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Introduction

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Overview

The fact that the United States enjoys a high standard of living and a prosperous economy is partly attributable to our willingness as a nation to invest significant public resources for public goods not readily attainable by the normal workings of the marketplace. Much has been written on the value of basic research and the role of the federal government in sponsoring such research. The National Academy of Sciences, articulating a widely held view, notes that much of this nation's economic growth, quality of life, and security derive from previous investments and our national ability to lead in science and technology. The Department of Energy directs a sizeable portfolio of basic science that underpins DOE's applied R&D missions and that explores broad frontiers in fundamental science, leading the nation in the basic energy sciences and much of the physical sciences, and contributing to major advances in biological research.

Leading nations throughout the world sponsor basic research. The United States has historically held a leadership position in government-sponsored research. More and more, however, the complexity and the expense of basic research are increasing, and the private-sector finds such research increasingly difficult to support, especially when faced with near-term financial objectives. This shift by industry away from long-term, basic research toward applied research and development has been well documented in recent years and has created a sizeable vacuum for government-sponsored research to fill. The substantial benefits to the nation and indeed the long-term prosperity of the country depend on these investments. The benefits are real, as are the problems and challenges that they address. For example, major scientific discoveries at DOE are creating remarkable new opportunities and are leading the way toward radically new technologies, solutions to energy and environmental problems, and entire spinoff industries in such areas as:

- Hydrogen-based energy systems.
- High-temperature superconducting wires and devices.
- Batteries thinner than plastic wrap.
- Teraflop computers that set world benchmarks for speed.
- Medical diagnosis and imaging technologies.
- Biomolecular design based on DNA sequencing.
- Ion beam and plasma technology.

The energy and environmental problems of the future will likely be more complex and harder to deal with than those faced to date. Meeting the challenges of the future will often require entirely new approaches and options—revolutionary, not just evolutionary changes in technology. The key to this ability rests on advancements in basic science.

DOE—A Science Agency

Top Five Government Research Organizations for Basic Research*

1. Health and Human Services ($8.0 B)
2. National Science Foundation ($2.5 B)
3. **Department of Energy ($2.5 B)**
4. NASA ($2.1 B)
5. Department of Defense ($1.1 B)

* Numbers are from FY 99 President's Request in Billions and include adjustments to enable comparisons. Source: OMB.

With only minor exceptions, the Science Portfolio of the Department is contained entirely within DOE's Office of Science (SC). Formerly the Office of Energy Research, this office was given a new name by Congress during the FY 1999 budget deliberations, in recognition of the broad science mission of DOE and more than 50 years of contributions to basic research.

Overall, DOE's science portfolio totaled almost $2.7 billion in FY 00, and the data available for FY98 indicate that at that time, DOE was the third largest supporter of basic research in the United States.

Nearly **$2.7 billion** went into direct support for basic science, research facilities, and related infrastructure in FY 00. The budget, traditionally laid out by general science *discipline,* is depicted in the table below.

DOE's Science Portfolio Budget ($ Millions)*

	FY 99	FY 00	FY01
Basic Energy Sciences	759	720	963
Biological & Environmental Research	428	435	445
High Energy Physics	664	669	685
Nuclear Physics	321	330	350
Fusion Energy Sciences	216	238	240
Advanced Scientific Computing Research	153	125	175
Total All Other Science R&D Portfolio	154	144	157
Totals**	2695	2660	3015

*Excludes Program Direction
**Totals reflect accurate summation of numbers above, each carried to significant figures not shown.

Research in these disciplines is actually carried out at the national laboratories, universities and colleges, and at private-sector institutions under the direction and guidance of the Department.

A History of Discovery – The Promise of Discovery

This century has been a great age of scientific discovery, and DOE's science programs and national laboratories have played a leading role. Scientists have learned to control matter at the atomic level, explored the origins and fate of the universe, established the basis for a complex and far-reaching energy system, and found ways to help protect and restore the environment. And the pace of scientific discovery and technological advancement is accelerating dramatically.

For example, within just the last few years, DOE scientists have discovered a chemical responsible for cell-to-cell communication and have identified archeabacteria, which represent a third kingdom of life. The discovery of a new electrolyte system (lithium phosphorus oxynitride) has enabled the development of thin-film batteries with unsurpassed energy densities and the ability to operate safely at temperatures as high as 150 degrees Centigrade. A newly designed, elegantly simple experiment allows scientists to examine the interaction of chemistry and turbulence in quantifiable and verifiable detail for the first time. Light bulbs, fluorescent tubes, and neon lights may soon become things of the past, replaced by more efficient and brighter lighting sources utilizing light-emitting diodes (LEDs) based on newly improved gallium nitride semiconductors. A new field of optics came into being, based on a new way to capture and focus light. Scientists have introduced a set of solvent-degrading genes from one microbe into a radiation- and desiccation-resistant bacterium, thus demonstrating the potential for designing microbes that could survive in high-radiation environments and degrade or detoxify other contaminants. Research has confirmed that biogenic hydrocarbon chemistry is key to understanding ozone and other oxidant production in the eastern United States A new

DOE Science—Some Recent Breakthroughs

- Discovery of the Year (in the journal *Science*) that the universe seems to be expanding at an accelerating rate, based on research into supernovas and redshift.
- Genomic sequencing that confirmed a new, third kingdom of life on Earth that includes a deep ocean, methane-producing organism.
- World record for sustained fusion reaction in both length of reaction and peak energy.
- Discovery of the top quark, the last, unusually large subatomic element that helps flesh out the Standard Model.
- Calculation of Black Hole entropy from super-string theories.
- Improved high temperature superconductors through research into pairing mechanisms and vortex physics.
- Potential new ways to store hydrogen through the discovery of new graphite nanofibers that can store three times their weight of hydrogen.
- Computational ability that recently exceeded 1 teraflop in sustained performance for an application.
- Artificial photosynthesis through research into light-matter interactions and solar photochemistry.
- Collaboration in the development of a photovoltaic cell that holds three world records for efficiency.
- Improved miniaturization through research into nanowires: "magic structures" and conductance quantization.
- Improved models and measurement of the carbon cycle, the phenomenon of global warming, and the role of cloud formation.
- A tenfold increase in the electrical conductivity of semiconductors through research into gallium injection.
- Development of the current generation of high energy, power lithium and lithium ion batteries from research into non-aqueous electrolytes.
- Development of treatments for diseases and addictions that are newly enabled by PET brain imaging studies.

generation of observing tools and instruments are now making ground- and atmosphere-based measurements of clouds and atmospheric radiation.

DOE researchers sequenced more than 300 million base pairs of draft and high quality human DNA sequence, and genomic DNA sequencing has been completed on microbes related to bioremediation and carbon sequestration. Positron emission tomography (PET) and magnetic resonance imaging (MRI) have been merged, opening new possibilities in diagnostic imaging. Scientists have discovered elementary particles and their interactions. The development of super-string theory is a major step on the road to a unified theory of forces.

In support of its science programs, the Department manages the most extensive and advanced complex of scientific facilities in the world. Such facilities include powerful accelerators for high energy and nuclear physics, light and neutron beam facilities for the natural and life sciences, electron beam microcharacterization centers, multidisciplinary mission centers, and single-purpose research facilities. Through its computing facilities, the Department is enabling rapid strides in scientific simulation as an equal partner to laboratory science in testing concepts and modeling complex processes.

DOE’s science programs have a long and rich history of remarkable discoveries. To date, 70 Nobel prizes have been awarded to scientists supported by DOE—a total that far surpasses that of any other public or private institution. It is not surprising then that the future can be viewed with such great optimism.

Themes and Challenges at the Frontiers of Science

Over the past year, DOE has prepared a strategic framework to enhance its long-term thinking—a framework that reveals new opportunities at the boundaries of science disciplines, and one that identifies the major science ***themes*** and corresponding science ***challenges*** that, in keeping with our mission, define our purpose and guide our long-term actions. The four major themes for science are (1) Fueling the Future, (2) Protecting Our Living Planet, (3) Exploring Matter and Energy, and (4) Extraordinary Tools for Extraordinary Science. These themes, and corresponding challenges, are outlined below.

Fueling the Future
— Science for affordable and clean energy

Providing scientific foundations that keep the United States in a leadership position for abundant, affordable and clean energy is essential for a strong and secure nation. Fueling the Future is a critical theme, for it addresses the scientific foundations for the Department’s applied energy technology programs. The future of U.S. energy systems relies on basic research that allows existing energy systems to become cleaner, safer and more efficient—and, just as important, understanding what new fuels can be created and harnessed.

What new energy sources can be created and harnessed? American security and welfare require sustained, abundant, and clean energy. The Science Portfolio is addressing the demand for energy by providing the scientific foundation for energy production from carbon-free or low-carbon sources. Research on hydrogen-based energy systems and other carbon-free energy supplies is critical to this need. Central to meeting the long-term demand for energy is research on the science of controlling plasmas for fusion to understand fusion confinement systems and the properties of plasma ignition and behavior. Bioenergy systems, including improving photo-synthetic systems and energy conversion systems, are central to this problem. Energy research is also developing the detection instrumentation, monitoring, and modeling systems to understand the behavior of the earth's interior to better tap geothermal and petroleum energy supplies.

How can energy systems be made cleaner, safer and more efficient? Improvement in the efficiency, safety and cleanliness of energy technologies requires better materials and better conversion and utilization processes. At the heart of these challenges are advanced materials and high performance structures that can withstand demanding environments, including high temperature materials for more efficient combustion systems or high performance structures that may be tough, low friction or high strength. Improved catalysis and conversion processes can realize significant improvements in combustion and exhaust gas cleanup systems and improve yield of fuels and valuable chemicals in photoconversion. Developments in quantum engineering hold the promise of widespread deployment of high temperature superconducting materials, advanced electronic materials, or other materials with advanced properties from molecular design and assembly.

Fueling the Future poses the following major *scientific challenges* for DOE's science portfolio.

Challenges

- ***New Fuels*—**To understand the geological, chemical, biological, and physical processes for clean and affordable domestic fuels.
- ***Clean and Affordable Power*—**To understand the physical, material, and chemical processes for advanced power generation, storage and transmission.
- ***Efficient Energy Use*—**To understand the engineering, materials, and chemical processes to develop new energy efficient technologies.

Protecting Our Living Planet
— Energy Impacts on People and the Environment

As world population and the energy intensity of society increases, our planet is beset by increasing pollutants and waste streams. It is increasingly critical that we understand the complex interactions between man-made energy-related pollutants and the environment and living systems. Only through this understanding can effective strategies for mitigating the effects be developed. Protecting Our Living Planet is the theme that embraces these important science issues. Some of the key questions include:

What are the sources and fate of energy-related pollutants? Understanding the genesis, transformation, transport, and concentration of energy-related pollutants is the key to predicting their local, regional, and global effects. Advanced sensors and monitoring, with improved modeling and simulation, are required to understand these complex phenomena. This information is crucial for the information base that supports policy and regulatory decisions on energy and environmental matters.

How do complex biological and environmental systems respond to our energy use? Steeped in a long tradition of research aimed at understanding the biological effects of radiation, DOE-supported researchers have developed and applied some of the most advanced and sensitive analytic techniques to the examination of energy-related pollutants and their interaction with biological systems at the molecular, cellular, and organism levels. Similarly, DOE support has led to the development of information and models that can be used to explore the complex effects of pollutants on ecological systems at local and global scales. Additional basic research will reveal new and improved ways of protecting and restoring the environment, including the use of bioengineered micro-organisms for the restoration of contaminated land and water.

What factors change global climate and how can they be controlled? Perhaps one of the most pressing global environmental/energy issues of our time is the emergence of global climate change. Research in understanding the phenomenon, the rate of change, and ways to manage the carbon cycle more effectively will offer the long-term solutions that will shape our energy future.

Protecting Our Living Planet presents the following major *scientific challenges* for DOE's science portfolio:

Challenges

- ***Sources & Fate of Energy Byproducts*****—**To understand the molecular, atmospheric, geological, and biological pathways of energy byproducts in the biosphere.
- ***Impacts on People and the Environment*****—**To understand and evaluate the effects of energy byproducts on people and the environment.
- ***Prevention and Protection***—To create new scientific approaches to protect the biosphere from the effects of energy byproducts.

Exploring Matter and Energy
— Building Blocks of Atoms and Life

Understanding the nature of matter and energy and how these interact to form the material world presses the bounds of human imagination, mathematics, computation, and instrumentation. To understand the nature of matter and energy at the most fundamental level is an important science theme for DOE and one where it has traditionally held a worldwide leadership position. The key questions to be addressed through this exploration include the following:

What are the fundamental building blocks of matter? Understanding the nature of matter requires that the origin of mass of the most fundamental particles be determined, including the underlying constituents. The properties of quarks must also be understood, as well as the structure of nuclear matter, exotic high energy nuclei and matter under normal temperatures and pressures on Earth. The standard model explains the properties of matter that must be understood, including explanation of observed violations of the standard model, such as parity non-conservation. An extensive experimental program using high energy and high luminosity colliding beam accelerators is needed to explore the building blocks of matter as well as many other experiments designed to shed light on the standard model and to help bring together all of the known strong and weak forces into a unified theory.

How can the origin and fate of the Universe reveal the secrets of matter and energy? At the birth of the Universe, following the Big Bang, energy began to condense into quark-gluon matter, and into nuclear matter. The Universe is now expanding at a great rate, and understanding the conditions of the early universe and the fate of the expansion can reveal the secrets of the form of matter and energy. This question addresses why the universe is dominated by normal “matter” rather than “antimatter,” an asymmetry of matter that is a major enigma. The fundamental forces and properties of matter are incompletely characterized, so that a coherent, unified concept of the forces is needed.

How do atoms and molecules combine to form complex dynamic systems? Understanding the origins and structure of the material world is essential to harness energy, develop new materials, and improve the quality of life. For example, the behavior of extremely hot plasma states is essential to understand fusion energy. Understanding the molecular, ionic and atomic interaction of reactants is essential to understand the chemistry of energy conversion processes or materials production. Determining the sequence of DNA bases in complete genomes is essential for defining the basic set of RNAs and proteins essential for life, and determining the structures, functions, and interactions of biomolecules is essential for understanding how living systems function, behave, and adapt to changing environments.

Exploring Matter and Energy presents the following major *scientific challenges* for DOE’s science portfolio:

Challenges

- ***Components of Matter*—**To understand matter at the most fundamental level.
- ***Origins and Fate of the Universe*—**To understand the evolution of the universe from fundamental laws.
- ***Complex Systems*—**To understand and control complex systems of matter, energy, and life.

DOE manages the world’s preeminent infrastructure for basic

Extraordinary Tools for Extraordinary Science
— National assets for multidisciplinary research

research in the physical sciences and an increasingly important infrastructure for chemical and biomedical research. From the large, high energy research facilities, such as colliders, to advanced computational and simulation centers, to the national laboratory system itself, these core resources support multidisciplinary research within DOE and for the nation. Included are the large number of scientific user-facilities that are operated for the express purpose of providing our nation's leading scientists with one-of-a-kind experimental tools for scientific discovery. In providing these extraordinary tools, we must address three key questions:

How can we explore the frontiers of the natural sciences? Challenging questions in the natural sciences often require the application of probes that are capable of peering into the interactions at the sub-atomic, atomic, and molecular scales. Using these experimental probes to unlock the mysteries of matter and energy improves our ability to control these processes and to improve the human condition.

How can we predict the behavior of complex systems? Armed with increasingly powerful mathematical tools and large sets of data from experimental probes and monitoring equipment, scientists can develop super-high-speed computing abilities, create advanced software and visualization systems, and improve their understanding of the complex phenomenon at work.

How can we strengthen the nation's capacity for multidisciplinary science? More and more of the cutting edge of science can be found at the boundaries between technical disciplines. As we search for simpler truths, the process for getting there becomes more complex, requiring the ability to bring together the tools and the different scientists required to solve these problems. Our national laboratories, working in partnership with the private sector and academia, provide unique and powerful settings for conducting multidisciplinary research. In addition, we must be able to exchange information more readily and improve the general scientific literacy of the nation, to lay the foundation for successive generations of world-class scientists.

Extraordinary Tools for Extraordinary Science presents the following major *scientific challenges* for DOE's science portfolio:

Challenges

- ***Instrumentation for the Frontiers of Science*****—**To provide research facilities that expand the frontiers of the natural sciences.

- ***Scientific Simulation*****—**To advance computation and simulation as a critical tool in future scientific discovery.

- ***Institutional Capacity*****—**To strengthen the nation's institutional and human assets for basic science and multidisciplinary research.

The figure in the Executive Summary shows the strategic framework that has been constructed over the past year out of the national discussion of DOE's long-term research directions. The first analytic categories are the four major themes; beneath each of the themes are its three associated challenges. This organization of themes and challenges is reflected in the twelve chapters of this document; each chapter discusses one scientific challenge. The challenges of "Fueling the Future" are covered in Chapters 1-3. The challenges of "Protecting Our Living Planet" are covered in Chapters 4-6. The challenges of "Exploring Energy and Matter" are covered in Chapters 7-9. The challenges of "Extraordinary Tools for Extraordinary Science" are covered in Chapters 10-12.

Science Investments—A Portfolio Perspective

A distinguishing feature of the Department's basic science, and indeed basic science in general, is that it is primarily knowledge driven rather than application driven. That is to say, its main purpose is to *explore the complex phenomena and processes that define our physical world, to determine what factors influence them, and to understand how we may ultimately control them.* As such, discoveries usually have broad-reaching, diverse implications, not only for applied R&D and technology, but for other scientific investigations, revealing investments with extremely high leverage and societal benefit. Scientific discoveries resulting from basic research have had an enormous impact on technology development.

Some research activities within the Science Portfolio, although still basic in nature, are more easily understood in terms of potential areas of application that may benefit from corresponding discoveries. For example, some of the work conducted within basic energy sciences falls within this category. There is a usually a strong communication link between scientists engaged in this research and potential downstream beneficiaries, such as the developers of corresponding energy technologies. The research is usually informed, but not limited by, such user feedback and user-defined problems.

In other cases, the research is much more fundamental and exploratory in nature, pressing the limits of abstract thinking and core capabilities in mathematics, computation, and other areas. Even though highly fundamental and exploratory, it too often results in important spinoffs, and certainly improvements in the core capabilities that drive some of the other sciences. An example is research exploring the relationship between energy, matter, time, and space. In general, our portfolio reflects research that is integrated within a continuum of science that supports applied research and technology.

> "Not everything that can be counted counts, and not everything that counts can be counted."
>
> - Albert Einstein

At the outset, it must be noted that the development of **a portfolio in science requires a different approach, or at least a different frame of reference** than that for applied research and technology programs. In the latter case, it is possible to link investments more closely with segments in the industrial sector and/or applied benefits to society that they produce. The issue then becomes one of performing tradeoff analysis of the desired, oftentimes competing objectives. Such an approach is much less valid for science, and most experts agree that the collective wisdom of the science community and the recommendations of technical advisory committees may do more to inform proper investments in science and subsequent breakthroughs in discovery and knowledge than any quantitative approach ever could. Appropriately then, the quantitative aspects of this analysis are intended to provide some measure of additional insight into the general motivations and framework for our science investments—they are not intended to validate specific science investments.

Further guiding our analysis, eight *major goals* of a balanced portfolio were considered important. They are summarized in the box on the next page.

One of the more important consequences of our portfolio review effort came from our attempt to align our science activities against a new and different long-term strategic framework consisting of themes and challenges. This perspective has enabled us not only to explain, but to think differently across areas of science and program missions. Already new opportunities are beginning to emerge, for example, in the area of complex systems, based on initial multidisciplinary discussions held during our two national workshops and on follow-on activities at the labs and universities. Each of the next twelve chapters, and the appendix, summarize the results of this crosscutting approach to portfolio analysis.

Although many of our portfolio findings are validated by some of the quantitative information contained within this report, it is not our intent to overuse or overinterpret these results. Rather, the broad range of information contained in this report should be reviewed in its entirety and forms the basis for the observations contained below.

DOE provides broad and balanced support for ***science infrastructure***. The DOE national laboratories represent a crowning achievement in an era of scientific discovery. Among the infrastructure that will support science in the future, the national labs reflect our greatest hope and our best opportunities for conducting the broad-based, multidisciplinary research that will be the hallmark of future innovations. Residing at the laboratories and at universities are instruments that enable us to explore scales from the infinitesimally small to the infinitely large, from the sub-atomic to the cosmos. Instrumentation at the Frontiers of Science includes accelerators for high energy and nuclear physics, light sources and neutron beam facilities for natural and life sciences, plasma and fusion energy facilities, single purpose and multidisciplinary facilities, biological and environmental research facilities, and facilities for computing and computational support. Beyond these extraordinary tools of science, DOE invests some highly leveraged resources in science education to ensure that our future scientific workforce is capable of pushing the envelope of science.

Eight Goals for a Balanced Science Portfolio

(1) Support vital science infrastructure, including the national labs and advanced scientific instruments that will ensure the nation's future ability to conduct complex, multidisciplinary science; support a workforce of scientists prepared to meet our future science challenges.

(2) Maintain and build required core competencies, in particular, those vital to our future science programs, such as scientific simulation, anticipating the needs and domains of science.

(3) Provide strong support to DOE's applied research programs, particularly the energy, environmental, and defense missions of the Department, ensuring research is responsive to broad categories of user-defined problems and barriers to technology development.

(4) Support a balanced portfolio across the continuum of science, from exploratory basic research to strategic basic research, the latter informed but not limited by potential applied research problems.

(5) Examine the boundaries of science disciplines, recognizing that some of these offer the greatest potential areas for discovery in the years ahead and that required systems-level investigations/solutions will introduce a higher degree of scientific complexity than ever before.

(6) Collaborate for greater science impact, pursuing international collaborations for large fundamental science investigations and, to the extent possible, industry and university partnerships to increase the leverage of smaller scale, basic research.

(7) Promote diversity of performers and diversity of ideas, working to ensure that an open, competitive process enables the best and the brightest to flourish in a creative science environment, rewarding risk-taking, ingenuity, and excellence in pursuit of scientific discovery.

(8) Expand access to science and to scientific results, ensuring that research facilities and research results are responsive and easily accessible to the scientific community.

DOE's support for ***scientific core competencies*** is best observed in the earlier table that contains the discipline-oriented elements of the budget. Here can be seen the distribution and breadth of support for basic energy sciences, biological and environmental sciences, high energy and nuclear physics, plasma fusion sciences, and computational and technology research, all core competencies that underpin DOE's science mission. In addition, new opportunities have been identified in areas with high leverage, such as scientific simulation. This portfolio demonstrates the interconnected and vital future role of scientific simulation. The Department is preparing a science roadmap for scientific simulation that will clarify the opportunities and options for moving forward in greater detail.

DOE's science portfolio provides strong ***support to the Department's applied research programs*** in energy, environmental management, and national security. For example, research in Fueling the Future maintains a strong eye toward the needs of the applied energy programs. In addition, the strategic framework that includes Fueling the Future was designed to be consistent with the framework adopted in the Energy R&D portfolio, a companion to this report. The Energy R&D Portfolio also includes a detailed chapter outlining the supporting role of science in energy R&D.

Examples of some specific energy technology areas that have benefited from recent strengthened integration between basic science and the applied energy programs include:

- Office of Energy Efficiency's Industries of the Future Program.
- Partnership for a New Generation Vehicle.
- Advanced Computation Initiative, which includes the Office of Energy Efficiency as well as the oil and gas industry.
- Advanced Turbine Systems Program.

Similarly, research that supports challenges in Protecting Our Living Planet strongly supports DOE's environmental management/cleanup mission, and research documented there addresses the need for more timely and cost-effective cleanup solutions. Finally, research in plasma sciences and the general area of scientific simulation are examples of science that also supports our national security mission.

The portfolio ***balances exploratory, fundamental research with strategic basic research***, that is, research with a general class of problems in mind. On the one end of the spectrum, research that supports Components of Matter, as well as Origins and Fate of the Universe, substantiates our continued commitment to the frontiers of knowledge. The heart of this research is exploration—exploration of the cosmos, exploration of the microcosm, but nothing less than exploration of the nature of the physical universe and physical laws that govern energy, matter, time and space. On the other end of the spectrum is work in the Basic Energy Sciences, where, for example, research into new classes of materials or catalysts offers solutions to vexing technology barriers.

This portfolio portrays a major new attempt at strengthening capacity and pursuing opportunities at the ***boundaries of science disciplines***. Support for interdisciplinary science is captured across many of the challenges. For example, pieces of the life sciences are included under Components of Matter, specifically as biomolecular building blocks; and under Origins and Fate of the Universe, life sciences are addressed in the Formation of Life, specifically, simple, primitive organisms and their existence in extremely harsh conditions. The strongest interdisciplinary mix is contained in Complex Systems. Here, research is highly leveraged and builds on ideas spanning many different science disciplines to address collective phenomena and adaptive systems. The challenge of complex systems has received considerable attention, both during our national workshops and in follow up at laboratories and universities.

Many factors make international ***collaboration*** on large science ventures beneficial to the United States. In some cases, the science that underlies the problem is so complex and the impacts so far-reaching that all countries must share in the expense of research. This is the case with Global Change Research. In other situations, the scale and costs of the equipment are so large that even wealthy nations can no longer afford independent activities. In this latter case, the benefits and risks are shared across teaming participants, offering the benefits of new ideas, improved sharing of technical data and science infrastructure, and overall improved communications within the scientific community. The Large Hadron Collider for high energy physics is an example and it demonstrates the sheer physical size and tremendous costs associated with extending research to the next energy level in physics. Also, the U.S. fusion program has similarly exercised leadership in establishing and fostering international collaborations that have involved scientific and technological exchanges, joint planning, and joint work at facilities in the U.S. and abroad. In general, exploratory challenges within Components of Matter and within Origins and Fate of the Universe present many such opportunities for scientific collaborations.

The Department continues to seek ***diversity of ideas and new perspectives on science***. Maintaining a diverse portfolio of research performers is an important component of this overall goal. Researchers at the national laboratories and at universities form the core of DOE-funded scientists, with a larger share going to the national labs. A very sizeable amount went to colleges and universities. Unlike DOE's applied energy programs that have a substantial portfolio investment with industry, the science portfolio invests only a modest amount with industry (see Appendix A), as one might expect given the infrastructure, time-frames of interest, and priorities of industry. Described under the Institutional Capacity challenge, programs and investments designed to broaden the scope of S&T programs/performers has been quite successful. Research sponsored out of one of these programs resulted in findings that were awarded the journal *Science's* 1998 Discovery of the Year—research on the nature and possible fate of the universe.

Finally, and beyond DOE's own research activities, the science portfolio supports ***access*** to its more than 30 major scientific user facilities for many thousands of the nation's scientists, industry researchers, and graduate students. Literally hundreds of colleges and universities and a similar number of companies, as well as many federal labs, are routine users of light and neutron beam facilities, electron microscopy centers, materials analysis centers, and accelerators for high energy and nuclear physics, to name just a few of these advanced tools for science. To assure a connected science community, the portfolio includes support for ESNet, a high performance network which links computational and experimental facilities to users. ESNet is a critical component of the research infrastructure for the nation. Further improving connections within the science community is the Information Bridge, a system designed to make scientific and technical information more accessible to scientists, technology developers, and the public.