The Future of the DOE National Laboratories

CROs of the National Laboratory Director's Consortium

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Executive Summary

The 17 national laboratories of the U.S. Department of Energy (DOE) play a critical role in the nation's research and development (R&D) enterprise. These laboratories have historically taken on large-scale, long-term, high-risk R&D challenges that are beyond the scope of industry or universities. Functioning as an interdependent system with an exceptional set of distinctive capabilities and world-leading facilities, they have delivered the science and technology (S&T) needed to solve problems of national importance, beginning with a focused effort to develop the nuclear weapons that ended World War II and expanding to produce a host of scientific discoveries and technology innovations in support of DOE's overarching mission of advancing the national, economic, and energy security of the United States. They work in partnership with universities and industry, transfer the results of their R&D to the marketplace, and support the training of the future science and engineering workforce.

It is increasingly clear that transformational science and breakthrough technologies will be needed to overcome the complex and interlocking challenges that we face as a nation in the 21st century: addressing environmental issues such as climate change while increasing the availability of clean, reliable, and affordable energy; ensuring our national security in a changing world; improving human health; and enhancing U.S. competitiveness by encouraging innovation. The DOE national laboratories are uniquely equipped and positioned to make substantial contributions to the execution of a balanced federal R&D strategy by a strategically focused U.S. research enterprise. However, to ensure the continuing vitality of the national laboratories, several actions must be taken:

- Ensure the national laboratories, individually and as a system, have a focus and missions that are aligned with compelling challenges of national importance.
- Update the governance model of the national laboratories to take into account the nature of today's research challenges and the emergence of a new U.S. R&D paradigm.
- Make the necessary investments in research, infrastructure, and education at the national laboratories as part of a program of broad investments across the U.S. research enterprise, to keep the nation at the forefront in S&T.
- Strengthen partnerships between national laboratories and both Universities and Industry, and facilitate technology transfer to take full advantage of the knowledge and technology produced by the national laboratories.

Introduction

Science and technology (S&T) can have a substantial impact on many of the complex and interlocking challenges that we face as a nation in the 21st century. These challenges include addressing environmental issues such as climate change while increasing the availability of clean, reliable, and affordable energy; ensuring our national security in a changing world; improving human health; and enhancing U.S. competitiveness by encouraging innovation. They are outlined in two pivotal National Academies reports—*Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (2002) and *Rising Above the Gathering Storm, Energizing and Employing America for a Brighter Economic Future* (*RAGS*, 2007)—and in the National Quadrennial Defense Review, the Department of Defense (DoD) Strategic Research and Development (R&D) Plan, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, and the Grand Challenges developed by the National Academy of Engineering (see Appendix A).

It is clear that success in meeting our 21st century challenges is predicated on a balanced federal research and development (R&D) strategy and a strategically focused U.S. research enterprise—consisting of universities, industry, and national laboratories—that actively engages in open scientific exchanges and provides leadership in the global community. Maintaining such a research complex in turn requires the availability of a highly skilled science, technology, engineering and mathematics (STEM) workforce.

The U.S. Department of Energy (DOE), as the Nation's fourth largest federal R&D agency, has a leading role in addressing many of these challenges. DOE's mission (as described in Appendix B) spans energy security, nuclear security and nonproliferation, environmental cleanup, and scientific discovery and innovation. Integral to DOE's execution of this mission are its 17 national laboratories. These laboratories comprise a system, unique in the world, that was created and is supported by the federal government to carry out essential national scientific and technical functions that cannot be accomplished in a purely academic or commercial environment because of their scale (in time, size, or complexity) and/or because of security restrictions. DOE laboratories work with industry to apply the outcomes of their research efforts to strengthen overall U.S. industrial competitiveness and collaborate with the academic community to conduct research and to provide research and learning opportunities for faculty and students to further U.S. STEM workforce development.

The national laboratories function as an interdependent system. They act as partners in bringing their resources to bear on understanding and solving problems of national importance, while simultaneously competing to provide the best S&T to address those problems. This competition is at the very heart of the creativity of the national laboratories and depends critically upon the concept of peer review. National laboratory researchers working in unclassified areas are part of the global S&T community and their work is subjected to rigorous peer review, similar to their colleagues at universities and other research institutions. Even in classified areas, a strong culture of peer review ensures that ideas are challenged critically before implementation.

The national laboratory system served the nation exceedingly well in the 20th century. The challenges that we face in the 21st century are more complex and interdependent, and thus the need for the system to function at the highest possible level is more important than ever.

Historical Perspective

The national laboratory system grew out of the Manhattan Project during World War II. To address a critical national need—winning the race with Nazi Germany to develop the atomic bomb—required large teams of talented scientists and engineers, working together in a secure environment to pursue the underlying fundamental science, develop the technologies, and apply the knowledge to develop these new weapons. Facilities were established at several locations, some near leading universities and others in very remote areas for reasons of security and public safety. These facilities, which came to be known as Federally Funded Research and Development Centers (FFRDCs), were owned by the U.S. government; however, they were managed and operated by contractors (typically industrial, academic, or nonprofit organizations). This government-owned/contractor-operated (GOCO) approach was chosen because it provided for maximum flexibility in the management of the laboratories and for the recruitment of the nation's best scientists and engineers.

Following the end of World War II, the national laboratories were charged with supporting the development of civilian nuclear energy in addition to the design and development of nuclear weapons. Accordingly, R&D at the national laboratories centered on nuclear energy and related research in the physical and life sciences and engineering, the processing of nuclear waste, nonproliferation of nuclear materials worldwide, understanding of weapons effects and detection of remote nuclear tests, advancement of micromechanical systems and radiation-hardened electronics for diagnostics and weapon systems, and environmental cleanup of the nuclear sites. The breadth of activity led to many "spinoffs"; for example, the use of computers to track and predict fallout from atmospheric nuclear tests provided the basis for today's global atmospheric circulation models (climate models).

As the challenges facing the nation evolved, the system of national laboratories evolved as well, always focusing on long-term U.S. government needs with substantial S&T content, often with complex security, safety, project management, and other operational challenges. In response to the energy crises of the 1970s, the national laboratories were charged with conducting fundamental and applied R&D on a variety of energy sources; in the 1980s, national laboratory capabilities in biological and environmental research and in computing and computational science were leveraged to initiate the Human Genome Project. The continuing need for a science-based understanding of complex phenomena, and the resulting desire for fundamental knowledge, led to development of the broad S&T enterprise and the large-scale experimental and computational tools available at the national laboratories today. From the beginning, much of the R&D effort

at the national laboratories has fallen at the intersection of traditional fields of science and engineering, affording unique opportunities for innovation.

Use of the GOCO approach, with a management and operation (M&O) contract establishing the terms of the partnership between the government and a contractor, has endured at the national laboratories. However, a contract reform effort initiated in the 1990s has brought a number of changes to the GOCO model and to laboratories. During the past decade, M&O contracts for many national laboratories were opened to competition for the first time. Today, all contracts for national laboratories are awarded on a competitive basis.

Practical Applications of National Laboratory R&D Achievements

Research activities at the national laboratories have resulted in ideas and discoveries with far-reaching impacts; overall, work sponsored by DOE and its predecessor agencies at national laboratories and universities has led to 87 Nobel Prizes for scientific research. The application of research results and the derivative impacts of the technologies needed to perform the research have resulted in a number of practical applications; a few examples are presented below.

Industry: Energy generation, power transmission, semiconductor manufacturing, and biomedicine and drug development

The national laboratories have been directly involved in developing many energy technologies that are in use or near use today. Commercial nuclear power plants were developed from prototype reactors designed and constructed by the national laboratories in conjunction with companies such as GE and Westinghouse. A National Research Council analysis of advances in energy and environmental technologies that were developed from 1978 to 2000 by the national laboratories in collaboration with industry (e.g., buildings technologies and emissions controls for large utility boilers) concluded that the benefits from these programs exceeded $30B in net energy efficiency savings and $60B in environmental benefits. An emerging example is the development of advanced materials that could replace underground copper transmission lines or power cables, which are near their capacity in many densely populated areas. Cables based on these high-temperature superconductors, with their greater capacity and lower power losses, offer an opportunity to meet continued demand with higher reliability—a crucial element of the electric grid of the future. Biomedical scientists use particle physics technologies to decipher the structure of proteins; this information is a key to understanding biological processes, curing disease, and developing more effective drugs such as Kaletra, one of the world's most frequently prescribed drugs to fight AIDS. The need for ultraclean manufacturing for nuclear weapons led to the development of the laminar flow clean room, now an essential tool for all of modern semiconductor manufacturing and for many other areas, including medicine.

High-performance computing

The end of nuclear weapons testing in the early 1990s led to the science-based Stockpile Stewardship Program and the need for vastly improved capabilities for simulating the physics and materials processes relevant to weapons performance and aging. The national laboratories, in partnership with U.S. industry, generated a million-fold enhancement of scientific computation and simulation, dramatically reducing the cost of high-performance computing (HPC), creating a world-leading U.S. commercial capability, and enhancing the ability to simulate real materials at scale. The expanded availability of HPC is creating a revolution in the design of sophisticated industrial material parts, such as airplane wings and automobile tires, and in the selection of drug targets by the pharmaceutical industry. A similarly demanding R&D effort is now required to create quantitative predictive models of regional climate under specified scenarios to inform policy decisions.

Tools for science

The need for fundamental breakthroughs in science has driven the development of new research tools: large particle accelerators, synchrotron light sources, research reactors and spallation neutron sources, X-ray lasers, the first genome sequencing institute, large machines for studying magnetically confined plasmas as a pathway to fusion energy, and the world's largest pulsed-power accelerators and lasers for high energy density physics and for inertial confinement of plasmas as another pathway to fusion energy.

Particle physicists originally built electron accelerators to explore the fundamental nature of matter, and synchrotron radiation was a nuisance energy loss. Over time, synchrotron radiation was recognized as a uniquely powerful tool, and now at synchrotron light sources around the world, researchers use the ultrapowerful X-ray beams for basic energy research, protein structure analysis, pharmaceutical research and drug development, real-time visualization of chemical reactions and biochemical processes, materials science, semiconductor circuit lithography, and historical research and the restoration of works of art.

Medicine: Cancer therapy and diagnostic instrumentation

The nuclear reactor constructed to demonstrate the production of plutonium for the Manhattan Project was also used to produce radioisotopes for medical applications, launching a long-term program of leveraging national laboratory resources to improve human health. Today, major medical centers use accelerator-produced X rays, protons, neutrons, or heavy ions for the diagnosis and treatment of disease. DOE physicists and engineers built the nation's first proton accelerator for cancer therapy, now located at the Loma Linda University Medical Center, where some 7,000 patients have been treated. Particle accelerators and detectors have become ubiquitous in medical imaging; positron emission tomography (PET) scans have joined other physics-based medical imaging techniques. The scale of DOE's accelerators supported the cost-effective production of superconducting magnets, which in turn enabled the technology for magnetic resonance imaging (MRI). Around the world, accelerators have been used to treat an estimated 30 million patients.

Homeland security: Monitoring nuclear nonproliferation

The national laboratories have developed variety of technologies for responding to homeland security issues, from nuclear smuggling to bioterrorism to attacks on the electrical grid. A detector developed for basic research in nuclear physics, which takes advantage of differences in the antineutrino emissions of plutonium and uranium, is being adapted for use in the field for nuclear nonproliferation monitoring.

Defense complex cleanup: Environmental management

Many first-of-a-kind facilities and technologies have been developed to clean up the unique hazards presented by the nuclear weapons production complex. For example, the Defense Waste Processing Facility for immobilization of high-level waste (HLW) incorporates a range of technologies, from feed preparation to decontamination of the canisters containing the HLW glass, that could not have been developed easily by commercial vendors unfamiliar with handling such types of waste, particularly at this scale. The Waste Isolation Pilot Project has brought together strengths in design, technology, risk analysis, waste acceptance process development, and operation to create the nation's first geologic repository that is now routinely accepting waste.

The National Laboratory System Today

The DOE laboratory system is unmatched in the world in its breadth, its capacity for world-class, large-scale, multidisciplinary R&D, its cutting-edge research facilities, and its world-leading computational capabilities. DOE's 17 national laboratories, while diverse in expertise, focus, size, and location, operate as an integrated system that provides core research capabilities and competencies (ideas, people, and tools) for tackling science-intensive, large-scale, long-term, team-oriented, interdisciplinary undertakings of great national importance. These undertakings typically require large facilities and often involve the control of significant hazards or require protection of classified information.

The national laboratory complex is an important component of the broader research enterprise that also includes universities and industrial research laboratories. While there is overlap, universities generally provide their researchers with the freedom to pursue activities driven by their individual curiosity and academic interests, and industrial laboratories take scientific discoveries and turn them into valuable products. Collaboration and communication between the researchers in each part of the enterprise ensure that the strengths of each model are exploited to maximum benefit, such use by researchers from universities, industrial laboratories and national labs of the unique user facilities hosted at national laboratories.

Functions and characteristics

The national laboratories conduct a broad range of R&D, primarily for DOE but also for other federal agencies and for other sponsors, both public and private. They conceive, construct, and operate distinctive scientific facilities that are shared with the international

scientific community; these national user facilities, which are available at no cost to scientists who plan to publish the results of their experiments in the open literature, were used by more than 21,000 researchers in 2007. The national laboratories also transfer the knowledge and technology that are the products of their R&D to the private sector and actively support the education of the next generation of scientists, engineers, technicians, and educators through programs for students and faculty at all academic levels.

Many of the capabilities maintained by the national laboratories are those deemed critical by the federal government and to which the federal government desires assured access. Other capabilities result from the co-location of resources that together offer otherwise unattainable science and from the laboratories' capacity for assembling and deploying multidisciplinary teams to attack complex challenges. (For additional information on the distinctive characteristics of the national laboratory system, see Appendix C.)

Through interactions with each other and with academia and industry, the laboratories focus their diverse capabilities and competencies on key programs and activities. This capacity for integration has resulted in many scientific successes; recent examples include multilaboratory efforts to design and build the Spallation Neutron Source, to establish and manage the Joint Genome Institute, to launch and administer the Atmospheric Radiation Monitoring (ARM) program, and to support the FreedomCAR Partnership for cooperative automotive research.

The FreedomCAR Partnership also demonstrates the ability of the national laboratories to collaborate with industry. Various mechanisms are available to enhance the nation's economic competitiveness by focusing the unique facilities and capabilities of the laboratory system on issues germane to the marketplace. These mechanisms range from Cooperative R&D Agreements (CRADAs) and Work for Others (WFO) agreements, through which industry can fund research at the national laboratories, to the interactions that take place when industry researchers make use of national user facilities and the licensing of technologies developed at the laboratories to the private sector.

Universities partner with the national laboratories not only through traditional R&D collaborations and academic use of national user facilities, but also through joint appointments of scientists to faculty positions and laboratory research posts and through a variety of programs designed to provide research and educational opportunities to faculty and students at all levels, from undergraduate to postdoctorate.

The national laboratories look to both the academic community and the industrial enterprise for insight on the priority of challenges to be addressed and for potentially applicable ideas. This insight is gained through scientific collaborations, input on the conception and design of scientific user facilities, workshops, and peer review.

Through these collaborations and interactions with the broader research community, both domestically and internationally, the national laboratories are engaged across the spectrum from fundamental science to technology development and deployment. Such

collaborations and integration across multiple laboratories, with academia, and with industry are vital in addressing the challenges that we face.

National Laboratory Management Model

As noted earlier, the GOCO model was originally selected for the national laboratories because it afforded the flexibility needed in managing scientific institutions that must be able to attract world-class scientific talent and adapt quickly to changing national research priorities and advances in S&T. The consistent recognition of the DOE laboratories as world-leading research institutions, with records of sustained scientific excellence and critical contributions to the nation's security, has been cited as an indication of the success of the GOCO model.

The GOCO approach represents a partnership between the government and the private sector: DOE enters into M&O contracts with universities, nonprofit organizations, and industrial organizations.[1] Contractors are expected to bring the best private-sector personnel and research management practices to the national laboratories and to broadly engage academia and industry. The effectiveness of the model is maximized when DOE specifies the mission and goals (the "what") and the contractor determines the best means to achieve them (the "how"). Contractor performance is evaluated at least annually, and most M&O contracts now include "award term" provisions to permit contract extension as an incentive for superior performance.

The National Laboratory Directors' Council (NLDC)

The *National Laboratory Directors' Council (NLDC)* is an organization recently formed by the Laboratory Directors from each of the seventeen DOE National Laboratories. The NLDC seeks to promote advances in the various DOE missions, increase the effectiveness of DOE and the National Laboratories through collaboration and coordination on high-level, strategic issues and concerns of broad interest, and provide a forum for presenting consensus views on matters that affect the participants effective and efficient mission execution. The NLDC is one mechanism for coordinating the interactions across the whole DOE laboratory complex.

A subset of four NLDC members comprise an Executive Committee that organizes and coordinates the activities of the NLDC and meets routinely with the Secretary of Energy and DOE senior management to identify, discuss and resolve issues on behalf of the NLDC. The four person Executive Committee consists of a Spokesperson, and one Director each from an NNSA Laboratory, a Multi-program Laboratory, and a program-dedicated Laboratory.

The NLDC also has three Working Groups. The Chief Research Officers (CRO) Working Group advises the NLDC on scientific and programmatic issues, serving as a forum for communication and coordination of the major activities related to the strategic

[1]One national laboratory, the National Energy Technology Laboratory, is both government-owned and government-operated.

direction for the laboratories. The Chief Operations Officers (COO) Working Group advises the NLDC on issues and improvement opportunities related to the management and operation of the National Laboratory infrastructure. The COO evaluates resource impacts of administrative and regulatory requirements to facilitate productive and cost-effective utilization of the DOE laboratory system; promotes practices based upon performance-based management; and shares best practices and lessons learned. The Chief Information Officers (CIO) Working Group advises the NLDC on issues related to computing and information processing. They serve as a forum for communication and coordination of the major activities in scientific computing and information processing throughout the DOE National Laboratories.

The Current Research Landscape

Over the past several decades, the U.S. R&D enterprise has experienced dramatic changes in the way research is performed and supported. In response to competitive pressures in the global marketplace, the great industrial laboratories of the 20th century have reoriented their research portfolios to emphasize near-term development. (The vast majority of the estimated $265.2 billion of R&D performed by U.S. industry in 2007 was development.) Basic research is increasingly funded by the federal government and performed by universities and national laboratories.

The decline in long-term research in industry has been only partially offset by individual investigator research at universities and larger scale mission-related research at national laboratories. In addition, research has become increasingly dependent on the large-scale facilities developed and operated by the national laboratories for the broader scientific community, including the ultrascale computing power available through DOE.

In many respects, the U.S. S&T enterprise today is in a position of unprecedented opportunity. The nation's university research system is the envy of the world. The U.S. network of national laboratories is unmatched in its capacity for carrying out sustained research on complex, multidisciplinary challenges and for developing and operating major research facilities. Effectively utilized and supported, these strategic assets can ensure continued U.S. leadership in science and technology.

On the other hand, cracks are beginning to appear in the U.S. R&D enterprise. The nation's dominance in scientific publications is beginning to erode, and investments in R&D infrastructure at universities and national laboratories have not kept pace with the state of the art. Europe and Japan have become major R&D competitors in all areas, and China is investing heavily in R&D. In addition, the U.S. public education system, once renowned, is failing to keep pace with the rest of the developed world in STEM education. Unaddressed, these developments place at risk the nation's ability to compete effectively in the 21st century.

The globalization of S&T is not a zero-sum game. Indeed, the global increase in R&D offers opportunities for the United States as well as the rest of the world; all would gain

from the pursuit and sharing of fundamental research results. The question is the extent to which the nation will be able to sustain its innovation economy in the face of global R&D competition. This will require leadership in basic research across the board, the ability to tackle the large-scale interdisciplinary research challenges that underpin technology, and access to the best possible research facilities. The United States has these capabilities today in its universities and national laboratories. To assure that the U.S. research enterprise and particularly the national laboratory system continue to provide value to the nation, DOE and its national laboratories should:

- Focus on addressing inherently governmental, complex, long-term, or high-hazard missions that warrant multidisciplinary teams over long periods of time.
- Conduct R&D of the highest caliber that is peer-reviewed and open, as allowable, to help couple the laboratories to each other and to the global S&T community.
- Develop and operate facilities needed for federal missions, and continue to make these unique capabilities available to other researchers.
- Pursue fundamental knowledge and the technological development that naturally follow from the development and application of these capabilities.
- Strive to remain agile to meet the changing missions and needs of the federal government and be responsive to emergent national issues that may be vital or otherwise inherently governmental (i.e., acting as an honest broker/objective observer). Examples include providing a neutral testing strategy for DHS on protocols and first responder devices and conducting independent peer review and “red team” reviews for classified programs.
- Reach out to other organizations to leverage DOE resources in solving national problems. Examples include providing R&D support to federal agencies such as DHS, DoD, and the intelligence community; working with the State Department and the International Atomic Energy Agency on nonproliferation; and supporting civilian nuclear power R&D, nuclear waste recycling, and scientific diplomacy.
- Use unique facilities and capabilities to assist researchers in playing an active role in the education of the future STEM workforce.

Supporting the education of the future STEM workforce is a natural and appropriate use of the DOE national laboratories. Basic science is a magnet that attracts inquisitive and capable students and has a profound influence on the workforce. A small fraction of those who complete their doctoral degrees ultimately pursue careers in basic research. Others find their way to industry, national defense, information, finance, and other fields that require highly developed analytical technical skills, the ability to work in large teams on complex projects, and creative thinking to solve unique problems. These skills are all common to the working environments at the national laboratories, and the laboratories, with more than 12,000 Ph.D. researchers and a collection of distinctive research facilities, must continue and expand their supporting role in training the next generation of scientists and engineers by providing research opportunities to faculty and students at all levels.

Path Forward

The DOE laboratory system represents a vital asset for the basic and applied research that can address not only today's challenges, but also those that may arise in the future. The solutions to our hardest problems often lie outside our best contemporary understanding and require profoundly new approaches. We can and should look to the capabilities and human resources of the national laboratories, especially when coupled with the assets of university and industrial partners, for these new approaches.

However, meeting the challenges and capitalizing on the opportunities requires:

- providing a focus and missions for the national laboratory system that are aligned with compelling challenges of national importance,
- reaffirming and refining the national laboratory management model to ensure agility,
- making the necessary investments in research, infrastructure, and education to maintain U.S. leadership in S&T, and
- strengthening partnerships and collaborations across the laboratories and with external partners.

Providing a focus and missions for the 21st century

The complex and interlocking problems of national security, energy security, health and environmental issues, and economic competitiveness call for a significant and sustained R&D effort. In particular, meeting the global energy challenge—broadly defined as providing sufficient energy to support higher standards of living for a growing fraction of the world's growing population, without creating intractable conflict over resources or irreparable harm to our environment—will require transformational advances in both science and technology and continued pursuit of fundamental scientific knowledge.

These advances can be made only through a sustained commitment to large-scale, multidisciplinary R&D that leverages the capabilities of the entire S&T enterprise. The DOE national laboratories are uniquely positioned to lead the world in the critically important "mission science" and "high-risk technology" components of the challenges outlined in Appendix A. In fact, much of their current portfolio is focused on delivering the substantial advances in the state of the art in energy generation, distribution, and end use that will be needed to meet this challenge. However, a comprehensive, long-term national energy strategy developed collaboratively by DOE (including the national laboratories), Congress, academia, industry, and other stakeholders is critically needed to underpin this focus. Part of this strategy will be development of specific roadmaps to attack the challenges in Appendix A, mapping activities to ensure the interrelations and dependencies are clear, and supporting the capabilities across our entire research enterprise, including at the national laboratories, to pursue these activities.

To accelerate the delivery of solutions to this and other challenges, DOE and Congress should clarify the missions of the national laboratories and ensure continuing support for the S&T base needed to execute the missions. The focus of the laboratories on mission-based S&T should be sustained and strengthened as necessary, keeping in mind the critical importance of fundamental scientific research in providing the basis for

development of new technological approaches and leading to the discovery of new concepts.

As part of this strategy, DOE should maintain a strong portfolio of laboratories with broad scientific and technological capabilities. Both the national laboratory system and each laboratory must have a viable and compelling long-term vision and strategy, consistent with the unique characteristics of national laboratories in general, the needs of the nation broadly, and the specific strengths of the individual laboratories. The national laboratory system should provide the full range of capabilities needed to deliver on long-term national missions, sustaining both its large multiprogram laboratories with their broad R&D portfolios and its single-program laboratories with their intense focus on specific research areas.

Improving governance

The 20th century model for managing and operating the national laboratories needs to be revisited in light of today's science-intensive challenges and new R&D paradigms. Sustaining and strengthening the agility and innovation potential of the original GOCO approach, while maintaining accountability, is essential to realizing the full potential of the laboratories. DOE must provide clear guidance on performance expectations and direct actionable performance feedback as an essential part of assuring that contractors' management and operation of the national laboratories result in effective stewardship of these essential national assets, the safety and security of those working at the national laboratories and the communities in which they reside, and the appropriate protection of information and materials. As noted earlier, the laboratories function most efficiently when DOE specifies the "what" and the contractors determine the "how."

In the well-established value system of the national laboratories, it is expected that contractors (both managers and employees) must and will subordinate any personal, corporate, or financial return concerns to serve the national interest. This essential ethos has been long in development, yet it is increasingly fragile as we confront the future. It is a commodity that cannot be bought at any price, and losing it could result in a cost that we would ultimately regret. National laboratories need to feel accountable for their important national roles and for superior performance in delivering results. Each institution must be managed with continual improvement in mind, expressed through an unwavering focus on becoming more effective, strengthening scientific and engineering capability, and providing the best value for the federal research dollar. Current trends toward complex GOCO contracts, with large fees and multiple M&O interests, risk driving the national laboratory leadership away from serving the national interest above all.

DOE should revisit its approach to contracting and performance management and the extent of the operational and program oversight that the government imposes, weighing the impact of these elements on the laboratories' ability to attract and retain world-class staff and execute their missions with innovation and agility.

Maintaining U.S. leadership in science

Maintaining U.S. leadership in science, which is widely recognized as critical to sustaining the nation's ability to compete in the global innovation economy, will require investments in research, infrastructure, and education. As the Administration and the Congress grapple with competing national priorities and adjust the federal R&D portfolio, it will be important to strike a strategic balance in support for individual researchers at universities, construction and operation of scientific user facilities that serve the research community as a whole, and large-scale multidisciplinary R&D at the national laboratories to address national challenges. The following factors should be considered in framing the debate:

- National challenges must be viewed strategically, since these problems may take decades to address, are not really appropriate solely for academic researchers, and are by their nature inherently governmental.
- Given the decline of corporate laboratories conducting long-term fundamental research in the physical sciences and engineering, it is incumbent upon the federal government to sustain U.S. scientific leadership in these essential fields.
- As an integral part of the U.S. research enterprise, the national laboratory system must be nurtured and used strategically, building on the laboratories' development and operation of world-leading research facilities, their contributions to advancing ultrascale computing, and their performance of world-leading research that requires a sustained commitment, multidisciplinary teams, and special infrastructure.
- Sustained investment in core laboratory research facilities, instrumentation, and supporting infrastructure, based on performance and peer review, is required to ensure continued U.S. leadership in S&T.
- Independent and authoritative guidance and peer review from government and nongovernment entities are integral to the establishing and performing of the research agenda.

Another important consideration for sustaining U.S. leadership in S&T is making the United States a reliable partner in the international research arena. The scientific opportunities provided by basic research bring together hundreds of scientists from every corner of the globe to work together on experiments and projects all over the world. In particular, both the technical scale and the costs of today's large projects in particle physics (e.g., LHC), nuclear physics, plasma physics (e.g., ITER) and others, put them beyond the reach of any single nation's ability to build or operate. These projects now take shape as international endeavors from their inception, and the scientific collaborations that they enable take on new significance as beacons for free and open exchange among men and women of science of all nations. They offer an inspiring model for expanding scientific cooperation.

The national laboratories are tightly connected to the international research enterprise, but maintaining their relevance and competencies in this emerging era of globalized science and engineering will require more active and intentional international engagement. Along with being discoverers and inventors, we will have to become harvesters of science and engineering, since in the future we will no longer have the monopoly on the best facilities

and universities in the world. Just as major U.S. universities are now locating campuses abroad to attract the best and brightest, so must DOE engage more vigorously on the global scale. For example, as China makes enormous S&T investments in energy, DOE must actively create opportunities for collaboration to ensure that we do not risk technological surprise to our economic detriment. These S&T opportunities will require more open and agile operational models that enable rather than inhibit our laboratories' global engagement.

Strengthening partnerships and technology transfer

The national laboratories are extremely effective when they partner with universities and industry. As advances in science and engineering come increasingly from the national and international university communities, such partnering will be instrumental to remaining at the cutting edge. Partnership includes commercialization activities, collaborative research, and educational collaborations. Mechanisms that enable national laboratories to partner with industry need to be streamlined to incorporate best practices from the private sector, and university partnerships need to be expanded across a broad spectrum of research and educational initiatives, including workforce development.

International trends point to increasing foreign government investments in targeted S&T parks that utilize the strengths of their private and public sectors. DOE has an opportunity to utilize its unique system of laboratories in partnership with universities and industry to accelerate the translation of mission-driven R&D into solutions with positive impacts on both our energy and economic security. This is particularly important for those missions that rely on the private sector for implementation, a general characteristic of the energy area.

Expanding partnerships with universities, thus enabling more students to experience the unique facilities and capabilities within the DOE laboratories, can be an important contribution to "filling the pipeline" of future scientists and engineers. This pipeline will be important not only for the national laboratories, but also for industries and universities. Increased support for internships, fellowships, and programs that open laboratory facilities to students and faculty can have significant positive impacts on the development of the workforce of the future.

Appendix A:
National Challenges in the 21st Century

Two pivotal National Academies reports—*Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (2002) and *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (*RAGS*, 2007)—together with the National Quadrennial Defense Review, the Department of Defense Strategic R&D Plan, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, and the Grand Challenges for Engineering identified by the National Academy of Engineering delineate the major challenges that we face as a nation in the 21st century and outline the role that science and technology will play in meeting them. A partial listing of 21st century challenges for which transformational research and development (R&D) is essential is presented here.

National Security

1. Deterrence of, mitigation of, and recovery after a catastrophic nuclear—or other weapon of mass destruction—event.
2. Securing the homeland against terrorist or disruptive technical (cyber, biological, directed energy, space, …) or economic attacks.
3. Nonproliferation, remote radiation sensing and monitoring, and port monitoring, in parallel with the global resurgence of nuclear power plant construction.
4. Defense of American interests against rogue states and asymmetric threats.

Energy—Environment—Health Security

1. Energy efficiency, carbon management/sequestration, and emissions monitoring technologies.
2. New sustainable, affordable, low-carbon energy technologies and alternative fuels to replace those derived from coal and oil.
3. Stewardship of the Earth's climate system—providing a predictive understanding at a regional level with quantifiable margins of uncertainty to enlighten strategies for mitigation of and adaptation to climate disruptions and to aid in forecasting the effects of and recovering from natural disasters.
4. Sustaining and enhancing the global supply of clean water and food.
5. Affordable health care for all Americans in view of an aging population and increasing probability of pandemics due to global spread of infectious disease.

Economic Security

The *RAGS* report identifies major challenges that the nation faces in the global economic competition of the 21st century: the United States is falling farther and farther behind in maintaining scientific leadership, innovation, high-tech industries, and a world-leading R&D workforce. In addition, the nation's international trade deficits continue to increase as high-tech industry moves abroad. In order to reverse these trends, the United States must have:

1. A scientifically literate general public and a highly skilled workforce with strengths in science, technology, engineering, and mathematics.
2. A balanced, strategic federal R&D portfolio to sustain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life.
3. A highly attractive setting for higher education so that we can recruit, develop, and retain the best graduate students, scientists, and engineers from the United States and around the world.
4. Competitive incentives for on-shore innovation in high-tech industry, such as tax credits for R&D, to provide high-paying jobs.

Appendix B:
Mission of the U.S. Department of Energy

The overarching mission of the U.S. Department of Energy, as described in its 2006 strategic plan, is "Discovering the solutions to power and secure America's future" by advancing the national, economic, and energy security of the United States; promoting scientific and technological innovation in support of that mission; and ensuring the environmental cleanup of the national nuclear weapons complex. The Department's strategic goals to achieve the mission are designed to deliver results along five strategic themes:

- Energy security: Assure a supply of reliable, clean, and affordable energy
- Nuclear security: Maintain the nation's nuclear deterrent, nonproliferation, and other national security programs
- Scientific discovery and innovation: Strengthen U.S. scientific discovery and economic competitiveness and improve quality of life through innovations in science and technology
- Environmental responsibility: Protect the environment by providing a responsible resolution to the environmental legacy of nuclear weapons production
- Management excellence: Enabling the mission through sound management

Appendix C:
The DOE National Laboratories:
Locations and Distinguishing Characteristics*

The national laboratories of the U.S. Department of Energy (DOE) are research and development (R&D) institutions created and authorized by the Federal government to carry out inherently governmental functions involving the well-being and security of our nation in ways that cannot be met by the private or public sector. The 17 DOE national laboratories listed in the table below comprise a system whose broad function is to:

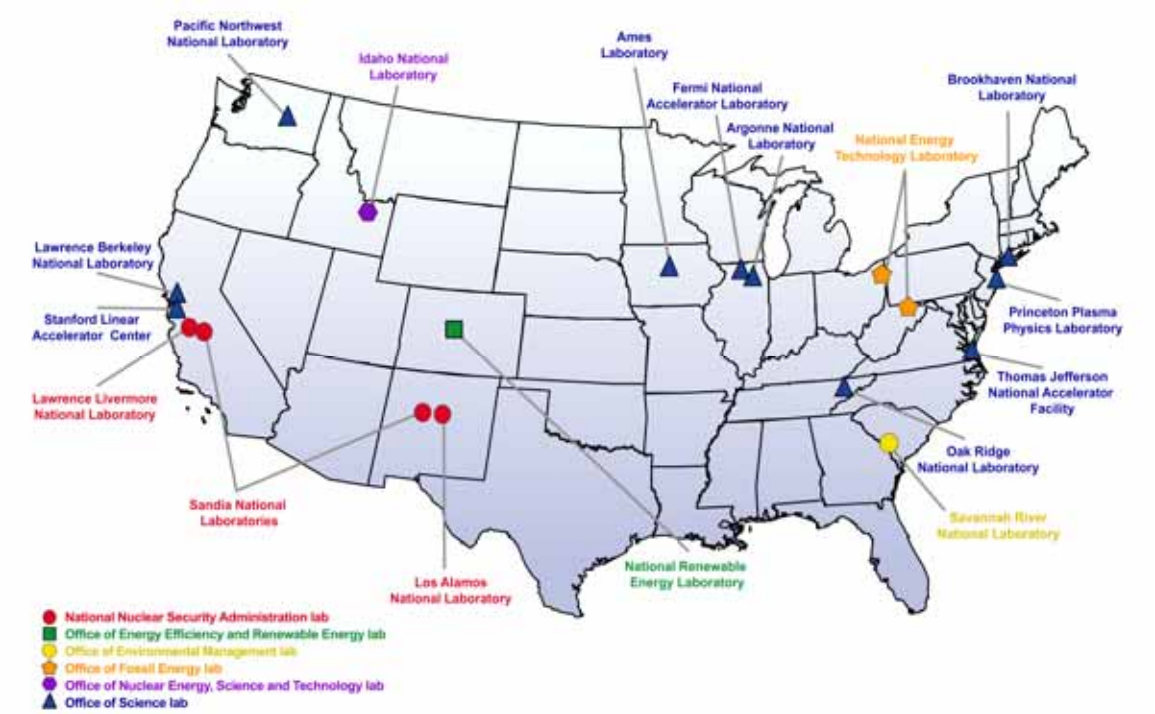
- execute long-term missions with substantial scientific, technological, and classified content,
- develop unique scientific capabilities and facilities that are beyond the scope of academic and industrial institutions, and
- develop and sustain scientific and technical capabilities deemed critical by the government and to which the government desires assured access.

The laboratories support the execution of the DOE mission and other national needs with a broad range of core competencies and capabilities. DOE is vertically organized along the strategic themes through which it delivers on its mission of discovering the solutions to power and secure America's future; however, much of the required supporting science and technology (S&T) cuts across programmatic boundaries.

DOE Programmatic Offices and National Laboratories	
Office of Science	• Ames National Laboratory • Argonne National Laboratory • Brookhaven National Laboratory • Fermi National Accelerator Laboratory • Lawrence Berkeley National Laboratory • Oak Ridge National Laboratory • Pacific Northwest National Laboratory • Princeton Plasma Physics Laboratory • Stanford Linear Accelerator Center • Thomas Jefferson National Accelerator Facility
Office of Nuclear Energy	• Idaho National Laboratory
Office of Fossil Energy	• National Energy Technology Laboratory
Office of Environmental Management	• Savannah River National Laboratory
Office of Energy Efficiency and Renewable Energy	• National Renewable Energy Laboratory
National Nuclear Security Administration	• Lawrence Livermore National Laboratory • Los Alamos National Laboratory • Sandia National Laboratories

*Some of this material is adapted from "Distinctive Characteristics of the U.S. Department of Energy's National Laboratories," http://science.doe.gov/OLPE/National%20Laboratory%20definition%209-07.pdf (accessed September 28, 2008).

The locations of the laboratories and their assignment to programmatic offices are shown in the figure below. The geographic diversity of the national laboratories facilitates collaborations and interactions across the nation's academic community and with a broad spectrum of industrial partners.



Locations of the DOE national laboratories

Distinguishing Characteristics of the DOE National Laboratories

A DOE national laboratory is distinguished by most, and typically all, of the following characteristics:

- *Mission driven.* A national laboratory provides sustained support to further one or more long-term goals in support of the Department's mission. Examples include stewardship and certification of the Nation's nuclear weapons stockpile, discovering the fundamental nature of matter and energy, helping to prevent the proliferation of nuclear material throughout the world, developing breakthrough technologies for energy efficiency, strengthening the civilian nuclear energy capability, and understanding the science behind environmental management and global climate change.
- *Science of scale.* Large-scale, long-term programs make up much of the work of a national laboratory. U.S. leadership in key fields often requires a coordinated effort of substantial magnitude to overcome technical obstacles. For example, the discovery of fundamental characteristics of matter typically involves teams of hundreds to thousands of researchers and budgets of up to billions of dollars over periods of many years. Similarly, in support of a very different national goal, applying nanoscale science and technology to efficiently develop sustainable low-carbon fuels requires an attack by large groups of researchers over many years.

- *Multidisciplinary teams.* National laboratories routinely assemble and deploy well-integrated teams that span a broad suite of scientific, engineering, and technical disciplines to execute their mission assignments. For example, surveillance and assessment of the nuclear stockpile requires the insight and expertise of large numbers of physicists, materials scientists, engineers from multiple disciplines, computer scientists, and a host of other specialists. Similarly, managing the carbon cycle will require an understanding of the earth's atmosphere and subsurface that can only be gained by researchers across the full spectrum of environmental sciences, from climate physics to environmental microbiology and biogeochemistry, working closely with computational scientists and modelers. Recycling nuclear fuel is another complex challenge that calls for multidisciplinary teams of chemists, chemical and nuclear engineers, materials scientists, economists, and other experts.
- *Distinctive, powerful research facilities.* National laboratories develop, build, and operate large-scale scientific research facilities; each laboratory is home to one or more national user facilities linked to its core competencies. These facilities support the laboratories' research programs and also provide otherwise unaffordable experimental capabilities to the international research community. For example, the Spallation Neutron Source is a one-of-a-kind facility that provides the most intense pulsed neutron beams in the world for scientific research and industrial development. The National Ignition Facility, the world's largest laser, will deliver more than 60 times the energy of any previous laser system, enabling the performance of experiments with direct application to stockpile stewardship, national security, energy research, high energy density science, and astrophysics. The High-Flux Solar Furnace concentrates solar radiation, providing flux at concentrations greater than 20,000 suns and serving as an ideal tool for testing high-temperature materials, coatings on metals and ceramics, and other materials-related applications. The national laboratories also operate synchrotrons; neutron scattering facilities; particle accelerators for nuclear and high energy physics research; intensively instrumented, large-scale field sites for investigating the effects of clouds on atmospheric radiation and other environmental effects; comprehensively equipped nanoscience and molecular science centers; and many of the world's most powerful computing facilities. Together, DOE's laboratories provide world-class facilities where more than 30,000 scientists and engineers each year perform cutting-edge research.
- *Responsive to technological surprise.* The national laboratories comprise capabilities that enable the nation to anticipate and respond to technological surprises that could come from our global competitors or adversaries and that could have negative impacts on our national security, energy security, or competitiveness. They can quickly assemble multidisciplinary teams to address national issues, as evidenced in the aftermath of the September 11, 2001, attacks on the nation. Their technological capabilities inform national intelligence efforts to assess international threats, such as proliferation of nuclear weapons or other weapons of mass destruction, and are being used to protect critical infrastructure, such as the electric grid.
- *Safe and secure operating environments.* The national laboratories can safely and securely conduct research involving special operating considerations. As required to meet national needs, they operate facilities that enable the performance of hazardous, sensitive, or classified research essential to national interests.

The presence of most (if not all) of these characteristics distinguishes the DOE national laboratories from both industrial laboratories, which mainly pursue applied research germane to the business interests of the company, and academic laboratories, which focus largely on individual investigator research and are not mission driven.