technology networks**
- **Education (K-12, teachers and higher education)**

7.1. INTRODUCTION TO JPL

NASA's Jet Propulsion Laboratory (JPL) in Pasadena designs and operates robotic spacecraft. The California Institute of Technology (Caltech) established JPL in the 1930s. In the decades that followed, JPL created America's first satellite, Explorer 1, sent the first robotic craft to the Moon, and then launched a series of craft to all of the planets, save Pluto. Today, JPL continues to have three main exploration programs:

- Robotic missions to the planets and other bodies in the solar system. Recent missions include Deep Impact, which successfully blasted a hole in the comet Tempel 1 to reveal for the first time a comet's inner material; the two highly successful Mars Exploration Rovers, Spirit and Opportunity; and the Cassini mission to Saturn.
- Earth-orbiting satellites, some of which monitor environmental conditions on earth and some of which peer out into deep space.
- NASA's Deep Space Network, a set of antenna complexes around the world used to communicate with distant space probes.

In addition to these exploration missions, JPL also conducts a number of space technology demonstrations in support of national security, develops technologies with applications in fields ranging from public safety to medicine, and has an extensive education outreach program.

JPL is the one NASA field center managed by a contractor, in this case Caltech. In federal fiscal year 2004, the laboratory had a budget of $1.559 billion and 5,452 employees. JPL has a 21-person executive council of senior managers, headed by Charles Elachi. Information on the Executive Council is available at: http://www.jpl.nasa.gov/images/people/council/index.cfm.

JPL also conducts a number of space technology demonstrations in support of national security.

7.2. HISTORY OF JPL[26]

Early History

Jet Propulsion Laboratory's history dates back to the 1930s, when Caltech professor Theodore von Kármán oversaw pioneering work in rocket propulsion. Von Kármán headed Caltech's Guggenheim Aeronautical Laboratory and became interested in rocket engines. In

[26] The following history is drawn from JPL, "Jet Propulsion Laboratory," September 2004, available at: http://www.jpl.nasa.gov/news/fact_sheets/jpl.pdf.

October 1936, he and his students conducted their first test of a primitive rocket engine, in a dry riverbed wilderness area in Arroyo Seco, north of the Rose Bowl in Pasadena.

After his group's successful rocket experiments, the U.S. Army Air Corps funded von Kármán's work to develop strap-on rockets (called "jet-assisted take-off") to help overloaded Army aircraft take off from short runways. When World II began, the rockets were in demand. The Army later asked him to analyze the German V-2 rocket, and he then proposed a U.S. program to understand, duplicate, and then reach beyond the German guided missiles. The result was the Corporal, first launched in May 1947.

Subsequent work for the Army improved the technologies of rocket communications and control. This made it possible for JPL to design and fly the first successful U.S. space mission, Explorer 1. The entire effort took only three months, begun in November 1957 shortly after the Soviet Union launched Sputnik 1 and culminating in the successful launch on January 31, 1958.

On December 3, 1958, two months after Congress created NASA, JPL was transferred from Army jurisdiction to the new civilian space agency. By this time, JPL was located next to the site of von Kármán's early rocket experiments, in the hills above Caltech. Jet propulsion was no longer the focus of JPL's work, but the famous name remained.

Space Exploration

In the 1960s, JPL began to conceive and carry out robotic spacecraft missions to other worlds. This effort began with the Ranger and Surveyor missions to the Moon, paving the way for the Apollo landings. During the 1960s and 1970s, JPL carried out the Mariner missions to Mercury, Venus, and Mars. The first search for life on Mars came in 1975, when two Viking landers arrived on the red planet. JPL played a major role in the missions. Then in 1977, NASA launched JPL's Voyager 1 and Voyager 2, which traveled to Jupiter and Saturn. Voyager 2 then went on to make the first visits to Uranus and Neptune. The Voyagers are now leaving the solar system, heading into interstellar space, and still communicating periodically with JPL's Deep Space Network.

Recent missions include the Cassini-Huygens mission to Saturn and the Stardust and Deep Impact comet missions.

Later missions included Magellan to Venus, Galileo to Jupiter, and Ulysses to study the Sun's poles. A new series of Mars missions followed in the 1990s, most recently the Mars Exploration Rovers, Spirit and Opportunity. Other recent missions include the Cassini-Huygens mission to Saturn and the Stardust and Deep Impact comet missions. On the ground, JPL created the Near-Earth Asteroid Tracking system, an automated system used at an Air Force observatory in Hawaii to scan the skies for asteroids or comets that could threaten Earth.

Earth Science

In the late 1970s, JPL began developing earth monitoring satellites and instruments. Over the years, NASA has used these satellites and instruments for Earth mapping and for measuring ocean conditions, winds, the stratospheric ozone layer, the role of clouds in global climate, soil moisture, and atmospheric carbon dioxide.

QUICK FACTS ABOUT THE JET PROPULSION LABORATORY

Full name: Jet Propulsion Laboratory
Nickname: JPL
Location: Pasadena
Year established: 1930s
Type of laboratory: government-owned/contractor-operated
Management: managed for NASA by the California Institute of Technology
Director: Charles Elachi
Number of employees: 5,452 plus 353 on-site contractors
FY 2004 budget: $1.559 billion
Web site: http://www.jpl.nasa.gov/
Main activities:

- Robotic spacecraft to the planets and other deep space objects
- Earth-orbiting observatories (both Earth-observing and telescopes to watch deep space)
- Deep Space Network (communications network)

User facilities:

- Supercomputer facilities

Examples of technological and economic contributions to California:

- Licenses of JPL technologies to a mapping company in Fresno, Hughes Space and Communications Company of El Segundo, and a fuel cell company in Los Angeles
- Small Business Innovation Research awards to numerous small California firms

Examples of educational contributions to California:

- A wide range of educational programs, including continuing partnerships with nine schools in Southern California
- Many space research collaborations with professors at California universities

Astronomy and Physics

Other JPL missions are orbiting observatories, designed to gather information on distant objects in space. JPL developed and manages the Spitzer Space Telescope, a sibling to the Hubble Space Telescope. Spitzer uses infrared technology, just outside the range of visible light, to study objects that are too cool, too dust-enshrouded, or too far away otherwise to be seen. It has found hundreds of stars never seen before. JPL also developed the main camera for the Hubble. JPL is currently developing instruments for several upcoming infrared missions, and also manages the upcoming Kepler mission on behalf of a science team based at the Ames Research Center. Kepler will look for Earth-like planets around distant stars.

7.3. MAJOR PROGRAMS, FACILITIES, AND INITIATIVES

Programs and Facilities

As mentioned earlier, JPL has three major sets of programs: deep space robotic missions, Earth-orbiting satellites for both Earth observation and viewing distant stars and galaxies, and a sophisticated space communications capability based on its Deep Space Network of antenna stations.

The following text box summarizes Jet Propulsion Laboratory's budget in recent years and how JPL allocated its FY 2004 budget among its different major activities. This information comes from JPL's 2004 annual report.

Figure 7.1. JPL Budget Breakdown

To carry out these programs, JPL has developed skills and innovations in several technical areas, including deep space navigation and communication, digital imaging processing, imaging devices and systems, intelligent automated systems, instrument technology, and microelectronics. Today, the miniaturization of electronics and sensors is one technical priority. JPL also has an active program of automation and robotics supporting planetary rover missions and NASA's space station program. In supercomputing, JPL has pioneered work with new types of massively parallel computers to support the processing of enormous quantities of data returned by space missions. JPL also has a number of unique facilities, summarized in the next text box.

JPL LABORATORIES AND FACILITIES

Advanced technologies are in constant development in the many unique laboratories throughout JPL's 177-acre complex. Specific innovations in individual labs allow for cutting-edge space exploration as well as practical use here on Earth.

- ***The Microdevices Laboratory (MDL)*** specializes in developing miniature (nanometer-sized) semiconductor and superconductor sensors and structures. Sensors built here have proven their mettle in the medical field in the form of sensors that can "see" into the infrared and extreme ultraviolet and allow for non-invasive imaging. Other sensors developed in this lab might one day serve as the equivalent of a human inner ear for rovers - keeping them oriented and balanced.
- ***The Optical Communications Group*** focuses on new radio frequency and optical technologies that are poised to provide breakthrough increases in deep-space telecommunications capacity. This will better allow NASA to meet the growing and challenging data return needs of NASA missions. NASA is developing laser communications technology for sending data back from future space missions. Because of its narrow beamwidths, laser communications can enable significant (10-100x) increases in data return rates, while simultaneously decreasing the mass, power consumption, and size impact of the communications system on the space mission vehicle (e.g. 1/2 mass, 1/2 power, 1/10 volume).
- ***The Frequency Standards Laboratory*** does everything from testing the fundamental laws of physics to developing ultra-precise atomic clocks and field instruments. For the Cassini-Huygens Mission to Saturn and Titan, the lab has created a cryogenic frequency standard that, at its heart, is a piece of sapphire that is cooled to 8 Kelvin (-265.15 Celsius, -445.27 Fahrenheit) for examining the rings and atmosphere of Saturn as well as to search for gravitational waves.
- ***The Nondestructive Evaluation and Advanced Actuators Laboratory (NDEAA)*** develops a variety of advanced devices from biologically-inspired artificial muscles to ultrasonic drills that could be used in future sample return missions.
- ***The Planetary Robotics Laboratory (PRL)*** focuses on improving rover capability for planetary exploration. Rovers tested here could one day travel over harsh planetary landscapes. The Limbed Excursion Mobile Utility Robot (LEMUR) prototype functions as a six-legged primate, with each of its appendages serving as a different tool for exploration. Other rovers, dubbed "Robotic Work Crews", are designed to work in teams to accomplish complicated tasks. The veteran Field Integrated Design and Operations (FIDO) rover is a prototype for the 2003 Mars Exploration Rovers, Spirit and Opportunity. To prepare for Mars surface operations in January 2004, FIDO has spent many hours exploring various Mars-like locations on Earth during mission simulation tests.

Source: http://technology.jpl.nasa.gov/unique_facilities/index.cfm?page=techLabs

Recent Developments and Initiatives

Two policy developments over the past decade have shaped JPL and the initiatives that it pursues.

First, in the mid-1990s NASA made an important policy change that deeply affected robotic space missions and JPL's operations. Until that time, the major robotic spacecraft were large, expensive items, with missions sometimes costing up to $1 billion each. These big missions were successful, including Magellan to Venus, Galileo to Jupiter, and now the final such mission, Cassini's voyage to Saturn. But the high cost meant that JPL pursued a few big missions instead of a larger number of small projects. In the mid-1990s, the then director of NASA decided to place the emphasis on smaller missions, using the motto of "faster, better, cheaper."

The results included a series of experimental programs to design and launch smaller probes as well as changes in how JPL conducts its work. Some of the new, low-cost, and highly experimental missions succeeded, including the notable Mars Pathfinder mission, which placed a small rover on Mars in 1997. Other new-style missions failed, including two other Mars missions in 1999. But JPL learned how to design and manage these smaller projects. As JPL moved towards managing a larger number of smaller, less-expensive missions each year, it found itself contracting out many of the operational aspects of space missions and focusing more on spacecraft design and the development of new technologies, especially miniaturized instruments. JPL always invented new technologies, but the 1990s brought revived efforts.

The second major policy change affecting JPL came in January 2004, when President Bush announced his space exploration vision, with its emphasis on returning humans to the Moon and preparing for possible human trips to Mars. JPL of course focuses on unmanned missions, but its robotic missions to Mars are an important part of any preparations for human visits to that planet. JPL is thus a major participant in the new NASA strategy, and its Mars program in particular is expected to continue and grow.

Meanwhile, beyond these general changes JPL continues to develop specific new missions and associated technologies. One major initiative is Prometheus, a new generation of deep space probe powered by small nuclear reactors. Missions to the outer planets are too far from the sun for solar panels to work, and earlier deep missions received power from devices that generated electricity through the heat given off by small amounts of radioactive material. These heat generators did not produce much power, however, and NASA is now looking for a device that generates more electricity. Under the Prometheus project power, JPL and the Department of Energy will develop a small, safe fission reactor for a new generation of deep space probes. The first planned mission, Prometheus 1, will travel to Jupiter and have enough power to make close observations of both the planet and its major moons.

7.4. CONTRIBUTIONS TO CALIFORNIA

Technological and Economic Contributions

Jet Propulsion Laboratory conducts technology development programs for other federal agencies, and works closely with industry, including the aerospace industry in Southern California. It also works with small high-tech companies throughout California. Some of its work for other federal agencies directly benefits California. One such project is Firefly, an aircraft-borne infrared fire mapping system for the U.S. Forest Service.

JPL activities have benefited California companies and the California economy in several ways:

- ***Technology licenses.*** Over the period 2000-2003, JPL was granted more patent licenses than any other NASA center (nearly 140) and, through the Caltech Office of Technology Transfer, executed more patent licenses than any other NASA center (nearly 60). Over the past 10 years, examples of technologies that JPL has licensed include a methanol fuel cell licensed to a Los Angeles company, a computer chip that mimics how the human mind works licensed to the Ford Motor Company, a high-performance gyroscope licensed to the Hughes Space and Communications Company of El Segundo, and a new radar mapping technology licensed to EarthData International of Fresno.

JPL conducts technology development programs for other federal agencies, and works closely with industry.

- ***SBIR awards.*** JPL has an active Small Business Innovation Research (SBIR) program, and has funded small firm R&D in several technical areas of interest to NASA. Many of these small firms are in California, and the NASA funding has helped them to create and sell new products and services. A few examples are summarized in the next text box.[27]

EXAMPLES OF CALIFORNIA FIRMS HELPED BY JPL SBIR AWARDS

Physical Optics Corporation, Torrance
3-D Visualization System for Robotic Teleoperations

- Commercial Application. This 3-D color holographic system provides high quality, real time 3-D visualization. Physical Optics Corporation is working with the Army on a medical imaging system, a Japanese company on a game application, and the Ford Motor Company on an automotive design tool.
- NASA Application. Potential NASA applications include holographic displays for future missions and 3-D displays for spacecraft design.
- Social/Economic Benefit. Real time 3-D image displays have many potential applications in the fields of design and demonstration. These displays can be observed without the aid of special glasses

Biospherical Instruments Inc., San Diego
Instrument for Measuring Marine Productivity

- Commercial Application. This moored instrument provides unattended monitoring of ocean environmental conditions. More than 50 units of the original design have been sold, approximately half for export. The company continues to sell updated versions of the equipment.
- NASA Application. These moored instruments, called spectroradiometers, are used to calibrate satellite observations of ocean surface water conditions. By this procedure, satellites can provide accurate coverage of large areas of ocean that would otherwise not be possible.
- Social/Economic Benefit. Instruments installed at several long-term moorings have provided data for studies of ocean productivity and for calibrating satellite observations. This information supports scientific studies of the factors determining the productivity of the world's oceans and the factors that affect ocean productivity.

Energy Science Laboratories, Inc., San Diego
Carbon Grid Materials

- Commercial Application. Under the SBIR contract, Energy Science Laboratories developed carbon materials, including coatings. These unique materials have won the company contracts with the Fermi Laboratory to provide detector supports for high energy physics research, and with the Keck Observatory in Hawaii and the Stuart Observatory in Arizona for telescope lining material for stray light suppression.
- NASA Application. Longer life carbon grids will increase the performance of ion engines for future NASA deep space missions. These materials are presently being used in developing the technology.
- Social/Economic Benefit. These unique carbon materials are improving the performance of a variety of things from telescopes to ion engines for satellite applications. The ability of the carbon flocking material to absorb a high energy particle is expected to lead to its application in commercial deposition reactors. Energy Science Laboratories is working with a number of other customers to develop these materials for other new applications.

[27] These case studies come from JPL, http://sbir.jpl.nasa.gov/stories.html#1.

- ***Aerospace R&D cluster.*** JPL has strong ties with other major aerospace R&D centers in Southern California, including the government-supported Aerospace Corporation; Los Angeles Air Force Base, home of the Air Force's Space and Missile Systems Center; and major aerospace companies such as Northrop-Grumman, which currently is building NASA's next-generation space observatory, the Webb telescope. These organizations share information, technology, and skills, helping to keep California a world leader in satellites, launch vehicles, and other aerospace fields.

Contributions to Education and Academic Research

Education. JPL has extensive education programs in four areas: K-12 education, higher education, faculty/institutional/curriculum programs, and informal education. These programs encourage young people to enter science and engineering careers, as well as provide general information to the public about science, space, and technology. At the university level, programs also specifically encourage young scientists and engineers to consider careers with NASA.

- ***Precollege student programs.*** These programs offer tutoring, mentoring, and internship opportunities. They also include outreach to women and underrepresented minorities. One program is the NASA Summer High School Apprenticeship Program. Under NASA's Explorer Schools program, JPL has established partnerships with nine schools around Southern California, dedicated to improving the teaching of science and technology. JPL also offers robotics competitions.
- ***Undergraduate/graduate programs.*** These programs offer summer employment, cooperative education opportunities, research positions, and fellowships. There are both general programs and special programs for women and underrepresented minorities. JPL also has programs to recruit post-doctoral fellows, some of whom are later offered permanent positions at the laboratory.
- ***Faculty/institutional/curriculum programs.*** Most of JPL's programs for K-12 teachers offer curriculum materials, seminars and other events, classroom speakers, and tours of JPL. As part of the Explorer Schools program, science and mathematics teachers from participating schools attend summer courses at JPL. For college and university faculty, JPL offers research awards, fellowships, and awards for integrating research into undergraduate education.
- ***Informal education.*** JPL offers a speakers bureau, public tours of JPL, special events for the public, and traveling exhibits. JPL maintains close relations with science museums and planetariums around the country, and in 2004 created a video presentation about Saturn, *Ring World*, that played at 30 planetariums.

Academic research. As a center for space science, JPL has close ties to the university space science community. University researchers participate in major JPL missions, including Cassini and the Mars Exploration Rovers. In FY 2003, 523 university researchers participated in JPL projects. JPL also has several strategic university research partnerships with major universities, along with its close ties to Caltech.

Contributions to State and Local Government

In the past, Caltech has tried at times to provide technical services to California state agencies. However, the experience was not a good one. Like the Department of Energy laboratories in California, JPL is required by federal law to obtain funding for reimbursable projects up front, at the beginning of projects. As discussed elsewhere in this report, California state agencies generally will not pay for technical services until after the services are delivered. JPL is open to further work with the state, and has a great deal of expertise to offer in fields such as remote sensing of natural resources, climate information, and information technology. However, until and unless state agencies develop new ways to do business with federal laboratories, new projects with JPL are not likely.

7.5. OPPORTUNITIES AND CHALLENGES

It is fair to say that JPL is now in a golden age of planetary exploration. And NASA is likely to keep assigning new robotic missions to JPL, given the laboratory's technological excellence and the emphasis that the new national Moon-Mars Initiative places on studying Mars and other planets.

JPL, though, faces at least two challenges. First, it needs new and refurbished buildings and possibly additional land. Second, there is some concern about staffing over the long term. Almost all of JPL's work is unclassified, but for security reasons NASA does not want JPL to hire scientists and engineers who are not U.S. citizens or resident aliens. While the concern about security is real and understandable, the problem is that today roughly half of all people coming out of U.S. universities with Ph.D. degrees in science and engineering are foreign-born, many of them from China and India. The NASA rules, while understandable, cut JPL and other NASA centers off from roughly half of the best young scientists and engineers in the country. So far, JPL has been able to hire outstanding young American-born scientists and engineers. But if the numbers of native-born Americans getting Ph.D. degrees in science and engineering continue to decline, this trend could pose long-term problems for JPL and other federal laboratories.

In terms of JPL's economic contributions, the laboratory continues to work with both established companies and small firms to develop new high-tech useful to both NASA and commercial markets. JPL's SBIR program is highly regarded, and the Caltech Office of Technology Transfer, which licenses JPL inventions, is also well regarded and considered friendly to industry.

Problems remain, however, in relations with the state government. As mentioned earlier, state procurement rules are a significant barrier to JPL providing technical assistance to agencies in Sacramento.

8. CONCLUSION: CONTRIBUTIONS, OPPORTUNITIES, CHALLENGES, AND RECOMMENDATIONS

8.1. REVIEW OF LABORATORY CONTRIBUTIONS TO CALIFORNIA

Federal laboratories are an important part of California's science and technology capabilities and infrastructure. California is home to the largest concentration of federal laboratories in the nation, ranging from small facilities to the six major institutions detailed in this report. While they exist to carry out federal missions — missions that of course benefit Californians as well as other Americans — they have also provided a wide range of direct benefits to the state, including:

- *$5 billion in annual spending.*
- *More than 23,000 jobs.*
- *Partnerships with local industry.*
- *Collaboration with research universities in the state.*
- *Research opportunities for young university graduates as well as seasoned scientists.*
- *Science education for thousands of school students.*
- *Expert assistance to state and local governments — from environmental clean up, to port security, to combating wildfires, detecting agricultural diseases, and beyond.*

At a time when California's economic future increasingly relies on scientific and engineering expertise, the federal labs provide critically important know-how and highly specialized facilities. Their presence spurs innovation in California's high-tech industries; collectively, they serve as a magnet for some of the best scientific minds in the nation. And today, going beyond their federal missions, the labs are working with California state and local agencies, industry, and universities to collaboratively solve local problems and pursue new research initiatives.

Even so, these laboratories remain a largely untapped resource by the state. Most of them are regularly called upon by the federal government to assist in disaster response; for example a team from Sandia National Laboratories/California helped analyze Hurricane Katrina's long-range effects on physical infrastructure, including the levee system, and industry in Louisiana. NASA used satellite imaging by the Jet Propulsion Laboratory to characterize the extent of flooding and damage to homes. However, while the federal government regularly calls upon these facilities, laboratory officials often find themselves struggling to determine how to best inform the state government of these same resources.

Given their many contributions, remarkable potential, and the intense competition for resources today, it is to California's advantage to ensure that federal laboratories housed here flourish.

8.2. SUMMARY OF OPPORTUNITIES AND CHALLENGES

The six laboratories have skills, facilities, and technologies to offer to California companies and governments. Certain new capabilities and programs deserve special note:

- In ***nanotechnology***, Berkeley Lab's Molecular Foundry will be a major research site, and already it has entered into a partnership with Intel. If NASA Ames and UC Santa Cruz succeed in building a new "bio-info-nano" facility, that too will be an important resource for academic and industrial researchers.
- In general ***materials research***, including the study of biological materials, SLAC's new powerful x-ray light source will be a valuable tool for researchers in electronics, biotechnology, nanotechnology, and other fields. Berkeley Lab's Advanced Light Source will also continue to make contributions.
- The growth of ***homeland security R&D*** at Livermore and Sandia/California offers a major opportunity to California's high-tech companies. The federal government is looking for industrial partners who can commercialize new federally funded technologies and get them into the hands of police, fire fighters, and other first responders.
- Several of the labs continue to build their capabilities in ***energy and environmental science***. Hydrogen fuel is one important new capability at Sandia/California, and Berkeley Lab remains a leader in energy efficiency. Ames and JPL have great capabilities in monitoring natural resources from aircraft and satellites. In addition, Livermore has special expertise in water management. Given that California's future population growth will put enormous pressures on ***water resources*** — a point documented in a new report by the nonpartisan Public Policy Institute of California[28] — these remote sensing and water management skills would be increasingly valuable to the state.

In short, these six laboratories are already a significant resource for California, but could do much more. State agencies of course have their own technical capabilities, but the laboratories could also contribute more to the state. For example, the labs could provide additional expertise in such areas as homeland security, water management, energy efficiency, and science and math education.

There are, however, significant issues to address before the gaps between the state and the federal laboratories can be bridged. The principal challenges fall into five main categories:

Challenges facing state government. State agencies that want assistance from federal laboratories face several challenges. The state's contracting rules run counter to the federal government's: state law generally prohibits agencies from paying in advance for research services; federal law requires advance payments — making the negotiation of cooperative projects exceedingly difficult. This state principle is codified in California's State Contracting Manual.[29] Moreover, different ways of managing indemnification, audits, and intellectual property also hinder the process. And because state agencies appear to have different procurement policies, each agreement must be individually crafted, leading to inevitable delays that impede prompt action on important issues.

---

[28] Ellen Hanak, *Water for Growth: California's New Frontier*, Public Policy Institute of California, July 2005, available at: http://www.ppic.org/content/pubs/R_705EHR.pdf.

[29] Section 7.32 of the *State Contracting Manual* (November 2004 version) states: "Advance payments by the state are permitted only when specifically authorized by statute and should be made only when necessary. Contracts or agreements containing provisions for advance payments by the state should preferably provide for small periodic payments rather than the total contract price or lump-sum advances…."

Challenges facing local governments. At the local level, officials do not routinely have access to the level of expertise they might need to help determine which research trends to follow and which new technologies to adopt. In other words, they may not know what they don't know, and so would have no way of assessing where to go for assistance, and even what questions to ask. The potential for local governments to benefit from what the federal labs are doing in the area of homeland security, for instance, is great, but a mechanism is needed to help facilitate the transfer of that knowledge down to the local level.

Challenges facing industry. While some of California's large corporations enjoy steady, ongoing relationships with the federal laboratories, smaller companies are not likely to know about the technical opportunities the labs offer. Intel, for example, works closely with several of California's federal facilities. But an examination of the list of collaborations among the labs and private firms reveals that few small companies are so engaged. And even large firms may not have the know-how to deal with the rules and procedures of the federal bureaucracy.

Competition from other states. The federal laboratories in California compete vigorously with labs in other states to win new projects and facilities. The fact is, other states are becoming increasingly sophisticated in the way they attract federal projects — providing their own money to attract or supplement new federal facilities — ultimately making the competition extremely difficult. For example, Illinois has provided funds for the Department of Energy's Argonne National Laboratory, and Virginia has funded both staff and buildings for DOE's Thomas Jefferson National Accelerator Facility. California must become more cognizant of the fact that other states are taking strong proactive steps such as this, and become more connected to its federal labs if they are to compete effectively against other states.

Internal laboratory issues. The laboratories themselves face limitations that sometimes affect their ability to conduct new kinds of research or work with California companies, universities, and governments. For example, often federal laboratory officials lack first-hand knowledge of the technical issues facing state, local, and industrial groups. The labs must of course give priority to their prime federal missions. Taking on other missions and activities requires careful planning and cooperation among the laboratories and industrial and government officials. But there are many areas of activity where the needs of state based entities are entirely consistent with the laboratories overall missions and hence offer excellent opportunities for federal-state and industry partnerships.

With the tremendous value already demonstrated by these facilities, and the enormous potential they possess to assist California's government, academic, and industry communities even further, it is in California's long-term interest to keep them in the state and work to overcome challenges inhibiting more successful leveraging of these important resources that contribute jobs, procurement dollars, and technology to California.

Given the reality of increased competition, bureaucratic snags, and other structural challenges, what can be done to help remedy the situation? There are some practical, achievable steps that state officials in the Governor's office, the Legislature, and state agencies could take, possibly in partnership with CCST that would help reduce these barriers and enable California to take better advantage of what the laboratories have to offer.

8.3. POLICY RECOMMENDATIONS

1. Streamline the contracting process with the state.

Administrative barriers could be reduced by standardizing rules and procedures. To accomplish this:

- The California Department of General Services should assemble a small working group of representatives from state and federal agencies to propose a set of standardized rules and policies that would facilitate — rather than hinder — collaboration.
- The California Legislature should enact a new law that would permit state agencies to pay for technical services in advance, once the contract has been signed.
- A standardized model contract for working with the laboratories, approved by the state attorney general and the Department of Finance, should be made available to all state agencies.
- The major state agencies with technical missions — such as the California Energy Commission, Environmental Protection Agency, and the Office of Homeland Security — should appoint specific individuals with principal responsibility for working with the federal laboratories — making contact, brokering agreements, and creating partnerships. Reciprocally, the laboratories should designate individuals who would provide liaison back to the state.

2. Create bridges between laboratory and state officials.

For the state to benefit more fruitfully from the federal labs in California, a richer exchange of information first must occur. In keeping with its mission of providing science and technology assistance to the state, CCST could organize special workshops for agency officials, legislators, and laboratory officials — so that they have the opportunity to better understand the missions, roles, and research areas of each, and brainstorm possible collaborative opportunities. Follow-up activities should then occur, including site visits and temporary personnel exchanges.

3. Use the laboratories to enhance state research on key issues such as homeland security.

The federal labs can provide vital expertise and direction for a range of state interests including energy research, water, and other key infrastructure issues. In addition, several of the laboratories, including LLNL, Sandia, and Ames, have important technologies that could help state disaster response at a variety of levels. For emergency response and security related issues, the Governor's Office of Homeland Security should build on recent visits to LLNL and Sandia and establish state-facilitated mechanisms that will help transfer laboratory technology and know-how to California first responders. The laboratories also can provide further training for local agencies. It is possible that new federal funding might become available for these activities, either from the U.S. Department of Homeland Security or through assistance from the California Congressional Delegation.

4. Assess the state's competitive edge.

To ensure California's competitiveness, a study should be commissioned that surveys private industry and universities throughout the state about the research capabilities and facilities that will be needed for the future — particularly in the key fields of information technology, aerospace, energy, biotech, agriculture, and nanotechnology. The survey should ultimately be directed to answer the question: What facilities should the federal laboratories located in the state have in place to ensure competitiveness in these areas?

> A related point is that opportunities exist for the state and the laboratories to partner in proposals to 'win' important facility construction programs from the federal government, e.g., in the near term, in proteomics and in energy efficiency from the Department of Energy (DOE). There also could be opportunities to enlist the support of the California Congressional Delegation for user facilities at the laboratories that would intentionally build in mechanisms for university and industry access to these facilities, based on models such as access to the Combustion Research Facility at Sandia or the Advanced Light Source at Berkeley Lab.

Along with the state's universities and high-tech companies, the six major federal labs provide the raw talent and research muscle that helps make California a world leader in science and technology. But more — much more — could be done to make the connections among the labs to industry, universities, and state agencies more seamless — and more productive. And time is of the essence — particularly in this era of increased competitiveness and a multitude of other challenges including natural disasters and terrorism. We offer these practical, achievable steps in the hopes of spurring fresh thinking, new partnerships, and a heightened sense of urgency and potential.

APPENDIX A: ABBREVIATIONS AND ACRONYMS

AEC	Atomic Energy Commission
ALS	Advanced Light Source
ASC	Advanced Simulation and Computing
CalEPA	California Environmental Protection Agency
Caltech	California Institute of Technology
CCST	California Council on Science and Technology
CEC	California Energy Commission
CISAC	Center for International Security and Cooperation
CNT	Center for Nanotechnology
CRADA	cooperative research and development agreements
CREST	California Report on the Environment for Science and Technology
CRF	Combustion Research Facility
CSEE	Center for Science and Engineering Education
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DRRC	Demand Response Research Center
ETS	Engineering Test Stand
EUVL	extreme ultraviolet lithography
FFRDC	federally funded research and development center
GOCO	government-owned, contractor-operated
GOGO	government-owned, government-operated
ICE	internal combustion engine
JGI	Joint Genome Institute
JPL	Jet Propulsion Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
LSTPD	Laboratory Science Teacher Professional Development
MDL	Micro Devices Laboratory
MEMS	Micro-Electro-Mechanical Systems
MOU	Memorandum of Understanding
MTBE	Methyl Tertiary Butyl Ether
NARAC	National Atmospheric Release Advisory Capacity
NASA	National Aeronautics and Space Administration
NDEAA	Nondestructive Evaluation and Advanced Actuators Laboratory
NERSC	National Energy Research Scientific Computing Center
NIF	National Ignition Facility
NIH	National Institutes of Health
NISAC	National Infrastructure Simulation and Analysis Center
NNSA	National Nuclear Security Administration
NSF	National Science Foundation
OSC	Operation Safe Commerce
PGF	Production Genomics Center
PIER	Public Interest Energy Research
PRL	Planetary Robotics Laboratory
R&D	Research & Development
RDCD	Rapidly Deployable Chemical Detection
SBIR	Small Business Innovation Research
SEGRF	Student-Employee Graduate Research Fellowship
SLAC	Stanford Linear Accelerator Center
SMUD	Sacramento Municipal Utility District
SNAP	Supernoval/Acceleration Probe
STTR	Small Business Technology Transfer
S&T	Science and Technology
UARC	University Affiliated Research Center

APPENDIX B: DATA ON SELECTED CONTRIBUTIONS TO CALIFORNIA MADE BY FIVE FEDERAL LABORATORIES[30]

B.1. DATA FROM LAWRENCE BERKELEY NATIONAL LABORATORY

	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
1. Annual Budget (thousands of dollars)	**373,068**	**396,927**	**448,187**	**433,114**	**483,790**
Funds from DOE					
Operating	245,597	254,983	282,228	273,026	304,288
PACE (Plant and Capital Equipment)	61,489	55,062	73,737	61,307	68,168
Total Funds from DOE	**307,086**	**310,045**	**355,965**	**334,333**	**372,456**
Funds from Other Federal Agencies	**42,444**	**51,762**	**62,381**	**61,860**	**70,828**
Funds from Non-Federal Sponsors					
Funds from Other Non-Federal Sponsors	5,183	12,856	10,567	20,291	25,613
CRADAs	6,312	5,050	3,821	1,307	354
Funds from California State Agencies	12,043	17,214	15,453	15,323	14,539
Total Funds from Non-Federal Sponsors	**23,538**	**35,120**	**29,841**	**36,921**	**40,506**

2. Laboratory Employees	**2000**	**2001**	**2002**	**2003**	**2004**
(a) Employees FTE[31] by Job Function					
Administrative/Support Staff	537	560	576	557	563
Executive	7	6	7	7	9
Professional	493	555	570	590	583
Scientific	526	562	571	578	573
Technological	854	846	799	778	748
Lab Employees Total	**2,417**	**2,529**	**2,523**	**2,510**	**2,476**
(b) On-Site Contractors FTE Total	**108**	**73**	**58**	**60**	**47**

3. Collaborations with Universities	**2000**	**2001**	**2002**	**2003**	**2004**
(a) Individuals from UC[32]					
Faculty Appointment	175	190	206	207	212
Graduate Student Research Assistant	116	191	251	354	343
Student Assistant		1	5	12	7
Visiting Postdoctoral Fellow	2			1	9
Total Individuals from UC	**293**	**382**	**462**	**574**	**571**
(b) Individuals from Non-UC Universities					
Faculty Appointment	30	18	10	1	0
Graduate Student Research Assistant	200	148	78	1	0
Postdoctoral Fellows	23	32	35	61	62
Student Assistant	25	31	32	17	15
Visiting Postdoctoral Fellow	163	181	200	216	214
Total Individuals from Non-UC Universities	**441**	**410**	**355**	**296**	**291**
Grand Total of Collaborations	**734**	**792**	**817**	**870**	**862**

[30] SLAC declined to provide data for this Appendix. So the data presented here are from Lawrence Berkeley National Lab, Lawrence Livermore National Lab, Sandia/California, NASA Ames, and JPL . When numbers are not available for a particular category, the entry is left blank.

[31] Employee Population: All Full time/Part time greater than 50%. Variable time employees not included.

[32] School codes cleaned up; better data collected in 2003 and 2004.

4. Interactions with Industry	2000	2001	2002	2003	2004
(a) Number of Active Licenses for that Year (licenses includes all intellectual property licensing agreements such as licenses and options, for both copyright and patent including both new and from previous years)	213	237	255	283	296
Of that Total, Number of New Licenses that Year	24	29	28	30	22
Number of Total Active Licenses that Year to Entities in California	63	69	77	81	86
(b) Amount of Royalties Paid to the Laboratory that Year (millions of current dollars)	0.881	1.107	1.371	2.012	2.114
(c) Number of Industrial Funds-in CRADAs Active that Year (calendar year)					
Number of New Funds-in CRADAs that Year	7	10	6	0	5
Number of those New CRADAs with Entities in California	4	3	3	0	1
Industrial Payments that Year for all CRADAs Active that Year (in millions of current dollars)	0.340	0.854	0.323	0.377	0.464
(d) Number of Laboratory-funded CRADAs Active that Year (if any) (calendar year)					
Number of New Lab-funded CRADAs that Year	0	0	1	0	1
Number of those New Lab-funded CRADAs with Entities in California	0	0	0	0	1
Lab Spending that Year on Lab-funded CRADAs (in millions of current dollars)	0	0	0.500	0	0.500
(e) Number of Work-for-others Projects Active that Year (calendar year)					
Number of New WFO Projects Initiated that Year	33	27	35	38	63
Number of those New WFO Projects with Entities in California	12	6	20	19	30
Payments to Lab that Year for all Active WFO Projects (in millions of current dollars)	2.147	3.163	4.197	5.866	6.064
(f) Number of New Spin-off Companies that Year Started with Lab Licenses	2	1	3	1	1
Of that Total, Number of Spin-off Companies in California	2	1	2	1	1

B.2. DATA FROM LAWRENCE LIVERMORE NATIONAL LABORATORY

	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
1. Total Annual Budget (in millions of current dollars)	**1,333**	**1,373**	**1,540**	**1,594**	**1,630**
Funds from DOE	1,180	1,242	1,397	1,422	1,380
Funds from other Federal Agencies	110	92	108	142	222
Funds from Private Industry	42	38	33	27	26
Funds from California State Agencies	1	1	2	3	2

2. Laboratory Employees (headcount)	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
(a) Total Laboratory Employees (headcount)	**7,949**	**8,090**	**8,893**	**8,846**	**8,742**
Scientists and Engineers	3,279	3,299	3,582	3,604	3,635
Technicians	1,884	1,926	2,171	2,154	2,122
Administrative/Support Staff	2,786	2,865	3,140	3,088	2,985
(b) Total Laboratory "Core" Employees (HEADS: career and flex-term appointment types only)	**6,171**	**5,960**	**5,981**	**6,434**	**6,393**
Scientists (Ph.D., M.S.)	1,530	1,508	1,522	1,596	1,604
Engineers (Ph.D., M.S., B.S.)	952	891	890	984	1,000
Technicians	1,884	1,829	1,864	2,102	2,068
Administrative/Support Staff	1,805	1,732	1,705	1,752	1,721
(c) On-site Contractors (headcount)	**664**	**567**	**567**	**667**	**703**

3. Collaborations with University Researchers and Students (either at the laboratory or at their institutions)	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
(a) Total Number of Individuals from UC Collaborating that Year with Lab Personnel	**418**	**570**	**486**	**413**	**490**
UC Faculty	176	262	309	241	246
UC Postdocs and other Non-faculty Ph.D.s	16	21	9	6	13
UC Students	226	287	168	166	231
(b) Total Number of Individuals from other California Universities	**132**	**157**	**99**	**92**	**127**
Other California Faculty	63	61	71	54	59
Other California University Postdocs and Non-faculty Ph.D.s	7	1	0	2	3
Other California Students	62	95	28	36	65
(c) Total Number of Individuals from Non-California Universities	**455**	**462**	**334**	**318**	**443**
Non-California Faculty	250	249	241	194	225
Non-California University Postdocs and Non-faculty Ph.D.s	21	4	2	5	7
Non-California Students	184	209	91	119	211

4. Peer-reviewed Publications	FY 2002	FY 2003	FY 2004
Total LLNL Publications	1,032	1,215	1,151
Co-authored with UC Collaborators	305	363	347
Co-authored with CSU Collaborators	9	10	10
Co-authored with Stanford Collaborators	45	49	81
Co-authored with Caltech Collaborators	36	47	70
Co-authored with USC Collaborators	4	5	2
Co-authored with 1 or more Collaborators from UC, CSU, Stanford, Caltech or USC	333	387	382

5. Total Spending that Year on Lab R&D Awards to University Researchers	FY 2002	FY 2003	FY 2004
University of California (in thousands)	4,179	4,698	5,853
Other, Non-UC University Contracts (in thousands)	10,690	8,242	8,554
Total	**14,869**	**12,940**	**14,407**
LLNL Funding from Universities			
University of California (in millions)		2.81	3.79
Other, Non-UC University Contracts (in millions)		2.26	1.44
Total		**5.07**	**5.23**

6. Interactions with Industry	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
(a) Total Spending that Year on Procurements from Industry (in millions of dollars)	529	490	587	560	599
Of that Total, Amount Spent that Year in California	232	204	241	243	265
(b) Number of Active Fee-bearing Licenses that Year (both new and from previous years)	421	435	457	488	567
Patent, Hybrid Licenses	83	77	84	88	89
Copyright Licenses	338	358	373	400	478
Of that Total, Number of New Licenses that Year	35	36	37	49	89
Patent, Hybrid Licenses	10	14	22	15	8
Copyright Licenses	25	22	15	34	81
Number of Total Active Licenses that Year to Entities in California	60	62	62	64	75
Patent, Hybrid Licenses	31	30	28	30	30
Copyright Licenses	29	32	34	34	45
(c) Amount of Royalties Paid to the Laboratory that Year (in millions of dollars)	2.4	3.4	3.2	4.0	4.6
(d) Number of Industrial Funds-in or Jointly-funded CRADAs Active that Year	22	23	26	27	16
Number of New Funds-in CRADAs that Year	1	7	8	5	1
Number of those New CRADAs with Entities in California	1	2	2	2	1
Industrial Spending that Year for all CRADAs Active that Year (in millions of dollars)	20.9	19.2	13.9	4.8	1.5
(e) Number of U.S. Government-funded CRADAs Active that Year (if any)	13	13	14	18	18
Number of New Lab-funded CRADAs that Year	4	3	2	5	4
Number of those New Lab-funded CRADAs with Entities in California	1	1	0	2	1
Lab Spending that Year on Lab-funded CRADAs (in millions of dollars)	2.3	1.8	1.2	1.7	2.7
(f) Number of Work-for-others Projects Active that Year	1,398	1,323	1,346	1,377	1,132
Number of New WFO Projects Initiated that Year	291	204	288	309	348
Payments to Lab that Year for all Active WFO Projects (in millions of dollars)	148	138	160	184	310
(g) Number of SBIR Awards Awarded that Year (if any)	4	4	2	3	8
Of that Total, Number of those SBIR Awards to Entities in California	0	2	0	2	4
(h) Number of New Spin-off Companies that Year	2	2	6	1	1
(new firms started with lab licenses, or by lab employees, or both)					
Of that Total, Number of Spin-off Companies in California	2	1	3	1	1

Additional LLNL Data: Other Collaborative Structures

Note: Beyond university collaborations listed in the table above, LLNL also has a set of formal collaborations with academic institutions, faculty, and students. Several of these programs are listed below, along with some numbers from FY 2005.

	FY 2005
Multi-Location Appointments (MLA)	
LLNL Employees at UC campuses	30
UC Employees at LLNL	9
Joint Appointments (decreasing, as they are converted to MLAs)	3
Adjunct Appointments of LLNL Staff	80
Faculty Participating Guest	237
Faculty Consultants to LLNL	122
Student Guests	125

LLNL Sabbatical Scholar Program: since its inception in 2001, the program has hosted 22 faculty (30% from a UC campus) and 33 students along with their advisors.

LLNL Professional Research and Teaching Program allows LLNL employees to teach full time on a UC campus for a term. 22 LLNL employees have participated since the beginning of FY 2000.

Centers: Some Examples

- NSF Center for Adaptive Optics: NSF Science and Technology Center, founded in 1999, headquartered at UC Santa Cruz. First 5-yr funding $40M, renewed for a 2nd 5-yr term. Center director, built her career at LLNL and established this center while in a joint UCSC/LLNL appointment.
- NSF Center for Biophotonics Science and Technology: NSF Science and Technology Center headquartered at UC Davis on Sacramento Medical Campus. 5-yr, $20M awarded in 2002. Involved 90 researchers at 10 institutions (UCD, LBL, LLNL, UCB, UCSF, Stanford, Fisk, Mills, UTSA, Alabama A&M). Center Director established center while at LLNL.
- UC Davis/LLNL Integrated Cancer Program: designated a National Cancer Center by the National Cancer Institute in 2002, renewed in 2005. 213 researchers between UCD and LLNL. Research grants total more than $40M, leveraging $140M.

Other Formal Collaborations: An Example:

- Memorandum of understanding among LLNL, UC Santa Barbara, and the Naval Postgraduate School, for the purpose of providing a framework for enhancing research and educational cooperation among the three institutions in the areas of national security science and technology.

B.3. DATA FROM SANDIA NATIONAL LABORATORIES/CALIFORNIA

	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
1. Total Annual Budget (millions in current dollars)	**165**	**179**	**194**	**218**	**233**
Funds from DOE	131	145	164	196	202
Funds from Other Federal Agencies	9	15	14	10	23
Funds from Private Industry	24	19	16	12	8
Funds from California State Agencies	0	0	0	0	0

2. Laboratory Workforce	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
Laboratory Workforce Total			**1,252**	**1,311**	**1,371**
(a) Regular Laboratory Employees (FTEs)	**886**	**842**	**873**	**907**	**921**
Scientists (Ph.D., M.S.)	137	140	139	134	128
Engineers (Ph.D., M.S., B.S.)	136	135	152	170	187
Technicians	226	214	229	243	252
Administrative/Support Staff	146	127	128	130	134
(b) Workforce-other Categories	**89**	**77**	**81**	**90**	**94**
Limited-term Employees	20	27	35	50	46
Postdoctoral Researchers	48	23	47	47	56
Contractors	N/A	N/A	297	309	348

3. Collaborations with University Researchers and Students (either at the lab or at their institutions)	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
(a) Total Number of Individuals from California Universities	**116**	**177**	**185**	**163**	**134**
California Faculty	25	26	29	28	29
California University Postdocs and Non-faculty Ph.D.s	3	11	8	12	10
California Students	88	140	148	123	95
(b) Total Number of Individuals from Non-California Universities	**200**	**199**	**213**	**224**	**246**
Non-California Faculty	40	38	39	41	39
Non-California University Postdocs and Non-faculty Ph.D.s	14	32	35	44	37
Non-California Students	33	122	100	137	124
Other Students with Non-specified State	105	3	37	2	45
Other Postdocs with Non-specified State	8	4	2	0	1
(c) Total Spending that Year on Lab R&D Awards to University Researchers (cumulative data for all Sandia locations)	N/A	22	23	21	27
Of that Total, Amount Awarded that Year to University Researchers in California	N/A	1.8	1.7	1.8	1.7

4. Interactions with Industry (cumulative data for all Sandia locations)	**FY 2000**	**FY 2001**	**FY 2002**	**FY 2003**	**FY 2004**
(a) Total Spending that Year on Procurements from Industry	.	586	896	968	1,154
Of that total, amount spent that year in California		86	143	133	175
(b) Number of Active Licenses that Year (both new and from previous years)	1,952	2,231	2,719	3,266	3,779
Of that Total, Number of New Licenses that Year	147	302	513	665	584
Number of Total Active Licenses that Year to Entities in California	59	72	101	121	134
(c) Amount of Royalties Paid to the Laboratory that Year	2.3	3.7	2.8	2.3	2.1
(d) Number of Industrial Funds-in CRADAs Active that Year	91	90	89	89	85
Number of New Funds-in CRADAs that Year	17	22	25	23	21
Number of those New CRADAs with Entities in California	2	1	1	7	3
Industrial Payments that Year for all CRADAs Active that Year	38	28	23	17	15
(e) Number of Laboratory-funded CRADAs Active that Year (if any)	98	80	62	58	54
Number of New Lab-funded CRADAs that Year	2	3	5	6	10
Number of those New Lab-funded CRADAs with Entities in California	1	1	3	1	2
Lab Spending that Year on Lab-funded CRADAs	22	17	14	11	9
(f) Number of Work-for-others Projects Active that Year (includes SBIR awards)	302	339	315	307	248
Number of New WFO Projects Initiated (executed*)* that Year	153	141	102	97	65
Number of those New WFO Projects with Entities in California	24	27	25	10	14
Payments to Lab that Year for all Active WFO Projects	30	32	23	24	40
(g) Number of New Spin-off Companies that Year[33]	6	1	0	2	1
Of that Total, Number of Spin-off Companies in California	1	0	0	1	0

[33] Information includes ONLY spin-offs from Entrepreneurial Separation to Transfer Technology (ESTT) program.

B.4. DATA FROM THE NASA AMES RESEARCH CENTER

	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
1. Total Annual Budget (in millions)	**690**	**763**	**765**	**770**	**904**
Funds from NASA	649	721	718	721	840
Funds from other Federal Agencies	34	35	39	40	48
Funds from Private Industry	7	7	8	9	15
Funds from California State Agencies	0	0	0	0	0

2. Center Employees (FTEs) (headcount at the beginning of each fiscal year)	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005
Scientists and Engineers (S&Es)						
Ph.D.'s	279	305	339	326	334	338
Masters	301	295	293	279	279	265
Bachelors	274	265	263	258	253	249
Other	2	2	2	2	2	2
Total S&E	**856**	**867**	**897**	**865**	**868**	**854**
Technicians	185	170	168	143	133	118
Administrative/Support Staff	461	467	466	453	470	486
Total Center Staff	**1,502**	**1,504**	**1,531**	**1,461**	**1,471**	**1,458**

3. Interactions with Industry	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005
(a) Number of Licenses that Year (both new and from previous years)	4	10	4	3	3	3
Number of Total Active Licenses that Year to Entities in California	1	6	2	3	2	1
(b) Amount of Royalties Paid to the Laboratory that Year	96,500	105,100	63,866	586,767	49,787	144,620
(c) Number of Reimbursable Space Act Agreements Active that Year	37	34	26	48	60	14
Number of those New CRADAs with Entities in California	15	14	13	19	32	7
(d) Number of Non-reimbursable Space Act Agreements Active that Year	15	18	15	18	20	6
Number of those New Lab-funded CRADAs with Entities in California	5	10	9	10	12	3
(e) Number of SBIR Awards Awarded that Year (if any)	31	33	32	36	30	
Of that Total, Number of those SBIR Awards to Entities in California*	9	10	13	14	9	
(f) Number of New Spin-off Companies that Year						
Of that Total, Number of Spin-off Companies in California	2	1	1	1	1	

4. Procurement Data	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
Business Category					
All (in thousands)	**354,567**	**392,989**	**403,175**	**419,238**	**485,169**
Business	251,678	286,130	285,922	286,291	323,343
Large Business	166,237	177.731	158,712	155,089	150,225
Small Business	85,442	108,399	127.209	131,202	173,118
Small Disadvantaged Business	22,761	40,312	51,648	50,373	67,506
8(a) Program	28,908	34,496	37,019	47,089	81,937
Woman Owned Business	28,672	46,461	55,677	47,119	38,257
Small Business Innovation Res.	3,447	4,021	4,778	4,806	4,056
Educational Total	**37,506**	**43,576**	**49,650**	**53,561**	**81,405**
Historical Black Colleges and Universities	567	445	702	375	199
Other Minority Institutions	9,288	8,545	12,354	15,970	25,662
Non-profit Institutions	**64,833**	**63,106**	**67,604**	**79,386**	**80,413**

B.5. DATA FROM THE JET PROPULSION LABORATORY

	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
1. Total Annual Budget (millions of current dollars)	**1,233**	**1,366**	**1,446**	**1,398**	**1,559**
Funding from Principal Agency (DOE or NASA)	1,161	1,306	1,393	1,340	1,483
Other Federal Agency Funding	72	60	53	58	76

2. Laboratory Employees (FTEs)	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
(a) Total Laboratory Employees (FTEs)	**4,958**	**5,103**	**5,342**	**5,368**	**5,452**
Scientists (Ph.D., M.S.)	199	189	189	198	202
Engineers (Ph.D., M.S., B.S.)	1,378	1,463	1,508	1,513	1,561
Technicians	1,056	1,097	1,184	1,215	1,225
Administrative/Support Staff	2,325	2,355	2,461	2,441	2,463
(b) On-site contractors (FTEs)	474	582	576	480	353

3. University Managed Labs: Collaborations with University Researchers and Students	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
(a) Total Number of Individuals from the Contractor University Collaborating that Year with Laboratory Personnel, either at the Laboratory or at the University	**484**	**526**	**479**	**523**	
Caltech Faculty					
Caltech Research Staff (including postdocs)[34]	60	55	48	52	50
Caltech Students	8	16	23	17	26

4. NASA Facilities: Interactions with Industry	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
(a) Total Spending that Year on Procurements from Industry (in millions)	693	822	677	701	852
Of that Total, Amount Spent that Year in California	213	278	269	256	294
(b) Licenses Current that Year (both new and existing)	94	101	113	114	124
Of that Total, Number of New Licenses that Year	10	26	38	230	381
Number of Total Licenses that Year to Entities in California	2	11	15	47	88
(c) Royalties Paid to the Laboratory that Year (in millions)	unknown	0.96	1.4	1.1	1.2
(d) Number of Industrial Funds-in Technology Partnerships Active that Year	104	117	120	126	72
Number of new funds-in partnerships that year	30	32	32	30	49
Number of those new partnerships with entities in California	9	21	18	16	23
Industrial payments that year for all partnerships active that year (in millions)	3.8	4.7	2.6	3.1	4.5
(e) Number of SBIR Awards Awarded that Year (if any)	51	55	51	58	53
Of that total, number of those SBIR awards to entities in California	19	17	14	21	12
(f) Number of New Spin-off Companies that Year	unknown	5	3	1	5
Of that total, number of spin-off companies in California	unknown	2	3	1	4

[34] The numbers for the "Caltech postdocs" represents the participants in the Caltech Postdoctoral Scholars at JPL Program. They are paid through the campus but work on-site at JPL.

Appendix C: Reviewers

The California Council on Science and Technology has the highest principles in providing independent, objective, and respected quality work. All work that bears the Council's name is reviewed by Board members, Council members, and selected Fellows. The council also seeks peer review from outside experts. The process as well as the outcome is reviewed. This results in a protocol that ensures the issue is well addressed, the response is targeted, and that the results are clear and sound.

We wish to extend our sincere appreciation to the reviewers, whose expertise and diligence in reviewing this report has been invaluable, both in rigorously honing the accuracy and focus of the work and in ensuring that the perspectives of their respective disciplines and institutions were taken into account. Without the insightful feedback that these reviewers generously provided, this report could not have been completed.

Special thanks go to the many people at the six federal laboratories and at the University of California who helped with this project. They include Michael Telson, Bruce Darling, and Todd La Porte of UC; at Lawrence Berkeley National Laboratory, Reid Edwards, Don Medley, Cheryl Fragiadakis, and their colleagues; at Lawrence Livermore National Laboratory, Cherry Murray, Rokaya Al-Ayat, Robin Newmark, Stan Hitomi, Paul Chrzanowski, and their colleagues; at Sandia National Laboratories/California, Rick Stulen, Paul Nielan, Karen Scott, Don Hardesty, Paul Boggs, Phillip Brittenham, and their colleagues; at Stanford Linear Accelerator Center, Neil Calder; at NASA Ames Research Center, Scott Hubbard, Peter Friedland, Michael Marlaire, David Morse, Betsy Robinson, Jonathan Trent, Bill Borucki, and their colleagues; and at the Jet Propulsion Laboratory, Richard O'Toole, Patty Rhee, Linda Rodgers, and their colleagues. They provided invaluable data and insight into the institutions described in this report. We also wish to thank Robert Spinrad, who contributed substantially to this report's discussion of "research clusters" and the California "innovation ecosystem." The research cluster discussion in this report also draws heavily on ideas from Lynne Zucker and Michael Darby of UCLA and Edward Furtek and Mary Walshok of UC San Diego. Their contributions are much appreciated. We also wish to thank David Cheney, formerly an official with the U.S. Department of Energy, for his insightful critique.

This report has been produced under the guidance of the CCST Large Science Project Committee. Members include:

Miriam E. John, Committee Chair
Michael R. Anastasio
Linda R. Cohen
Lawrence B. Coleman
G. Scott Hubbard
John P. McTague
Anneila Sargent

In addition, we acknowledge the valuable contributions from CCST's Laboratory Representatives including:

Reid A. Edwards, Head of Public Affairs, LBNL
Peter E. Friedland, Assistant Director for Technology & Chief Technologist, NASA Ames
Robin L. Newmark, Water and Environment Program Leader, LLNL
Richard P. O'Toole, Executive Manager, Legislative and International Affairs, JPL
Karen P. Scott, Manager, Government Relations, Sandia
William J. McLean, Director Emeritus, Combustion Research Facility, Sandia

Appendix D: Biographies

PRINCIPAL AUTHORS

PATRICK WINDHAM
Principal
Windham Consulting

Windham is a California-based consultant on science and technology policy issues. He is a principal in Technology Policy International, a five-person firm that analyzes technology policies and policy trends for international clients. He also operates his own firm, Windham Consulting, which focuses on how federal, state, and regional technology policies can promote national and regional economic growth. Mr. Windham also is a Lecturer in the Public Policy Program at Stanford University.

From 1984 until 1997, Mr. Windham served as a Senior Professional Staff Member for the Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, United States Senate. His work there focused primarily on policies to strengthen U.S. industrial competitiveness. He assisted Senator Ernest Hollings (D-SC) in the creation of several initiatives, including the Commerce Department's Manufacturing Extension Partnership and Advanced Technology Program. He worked in other U.S. Senate positions from 1976 to 1978 and from 1982 to 1984.

Mr. Windham received an A.B. from Stanford University and a Masters of Public Policy from the University of California at Berkeley.

MICHAEL R. DARBY
Warren C. Cordner Professor of Money and Financial Markets
John E. Anderson Graduate School of Management
University of California, Los Angeles

Darby is the Warren C. Cordner Professor of Money and Financial Markets in the John E. Anderson Graduate School of Management and in the Departments of Economics and Policy Studies at the University of California, Los Angeles, and is Director of the John M. Olin Center for Policy in the Anderson School. Concurrently, he holds appointments as Chairman of The Dumbarton Group, Research Associate with the National Bureau of Economic Research, Consulting Economist with City National Bank, and Adjunct Scholar with the American Enterprise Institute. He also serves as Associate Director for the Center for International Science, Technology, and Cultural Policy in the School of Public Policy & Social Research at UCLA.

Dr. Darby served in a number of positions in the Reagan and Bush administrations including Assistant Secretary of the Treasury for Economic Policy (1986-89), member of the National Commission on Superconductivity (1988-89), Under Secretary of Commerce for Economic Affairs (1989-92), and Administrator of the Economics and Statistics Administration (1990-92).

He received his A.B. summa cum laude from Dartmouth College, and his M.A. in 1968 and Ph.D. in 1970 from the University of Chicago. He is the author of eleven books and monographs and over one hundred other professional publications. His many honors include the 1989 Alexander Hamilton Award, the Treasury's highest honor.

LYNNE G. ZUCKER
Professor of Sociology and Policy Studies
Director, Center for International Science, Technology and Cultural Policy
School of Public Policy & Social Research
University of CA, Los Angeles

Zucker is Professor of Sociology (1989-present) and Policy Studies (1996-present) and serves as Director (1996-present) of the Center for International Science, Technology and Cultural Policy in the School of Public Policy & Social Research at UCLA. Concurrently, she holds appointments as Research Associate with the National Bureau of Economic Research, and was previously a consulting sociologist with the American Institute of Physics.

Zucker is the widely cited author of four books and monographs as well as numerous journal and other articles on organizational theory, analysis, and evaluation, institutional structure and process, trust production, civil service, government spending and services, unionization, science and its commercialization, and permanently failing organizations. She serves or has served as Associate Editor or Editorial Board Member for *Administrative Science Quarterly, American Journal of Sociology, American Sociological Review, Pacific Sociological Review*, and *Symbolic Interaction.*

Zucker received her A.B. with Distinction in Sociology & Psychology from Wells College in 1966. She took her M.A. in 1969 and Ph.D. in 1974 from the Sociology Department of Stanford University.

CCST LARGE SCIENCE PROJECT COMMITTEE

MIRIAM E. JOHN, COMMITTEE CHAIR
Vice President, California Division
Sandia National Laboratories

John is currently Vice President of Sandia's California Division. The principal programs of the division, located in Livermore, CA, include nuclear weapons stewardship, weapons demilitarization, chemical/biological weapons defense, combustion and materials research, advanced lithography development, micro-chemical and remote laser based chemical detection, and distributed, secure advanced computational and information systems.

In her previous position as Director of the Center for Exploratory Systems and Development, Dr. John led a multi-disciplinary organization of physical scientists, engineers, mathematicians, and computer scientists whose mission is to undertake major new initiatives for the California Division. Areas of emphasis included WMD non- and counter-proliferation and DOE complex system modeling.

Concurrent with her Sandia assignments, Dr. John has been recruited for a number of defense community efforts. She is a member of the Department of Defense's Threat Reduction Advisory Committee and the National Research Council's Naval Studies Board and Board on Army Science and Technology. She is also a National Associate of the National Academies of Science and Engineering.

She received a B.S. in Chemistry from Rice University, an M.S. in Chemical Engineering from Tulane University, and a Ph.D. in Chemical Engineering from Princeton University.

MICHAEL R. ANASTASIO
Director
Lawrence Livermore National Laboratory

Anastasio is the ninth director to lead Lawrence Livermore National Laboratory (LLNL) since it was founded in 1952. Anastasio began his laboratory career focused on the design, evaluation, and understanding of nuclear systems. As director, he is leading the Laboratory in its mission to ensure national security and apply science and technology to the important problems of our time. LLNL is a principal contributor to the Department of Energy's programs to maintain the U.S. nuclear weapons stockpile and to reduce the international dangers posed by weapons of mass destruction.

Anastasio received a bachelor's degree in physics from Johns Hopkins University and his M.A. and Ph.D. in theoretical nuclear physics from the State University of New York at Stony Brook. His career at Lawrence Livermore began in 1980 as a physicist in B-Division, one of the two nuclear weapons design physics divisions. He later served in Washington as a scientific adviser at the Department of Energy, providing advice to senior members of the department on a variety of Stockpile Stewardship Program issues.

He is the recipient of the 1990 DOE Weapons Recognition of Excellence Award for technical leadership in nuclear design. He is also a member of Sigma Pi Sigma, the national physics honor society.

LINDA COHEN
Professor of Economics
University of California, Irvine

Cohen is Professor for the Department of Economics at UC Irvine. She received an A.B. from UC Berkeley in Mathematics and in 1979, a Ph.D. from the California Institute of Technology in Social Sciences. Her fields of study are political economy, government regulation, government policy for science and technology, and positive political theory and law.

Dr. Cohen has held positions at the Brookings Institution, the Kennedy School of Government, Harvard University, and the Rand Corporation. She was the 1998 Olin Visiting Professor in Law and Economics, USC Law School and is a member of the Irvine Research Unit in Mathematical Behavioral Sciences at the University of California, Irvine.

Dr. Cohen is the coauthor of "The Technology Pork Barrel" and has published many articles on the economics and politics of science and innovation. She has advised numerous federal departments and agencies on science policies, including the Departments of Energy and Commerce, the Office of Technology Assessment and the Congressional Research Service and has served on several committees for the National Research Council.

LAWRENCE B. COLEMAN
Vice Provost for Research
University of California

Coleman is the Vice Provost for Research for the University of California and Professor of Physics at UC Davis. He served as Chair of the University-wide Academic Senate in the 1999-2000 academic year following a year as vice chair of the UC Senate during the 1998-1999 academic year. Arriving at Davis in 1976, he was promoted to Associate Professor in 1982. While at the University of California, Davis he has held the positions of Chair, Davis Division of the Academic Senate, 1995 - 1997; Director, The Internship and Career Center, 1988 - 1994; Acting Vice Provost - Academic Programs and Dean - Undergraduate Studies, 1991-1992; and Acting Associate Vice Chancellor - Academic Programs, 1990-1991.

Lawrence Coleman received a Ph.D. from the University of Pennsylvania in 1975 in experimental condensed matter physics He received a B.A. in physics from The Johns Hopkins University in 1970. He has been a consultant to the Jet Propulsion Laboratory and the Aerojet General Corporation.

Coleman was elected to membership in the Phi Kappa Phi, Honor Society in 1993. His society memberships include: American Physical Society (life member), Society for Applied Spectroscopy, American Association for the Advancement of Science, American Association of Higher Education, and Sigma Xi.

G. SCOTT HUBBARD
Center Director
NASA Ames Research Center

Hubbard serves as Director of NASA's Ames Research Center in the heart of California's Silicon Valley. Prior to his appointment, Hubbard was the Deputy Director for Research at Ames. In March of 2000, Hubbard was called to NASA Headquarters, where he served as the first Mars Program Director and successfully restructured the entire Mars Program.

Some of Hubbard's previous roles include the Ames Associate Director for Astrobiology and Space Programs; first Director of NASA's Astrobiology Institute, and Manager of the Lunar Prospector Mission. He is also credited with creating the Mars Pathfinder Mission. Prior to coming to Ames in 1987, Hubbard was Vice President and General Manager of Canberra Semiconductor and a Staff Scientist at Lawrence Berkeley National Laboratory.

Mr. Hubbard received a B.A. in Physics and Astronomy from Vanderbilt University and conducted graduated studies in Semiconductor Physics at UC Berkeley. He has been awarded five NASA Medals: three times the Outstanding Leadership Medal and twice the Exceptional Achievement Medal, and has twice been awarded Laurels by Aviation Week. Hubbard was elected to the International Academy of Astronautics, is a Fellow of the American Institute of Aeronautics and Astronautics and is the author of more than 40 papers on space missions and related technology.

JOHN P. MCTAGUE
Professor of Materials
University of California, Santa Barbara

McTague is professor of materials at the University of California, Santa Barbara. He served as president of laboratory management for the University of California, Office of the President, and was responsible for the management oversight of three national laboratories for the U.S. Department of Energy and the National Nuclear Security Administration.

McTague was founding co-chair of the Department of Energy National Laboratory Operations Board and a member of the Secretary of Energy Advisory Board from its inception in 1990 through 2000.

Prior to 1986, McTague served as deputy director and acting director of the White House Office of Science and Technology Policy. During the Bush administration, he was a member of the President's Council of Advisors on Science and Technology.

A physical chemist, McTague received his undergraduate degree with honors in chemistry from Georgetown University in 1960 and his Ph.D. from Brown University. Brown also bestowed on him an honorary Sc.D. in 1997.

Dr. McTague is a member of the National Academy of Engineering and a fellow of the American Physical Society and the American Association for the Advancement of Science. He has received the California Section Award of the American Chemical Society and the Pake Prize from the American Physical Society.

ANNEILA SARGENT
Professor of Astronomy
Director of the Owens Valley Radio Observatory
California Institute of Technology

Sargent is professor of astronomy at the California Institute of Technology (Caltech), director of Caltech's Owens Valley Radio Observatory, and director of the Combined Array for Research in Millimeter-wave Astronomy (CARMA). She received her B.Sc. with honors in physics from the University of Edinburgh (1963), and her Ph.D. in astronomy from the California Institute of Technology (1977). She was named associate director of Owens Valley Radio Observatory in 1992 and director in 1996. She has been a professor of astronomy since 1998 and is now the first director of CARMA.

In 1988, Professor Sargent was the California Institute of Technology's 1988 "Woman of the Year." She was awarded the NASA Public Service Medal in 1998 and named an associate of the Royal Astronomical Society in 2001.

Sargent has served on a wide variety of national advisory committees, including the National Research Council (NRC) Committee on Astronomy & Astrophysics and the NSF's Mathematical and Physical Sciences Advisory Committee. From 1994 to 1998, she chaired NASA's Space Science Advisory Committee and was a member of the NASA Council. She was president of the American Astronomical Society between 2000 and 2002. Currently, she is vice chair of the NRC's Board on Physics and Astronomy.

Appendix E: California Council on Science and Technology

2005 — 2006 BOARD MEMBERS

Karl S. Pister, Board Chair
Former Vice President-Educational Outreach, University of California
Chancellor Emeritus, University of California, Santa Cruz

Bruce M. Alberts **
Professor of Biochemistry and Biophysics
University of California, San Francisco

Lloyd Armstrong, Jr. *
Emeritus Provost, University of Southern California

Warren J. Baker
President, California Polytechnic State University, San Luis Obispo

Arthur Bienenstock
Vice Provost and Dean of Research and Graduate Policy and Professor of Materials Science and Engineering, and Applied Physics
Stanford University

Steven Bruckman
Executive Vice Chancellor and General Counsel, California Community Colleges

Bruce B. Darling
Senior Vice President, University Affairs, University of California

John S. Foster, Jr.
Consultant, Northrop Grumman Space Technology

David L. Goodstein
Vice Provost and Frank J. Gilloon Distinguished Teaching and Service Professor
California Institute of Technology

Susan Hackwood
Executive Director, California Council on Science and Technology

Charles E. Harper
Executive Chairman, Sierra Monolithics, Inc.

C. L. "Max" Nikias **
Provost, University of Southern California

Lawrence T. Papay
Council Chair, CCST
CEO and Principal, PQR, LLC

Robert J. Spinrad
Retired Vice President, Technology Strategy
Xerox Corporation

Cornelius W. "Neal" Sullivan
Council Vice Chair, CCST
Vice Provost for Research and Professor of Biological Sciences, University of Southern California

Carol Tomlinson-Keasey
Chancellor, University of California, Merced

* Member until December 31, 2005
** Appointed to Board January 1, 2006

2005 -2006 COUNCIL MEMBERS

Lawrence T. Papay, *Council Chair,* CCST
CEO and Principal, PQR, LLC

Cornelius W. "Neal" Sullivan, *Council Vice-Chair,* CCST
Vice Provost for Research, University of Southern California

Michael R. Anastasio, *Director,* Lawrence Livermore National Laboratory

David Auston, *President*, Kavli Foundation

Francine Berman, *Director,* San Diego Super Computer Center, University of California, San Diego

Alfonso Cárdenas, *Professor of Computer Science*, University of California, Los Angeles

Arthur N. Chester, *Retired President and General Manager,* HRL Laboratories, LLC

Michael T. Clegg, *Donald Bren Professor of Biological Sciences,* University of California, Irvine

Linda R. Cohen, *Professor of Economics*, University of California, Irvine

Lawrence B. Coleman, *Vice Provost for Research,* University of California

France A. Córdova, *Chancellor,* University of California, Riverside

Jean-Louis Gassée, *General Partner,* Allegis Capital

Milton Gordon, *President*, California State University, Fullerton

Ginger Graham, *President and CEO,* Amylin Pharmaceuticals

M.R.C. Greenwood, *Professor of Nutrition & Internal Medicine*, University of California, Davis

Carlos Gutiérrez, *Professor of Chemistry*, California State University, Los Angeles

Susan Hackwood, *Executive Director,* California Council on Science and Technology

Alice Huang, *Senior Councilor for External Relations*, California Institute of Technology

G. Scott Hubbard, *Center Director,* NASA Ames Research Center

Miriam E. John, *Vice President*, Sandia National Laboratories, California

Charles F. Kennel, *Director,* Scripps Institution of Oceanography, and *Dean and Vice Chancellor of Marine Sciences*, University of California, San Diego

John P. McTague,* *Professor of Materials,* University of California, Santa Barbara

David W. Martin, Jr., M.D.,** *Chairman & CEO,* AvidBiotics Corporation

Tina S. Nova,* *President, CEO and Founder,* Genoptix

Elisabeth Paté-Cornell, *Burt and Deedee McMurtry Professor and Chair,* Department of Management Science and Engineering, Stanford University

Stephen D. Rockwood,** *Executive Vice President*, Science Applications International Corp.

Stephen J. Ryan, **M.D.**, *Professor of Ophthalmology*, Keck School of Medicine, and *President,* Doheny Eye Institute, University of Southern California

Pamela Samuelson,** *Professor of Information Management & Systems*, University of California, Berkeley

Anneila Sargent, *Director,* Owens Valley Radio Observatory, California Institute of Technology

Andrew Viterbi, *President*, Viterbi Group, LLC

Max T. Weiss, *Retired Vice-President and General Manager,* Northrop Grumman Corporation

* Member until December 31, 2005
** Appointed to Council January 1, 2006

Credits

CCST Executive Director:
Susan Hackwood

Project Authors:
Patrick H. Windham, Principal Author
Michael R. Darby
Lynne G. Zucker

Project Writers and Editors:
M. Daniel DeCillis, Research Associate
Susan Turner-Lowe, Media Relations Consultant
Donna Gerardi Riordan, Director of Programs

CCST Staff:
Annzell Loufas, Sacramento Office Director
Susan M. Harris, Document Production
Donna King, Project Support
Erik A. Mattila, Graphic Artist
Christina Ramirez-Rios, Project Support

Printer:
Crystal Printing, Sacramento, California

SACRAMENTO OFFICE:
California Council on Science and Technology
1130 K Street, Suite 280
Sacramento, CA 95814
(916) 492-0996 (telephone)
(916) 492-0999 (fax)

RIVERSIDE OFFICE:
California Council on Science and Technology
5005 La Mart Drive, Suite 105
Riverside, CA 92507
(951) 682-8701 (telephone)
(951) 682-8702 (fax)
E-MAIL: ccst@ccst.us

INTERNET: http://www.ccst.us