THE FOUNDATION FOR DEVELOPING NEW ENERGY TECHNOLOGIES: BASIC ENERGY RESEARCH IN THE DEPARTMENT OF ENERGY (DOE) OFFICE OF SCIENCE

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

SEPTEMBER 10, 2008

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CONTENTS

September 10, 2008

	Page
Witness List	2
Hearing Charter	3

Opening Statements

Statement by Representative Nick Lampson, Chairman, Subcommittee on Energy and Environment, Committee on Science and Technology, U.S. House of Representatives	7
Written Statement	7
Statement by Representative Judy Biggert, Acting Ranking Minority Member, Subcommittee on Energy and Environment, Committee on Science and Technology, U.S. House of Representatives	8
Prepared Statement by Representative Bob Inglis, Ranking Minority Member, Subcommittee on Energy and Environment, Committee on Science and Technology, U.S. House of Representatives	8

Witnesses:

Dr. Patricia M. Dehmer, Deputy Director for Science Programs, Office of Science, Department of Energy	
Oral Statement	9
Written Statement	11
Biography	20
Dr. Steven B. Dierker, Associate Laboratory Director for Light Sources; National Synchrotron Light Source II Project Director, Brookhaven National Laboratory	
Oral Statement	21
Written Statement	23
Biography	27
Dr. Ernest L. Hall, Chief Scientist, Chemistry Technologies and Materials Characterization, GE Global Research	
Oral Statement	28
Written Statement	29
Biography	31
Dr. Thomas P. Russell, Silvio O. Conte Distinguished Professor, Polymer Science and Engineering Department, University of Massachusetts–Amherst; Director, Materials Research Science and Engineering Center; Associate Director, MAssNanoTech	
Oral Statement	32
Written Statement	34
Biography	43
Discussion	
Investigation of Research and Development Across the Department of Energy and Other Agencies	44
Retaining the Energy Science Workforce	46
Alternative Transportation Fuel	47
Industrial Use of Facilities	49
Energy Frontier Research Centers	50
Proprietary Information	51
Supporting BES Facilities	52
Basic Research and Long-term Scientific Challenges	54

Page

Appendix: Answers to Post-Hearing Questions

Dr. Patricia M. Dehmer, Deputy Director for Science Programs, Office of Science, Department of Energy 58
Dr. Steven B. Dierker, Associate Laboratory Director for Light Sources; National Synchrotron Light Source II Project Director, Brookhaven National Laboratory 63
Dr. Ernest L. Hall, Chief Scientist, Chemistry Technologies and Materials Characterization, GE Global Research 64
Dr. Thomas P. Russell, Silvio O. Conte Distinguished Professor, Polymer Science and Engineering Department, University of Massachusetts–Amherst; Director, Materials Research Science and Engineering Center; Associate Director, MAssNanoTech 67

THE FOUNDATION FOR DEVELOPING NEW ENERGY TECHNOLOGIES: BASIC ENERGY RESEARCH IN THE DEPARTMENT OF ENERGY (DOE) OFFICE OF SCIENCE

WEDNESDAY, SEPTEMBER 10, 2008

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 2:05 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Nick Lampson [Chairman of the Subcommittee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
RANKING MEMBER

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Subcommittee on Energy and Environment

Hearing on

The Foundation for Developing New Energy Technologies: Basic Energy Research in the Department of Energy (DOE) Office of Science

Wednesday, September 10, 2008
2:00 p.m. – 4:00 p.m.
2318 Rayburn House Office Building

Witness List

Dr. Patricia Dehmer
Deputy Director of Science, DOE Office of Science

Dr. Steven Dierker
Associate Laboratory Director for Light Sources, Brookhaven National Laboratory

Dr. Thomas Russell
Director of the Materials Research Science and Engineering Center on Polymers, University of Massachusetts at Amherst

Dr. Ernest Hall
Chief Scientist, Chemistry Technologies and Materials Characterization, GE Global Research

HEARING CHARTER

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

The Foundation for Developing New Energy Technologies: Basic Energy Research in the Department of Energy (DOE) Office of Science

WEDNESDAY, SEPTEMBER 10, 2008
2:00 P.M.–4:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Wednesday, September 10, 2008 the House Committee on Science and Technology, Subcommittee on Energy and Environment will hold a hearing entitled *"The Foundation for Developing New Energy Technologies: Basic Energy Research in the Department of Energy (DOE) Office of Science."*

The Subcommittee's hearing will examine the Basic Energy Sciences program in DOE's Office of Science, with a focus on stewardship of the major light and neutron source facilities as well as its recent initiatives to advance research for specific energy applications. The hearing will also explore the program's level of coordination with and role with respect to DOE's applied energy research programs.

Witnesses

- **Dr. Patricia Dehmer** is the Deputy Director of Science for the DOE Office of Science, and former Director of the Basic Energy Sciences program. Dr. Dehmer will summarize the program, and describe the Department's efforts to integrate energy research efforts between its basic and applied programs.
- **Dr. Steven Dierker** is the Associate Laboratory Director for Light Sources at Brookhaven National Laboratory. Dr. Dierker will testify on his experience both managing and building major light source facilities.
- **Dr. Ernest Hall** is the Chief Scientist for Chemistry Technologies and Materials Characterization at GE Global Research. Dr. Hall will testify on GE's experience as an industrial user of the facilities managed by the Basic Energy Sciences program.
- **Dr. Thomas Russell** is a Professor of Polymer Science and Engineering at the University of Massachusetts at Amherst and Director of its Materials Research Science and Engineering Center on Polymers. Dr. Russell will testify on his experience as a university user of the major facilities in the Basic Energy Sciences program.

Background

The Basic Energy Sciences (BES) program in the DOE Office of Science supports fundamental research in materials sciences, physics, chemistry, and engineering with an emphasis on energy applications. This includes a broad portfolio of basic research that provides essential knowledge that will lead to development of advanced energy technologies. BES is by far the largest program in the Office of Science, with a final FY 2008 budget of $1.28 billion and an FY 2009 Presidential Request of $1.57 billion. (The total FY 2008 budget for the Office of Science is $4.04 billion, and the FY 2009 Request is $4.72 billion.)

The expanded knowledge gained through research supported by BES underpins the applied energy research supported by other DOE programs and by the private sector. Better characterization of materials at a molecular level and greater knowledge of chemical reactions at the atomic level are necessary if we are to achieve major improvements in energy efficiency and develop new sources of energy. For example, better understanding of photochemistry and material characteristics will enable the development of more efficient photovoltaic cells and higher electricity production from solar energy. Research into the transport of electrical charge and the properties of new self-healing nanoscale materials may lead to the development of advanced batteries for vehicles and for large-scale use of intermittent renewable energy sources like wind and solar. Furthermore, geosciences research over a wide range of spatial scales and time scales will be necessary to predict with confidence the ability to safely sequester CO_2 emissions from coal and natural gas plants.

A major function of the BES program is its role as a steward of several large-scale facilities at various National Laboratories throughout the country. These national facilities house unique instrumentation that is essential to the conduct of advanced research in the basic energy sciences. The light sources and neutron sources are used to characterize materials and examine chemical processes by observing the ways in which either neutrons or specific kinds of light waves interact with the target that a researcher wishes to study. Approximately 9,000 scientists use these facilities each year. In addition to DOE scientists, the facilities are used by university researchers and their students and by researchers from roughly 160 private companies, including Boeing, Dow, Ford, General Electric, IBM, Merck, and Pfizer.

Light Sources

All of the currently operational light sources in the U.S. are synchrotrons, a generic diagram of which appears in Figure 1. They often have a diameter of several hundred meters and produce ultra-high intensity light over a wide range of wavelengths from infrared (long, low-energy) to x-rays (short, high-energy). This light can be precisely tuned to act like a powerful microscope that can be used to examine aspects of the atomic structure of materials that control their mechanical, thermal, electrical, optical, magnetic, and many other properties and behaviors. These operational light sources are the:

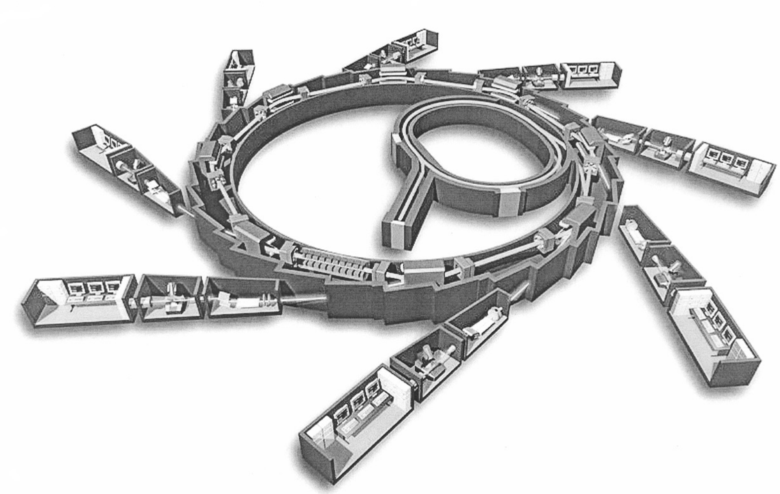

Figure 1: Generic diagram of a synchrotron facility, created by EPSIM 3D/JF Santarelli, Synchrotron Soleil. The circular ring is the synchrotron that brings electrons to very high speeds with the help of strong magnetic fields (to turn the particles so they circulate) and electric fields (to accelerate the particles). As the electrons turn around the ring, they emit a "synchrotron radiation", which is sent into the various beamlines (the straight lines branching out of the synchrotron). Each beamline contains scientific instruments, experiments etc. and receives an intense beam of radiation.

- **Advanced Light Source (ALS)** at Lawrence Berkeley National Laboratory in Berkeley, CA;
- **Advanced Photon Source (APS)** at Argonne National Laboratory in Argonne, IL;
- **National Synchrotron Light Source (NSLS)** at Brookhaven National Laboratory in Upton, NY; and

- **Stanford Synchrotron Radiation Laboratory (SSRL)** at Stanford Linear Accelerator Center (SLAC) in Stanford, CA.

In addition, two light sources are currently under construction. One is the **Linac Coherent Light Source (LCLS)** at SLAC, which is a linear accelerator rather than a synchrotron ring. It is being converted from a high energy particle physics facility to one that is designed to examine physical and chemical processes at a far higher time resolution than any light source operating today. DOE's total project cost for LCLS is currently $420 million, and it is scheduled to begin operating late in 2010. The other is the **National Synchrotron Light Source–II (NSLS–II)** at Brookhaven which will replace NSLS and have a far higher spatial resolution than current facilities. DOE's total project cost for NSLS–II is currently set at $912 million, and it is scheduled to begin operations in 2015.

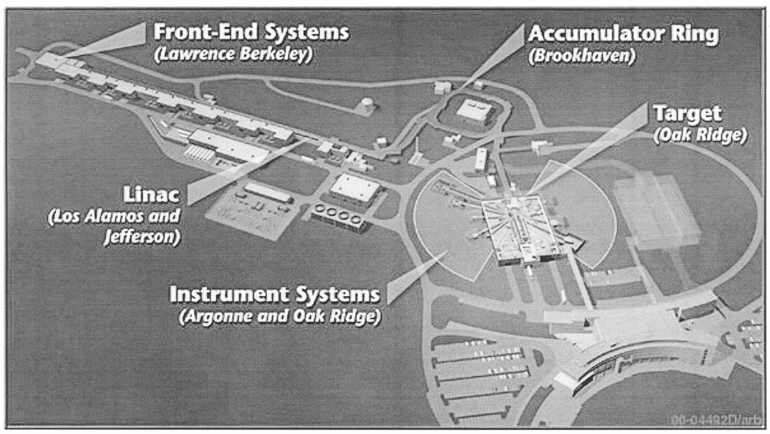

Figure 2: Artist's conception of SNS. Hydrogen ions are produced in the front-end and injected into a linear accelerator, which accelerates them to very high energies. They then pass into a ring where they accumulate in bunches. Each bunch is released from the ring as a pulse. The high-energy pulses strike a container of liquid mercury in the target area. Corresponding pulses of neutrons freed from the mercury upon impact are slowed down in a moderator and guided through beam lines to areas containing special instrument systems. Once there, neutrons of different energies can be used in a wide variety of experiments.

Neutron Sources

Neutrons can penetrate deep into materials to give precise information about positions and motions of atoms in the interior of a sample. Because of their unique characteristics, they are particularly well-suited to study the magnetic structure and properties of materials. They are also especially sensitive to the presence of light elements such as hydrogen, carbon, and oxygen which are found in many biological materials. The current operational neutron sources are the:

- **High Flux Isotope Reactor (HFIR)** at Oak Ridge National Laboratory (ORNL) in Oak Ridge, TN;
- **Manuel Lujan Jr. Neutron Scattering Center (Lujan Center)** at Los Alamos National Laboratory in Los Alamos, NM; and
- **Spallation Neutron Source (SNS)** at ORNL.

A fourth neutron source, the Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory was terminated this year.

SNS (see Figure 2) began operations in 2006 and was the last major facility completed by the Office of Science. Its total project cost was $1.4 billion. ORNL has integrated management of SNS and HFIR. HFIR provides continuous neutron beams, and SNS provides high intensity pulsed beams. Continuous beams allow researchers to study the effect of neutrons on materials over time and to produce unique isotopes that may be used for medical or other purposes. Pulsed beams allow scientists to get an instantaneous, high-resolution snap-shot of a material.

Electron Beam Characterization Centers

The three electron beam characterization centers contain various specialized instruments to provide information on the structure, chemical composition, and other properties of materials from the atomic level up using various techniques based primarily on the way a beam of electrons scatters from a research sample. The centers are the:

- **Electron Microscopy Center for Materials Research (EMCMR)** at Argonne National Laboratory;
- **National Center for Electron Microscopy (NCEM)** at Lawrence Berkeley National Laboratory; and
- **Shared Research Equipment (SHaRE) User Facility** at ORNL.

Nanoscale Centers

The five new BES Nanoscale Science Research Centers (NSRCs) are facilities in which new synthesis and processing capabilities are integrated with tools and expertise for characterization and corresponding resources for theory, modeling, and simulation. The centers are the:

- **Center for Functional Nanomaterials** at Brookhaven National Laboratory (to be completed within months);
- **Center for Integrated Nanotechnologies** at Sandia National Laboratories and Los Alamos National Laboratory;
- **Center for Nanophase Materials Sciences** at ORNL;
- **Center for Nanoscale Materials** at Argonne National Laboratory; and
- **Molecular Foundry** at Lawrence Berkeley National Laboratory.

Academic and Industrial Use

As indicated previously, these facilities are utilized by scientists from many institutions across the Nation. The demand for access to the facilities exceeds the time available, and management of the competing requests for time on the facilities is an ongoing challenge. DOE uses several methods to allocate time among the competing requests. The most common procedure for researchers to gain access to the facilities is through submission of a research proposal. DOE evaluates the proposals through a competitive process using standard peer-review procedures.

Industrial or academic institutions also have the option to fund the installation and maintenance of a workstation at the end of a particular beamline at some facilities. In exchange for their investment, the scientists associated with the funding institution have priority use for the majority of the time available through that workstation. Another option for industrial users who wish to maintain full intellectual property rights associated with their research project is to pay the total cost recovery of their facility use.

Competitive Research support through BES

The Office of Science also supports basic energy sciences through the award of grants to individual researchers and groups of researchers through a competitive process. University researchers and DOE scientists working at the National Laboratories are eligible to compete in these funding opportunities. Beginning in 2001, the Office of Science BES program held a series of ten Basic Research Needs workshops. The workshops included participants from industry, universities, and the relevant DOE applied programs. Topics included solar energy utilization; the hydrogen economy; superconductivity; solid-state lighting; advanced nuclear energy systems; combustion of 21st century transportation fuels; electrical-energy storage; geosciences as it relates to the storage of energy wastes (the long-term storage of both nuclear waste and CO_2); materials under extreme environments; and catalysis for energy-related processes. The purpose of the workshops was to bring together members of the energy research community to determine priority areas for future funding in basic energy sciences. The Basic Energy Sciences Advisory Committee integrated the findings of the workshops and produced a strategic plan that identified several "grand challenges" in energy research.

Chairman LAMPSON. This hearing will come to order. I wish you a good afternoon, and welcome to today's hearing on basic energy research in the DOE Office of Science. There has been a lot of attention in recent years on developing new clean energy technologies but not enough on strengthening the foundations that will make these future technologies possible. That is what the Basic Energy Sciences program in the Office of Science is all about.

This program covers a wide range of fundamental research that supports our efforts to achieve major advancements in energy technologies. Basic research in materials science, physics, and chemistry will enable us to make cheaper, more efficient solar cells; long-lasting batteries for plug-in hybrid vehicles; and high-temperature superconductors that would dramatically reduce energy losses on the electric grid. And these are just a few examples.

This afternoon we will also hear about the important role played by major research facilities built and managed by the BES program. These facilities are real jewels of our national research infrastructure. They are utilized by over 9,000 people each year, including professors and students from universities across the country, as well as researchers from companies that manufacture a wide range of products from power generation equipment and appliances to pharmaceuticals. There is high demand for use of these unique facilities and the research opportunities that they provide.

Today we will hear from a distinguished panel of witnesses about how this program is gearing up to address the broad scope of our energy challenges. I also want to hear about the relationship between the BES program in the Office of Science and the near-term applied programs at DOE, like those managed by the Office of Energy Efficiency and Renewable Energy and the Office of Fossil Energy. We want to ensure that important discoveries at BES move on to be incorporated into new energy applications.

The Basic Energy Sciences program is a critical component in our energy research and development portfolio. I thank our witnesses for appearing before the Subcommittee this afternoon, and I look forward to your testimony.

[The prepared statement of Chairman Lampson follows:]

PREPARED STATEMENT OF CHAIRMAN NICK LAMPSON

Good morning and welcome to today's hearing on basic energy research in the DOE Office of Science. There has been a lot of attention in recent years on developing new clean energy technologies, but not enough on strengthening the foundations that will make these future technologies possible. That is what the Basic Energy Sciences program in the Office of Science is all about.

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The Basic Energy Sciences program is a critical component in our energy research and development portfolio. I thank our witnesses for appearing before the Subcommittee this morning and I look forward to your testimony.

Chairman LAMPSON. I would like to recognize our distinguished acting Ranking Member, Ms. Biggert, for your opening statement. You are recognized for five minutes.

Ms. BIGGERT. Thank you, Mr. Chairman, and thank you for holding this hearing today on the Basic Energy Sciences Program in the Department of Energy's Office of Science. This is certainly near and dear to my heart. Unfortunately, Representative Inglis cannot be here today because of a scheduling conflict, but he will be submitting his statement for the record.

The BES Program supports vitally important fundamental research which will lead to the breakthroughs necessary to develop tomorrow's technologies and achieve energy independence. It also operates world-class scientific user facilities, three of which are located at Argonne National Lab in my district. Thanks to research supported by the BES program, Argonne has been able to take the lead role in developing the next generation of energy resources, particularly in the area of nuclear power. Most recently they have helped to develop an advanced nuclear reprocessing technology called UREX which literally reburns spent fuel to extract more energy. At the same time it improves efficiency and vastly reduces the toxicity and danger of the final waste product. This new process has the potential to end I think America's contentious debate over waste disposal, except maybe at Yucca Mountain, which has stymied efforts to bring this important source of clean, safe, carbon-free technology into more widespread use. But nuclear power is just one example of the technologies we must develop to meet our long-term energy needs. Moving forward, the BES Program and the research it supports will continue to play an integral role in solving our nation's energy problems.

So I welcome our highly experienced and informed panel of witnesses. I look forward to their testimony and would like to thank them for sharing their knowledge with us today.

With that, Mr. Chairman, I yield back the balance of my time.

Chairman LAMPSON. Thank you, Ms. Biggert. If there are additional opening statements, they will be placed in the record at this point.

[The prepared statement of Mr. Inglis follows:]

PREPARED STATEMENT OF REPRESENTATIVE BOB INGLIS

Good afternoon. Thank you, Chairman Lampson, for holding this hearing about the Basic Energy Sciences program in the Department of Energy's Office of Science.

In many ways, basic research is the lifeblood of our economy. Through better understanding of the nature of energy and matter in our universe, we can discover new ways to improve and harness these forces. We need Office of Science research facilities, like the Spallation Neutron Source, well before we can realize applications in superconductors, solar panels, and fuels of the future like hydrogen.

Basic research also plays a role in educating young scientists and cultivating the inventive spirit of American science. We need a constant supply of young, talented scientists to keep America on the cutting edge of expertise and competitiveness in energy and help us tackle the emerging problems of the future.

South Carolina research universities are pushing the envelope with innovative research in both basic and applied energy sciences. The Basic Energy Sciences program supports this work every year through competitive research grants. With nearly $3 million in grants to South Carolina universities in FY 2008 alone, the Basic Energy Sciences program is a partner in promoting innovative research and training the next generation of scientists in South Carolina.

I'm interested in learning how the resources and facilities of the Basic Energy Sciences benefit the scientists, students, and industry researchers that use them and what this program is doing to generate new energy advancements and ideas. I also hope to learn how this program can better serve the needs of its users.

I thank our witnesses for being here today and I yield back the balance of my time.

Chairman LAMPSON. At this time I am pleased to introduce our witnesses. Dr. Patricia Dehmer is the Deputy Director of Science for the Department of Energy Office of Science and the former director of the Basic Energy Sciences Program. Dr. Steven Dierker is the Associate Laboratory Director for Light Sources at Brookhaven National Laboratory. Dr. Ernest Hall is the Chief Scientist for Chemistry Technologies and Materials Characterization at GE Global Research. Dr. Thomas Russell is a Professor of Polymer Science and Engineering at the University of Massachusetts at Amherst and Director of its Materials Research Science and Engineering Center on Polymers.

Each of you have five minutes for your spoken testimony. Your written testimony will be included in the record for the hearing, and when you all complete your testimony, we will then begin with questions from the panel here. Each Member will be given five minutes to question each of you.

Before we get started and before I recognize Dr. Dehmer, I would like to recognize a lady who is in our audience. Her name is Mary Creagh. She is a member of the United Kingdom Parliament and is representing a constituency of Wakefield in Yorkshire. So welcome. Glad you are here joining us today and visiting the House of Representatives.

With that, Dr. Dehmer, you may begin.

STATEMENT OF DR. PATRICIA M. DEHMER, DEPUTY DIRECTOR FOR SCIENCE PROGRAMS, OFFICE OF SCIENCE, DEPARTMENT OF ENERGY

Dr. DEHMER. Thank you, Mr. Chairman, Congresswoman Biggert, for the opportunity to testify on the Basic Energy Sciences Program. I served as the Director of that program for 12 years from 1995 through 2007. This program has two components. The first is fundamental research structured to address DOE's missions, primarily its energy mission. The research program supports nearly 5,000 Ph.D. scientists and more than 1,500 students in the disciplines of chemistry, materials science, and aspects of biosciences and geosciences. The knowledge gained from this research ultimately underpins development of new energy technologies.

The second component of the BES Program is the design, construction, and operation of a truly remarkable collection of scientific user facilities. These facilities support the research program first by enabling the production of new materials and then by enabling their characterization at the atomic level using beams of x-rays, neutrons, and electrons. In fiscal year 2007, 9,000 users visited these facilities.

During the past decade the BES Program constructed $2 billion of facilities on schedule and within budget. This included the Spallation Neutron Source at Oak Ridge National Laboratory, the complete reconstruction of one of our synchrotron radiation light sources from the ground up, and five nanoscale science research centers. More than $1 billion of additional facilities are now in design or construction. This collection of facilities supported by BES is the best in the world and it is a critical component of maintaining U.S. supremacy in the physical sciences.

The central principle of the BES Program, and one that I take very seriously, is that discovery science is the foundation of innovation and future technologies. This was the inspiration for a series of one dozen workshops begun in 2001 that linked the basic research community, the applied research community, and industry in topics relevant to energy. About 1,500 researchers attended these workshops over a six-year period. We also involved representatives from DOE's National Nuclear Security Administration and all six of DOE's technology programs. Of the 10 specialty workshops, seven of them had plenary speakers from the Office of Energy Efficiency and Renewable Energy. The reports of those workshops describe what I call a new era of science, an era in which materials properties are designed to specifications and chemical reactions are manipulated at will. It is a science of control at the atomic level. It is the science of the 21st century.

But to do this we need knowledge that we do not have. I cannot overstate this. Even the simplest concepts still elude us. Here is just one example. Despite the efforts of hundreds if not thousands of researchers around the world, we still do not understand the mechanism of high temperature superconductivity which was discovered 22 years ago. There are now dozens of examples of high temperature superconducting materials. Now, you may ask, why is it important to understand the mechanism of this? Well, the application of superconductivity is no longer decades away, not even years away. Superconducting cable has been used for some time now, and earlier this summer nearly half-a-mile of power cable was installed in an existing underground right-of-way as part of the Long Island Power Authority.

But without knowing the mechanism of high temperature superconductivity, we are still using trial-and-error methods to develop these materials. We have no basis for the rational design of new and better materials. This is the 20th century way of doing business. It might even be the 19th century way of doing business. It is certainly not 21st century science.

This example is replicated in virtually every energy technology, from solar energy conversion to electrical energy storage in batteries to solid state lighting. We need to enter this new era of science that our workshops described.

I would like to close with one additional observation from our workshops. During the years of our workshops, we saw rapid growth of interdisciplinary energy and environmental science activities developed at institutions around the country, both at universities and national laboratories. Our two traditional funding mechanisms, individual investigator and small group awards, both focus largely on single-discipline research. In fiscal year 2009, we modified our small group funding mechanism to specifically address multi-disciplinary groups of investigators working on very challenging problems in energy. We call these group awards the Energy Frontier Research Centers. Together they represent a small part, about 15 percent, of the total research portfolio, but we think they will be an important part.

Mr. Chairman, thank you very much for inviting me to testify. Thank you also for your continued support of the Basic Energy Sciences Program in the Office of Science over these years.

[The prepared statement of Dr. Dehmer follows:]

PREPARED STATEMENT OF PATRICIA M. DEHMER

Thank you Mr. Chairman, Ranking Member Inglis, and Members of the Committee for the opportunity to appear before you to provide testimony on the Basic Energy Sciences (BES) Program in the Department of Energy's (DOE's) Office of Science. I served as the Director of the Office of Basic Energy Sciences for 12 years, from 1995 through 2007, and I am pleased to share with you my perspectives on that program.

Overview of the Basic Energy Sciences Program

Like other programs in the Office of Science, there are two signature components of the BES program. First, the BES program supports a robust program of fundamental research strategically structured to serve DOE's missions, primarily its energy mission. This program supported nearly 5,000 Ph.D. scientists and more than 1,500 students in FY 2007. Second, the BES program supports the design, construction, and operation of an unparalleled collection of major scientific user facilities, which provide the most advanced tools for materials research in the world. These facilities are a critical component of maintaining U.S. leadership in the physical sciences. Together these facilities hosted more than 9,000 users in FY 2007. In FY 2007, the BES program funded research in more than 173 academic institutions located in 48 states and in 13 Department of Energy laboratories located in nine states. Approximately 40 percent of the research activities were sited at academic institutions.

The research disciplines that the BES program supports—condensed matter and materials physics, chemistry, geosciences, and aspects of physical biosciences—are those that help us understand, predict, and ultimately control the material world around us. The research provides the knowledge base for:

- *The discovery and design of new materials with novel structures, functions, and properties.* Examples come from the world of nanoscale materials, where the unusual properties of materials at the nanoscale are exploited for energy technologies. For example, nanoscale particles permit a new-class of thermoelectrics, materials that convert heat into electricity. By embedding nanoscale structures into bulk thermoelectric materials, researchers have melded nanoscale electronic control with bulk-level microstructural tailoring, leading to very high thermoelectric conversion efficiencies. Such advances are especially critical for the conversion of waste heat in vehicles into useful electricity, which increases fuel efficiency.
- *The control of the physical and chemical transformations of materials.* An example is the control of chemical reactivity through catalysts that are more selective, more specific, and "greener" than those of past decades and that are used daily in the chemical, fuels, and biotechnology industries.

In the 20th century, scientists learned to observe and understand the interactions among atoms and molecules that determine material properties and processes. Now, scientists are poised to begin to direct and control the outcomes on an atom-by-atom and molecule-by-molecule basis. This will not be easy. We don't yet know how to achieve these capabilities. But their development is critical if we are to meet the formidable energy and environmental challenges that confront us now.

The central tenet of the BES program is that discovery science is at the foundation of innovation and future technologies. Many stories demonstrate that new knowledge can be quickly transferred to applications and technology development. One recent example is in the area of battery research.

A basic research project initiated by the BES program at the Massachusetts Institute of Technology more than a decade ago led to the discovery of a new nanostructured cathode[1] material for battery applications. Based on the knowledge gained, the faculty member that BES supported founded a high-tech start-up company, A123Systems in Watertown, Massachusetts, to commercialize this new battery technology. The development was further supported by a DOE Office of Science Small Business Innovation Research grant starting in 2002 and by a grant from the DOE Office of Energy Efficiency and Renewable Energy starting in 2006. Within the last three years, the A123Systems' batteries reached the commercial marketplace in power tools produced by North America's largest toolmaker, Black and Decker, and they currently are being implemented in hybrid and plug-in hybrid electric vehicles, among other applications. In August 2007, A123Systems and General Motors (GM) announced the co-development of A123Systems' nanophosphate battery for use in GM's electric drive E–Flex system for its hybrid vehicles. This joint effort is expected to expedite the development of batteries for both electric plug-in hybrid vehicles and fuel cell-based vehicles.

There are many illustrations of the importance of BES fundamental research, but I am particularly proud of five broad program areas that have had significant and long-term impacts in:

- *the design and discovery of new materials,* which have led to improved magnetic materials, superconductors, semiconductors, ceramics, alloys, and a host of new and exotic materials of potential technological importance;
- *the determination of the mechanisms of catalysis and the rational design of new catalysts,* which have impacted virtually all of the DOE energy missions including conversion of crude oil, natural gas, coal and biomass into clean burning fuels and the development of less-energy-demanding routes for the production of basic chemical feedstocks;
- *the conversion of energy from the sun* to electricity and to useful fuels through comprehensive programs integrating chemistry, materials sciences, and biosciences;
- *the determination of the chemical and physical properties of the heavy elements* (the actinides, their fission products, and the transactinides), which supports DOE missions in advanced nuclear fuels, predictions of how spent nuclear fuels degrade, and how radionuclides are transported under repository conditions; and
- *the development of major tools of the physical sciences* for visualizing materials at the atomic level and in real time, particularly the tools and facilities for x-ray, neutron, and electron beam scattering and the tools for ultrafast chemistry.

These activities represent comprehensive national programs and, in most cases, these are truly unique national programs.

The conviction that basic research in the physical sciences is a wellspring of new energy technologies was the inspiration for a series of *Basic Research Needs* workshops linking the basic research, applied research, and development communities in topical areas relevant to energy resources, production, conversion, transmission, storage, efficiency, and waste mitigation. The workshops, which were initiated in 2001, created levels of excitement and energy in the basic research communities supported by the BES program that I had never before experienced.

The workshops described how basic research could help address short-term showstoppers in energy technologies (such as the development of storage materials for hydrogen) and also how basic research must address grand science challenges to provide the foundation for new, transformational technologies. The workshops helped create a research portfolio in the BES program that both serves the present and shapes the future. Such a portfolio can underpin a national decades-to-century energy strategy.

Together, these workshop reports highlighted a remarkable scientific journey that took place during the past few decades. The resulting scientific challenges, which no longer were discussed in terms of traditional scientific disciplines, described a new era of science—an era in which materials functionalities would be designed to specifications and chemical transformations would be manipulated at will.

Over and over, the recommendations from the workshops described similar themes—that in this new era of science we would design, discover, and synthesize new materials and molecular assemblies through atomic scale control; probe and

[1] Electric current flows out of the cathode.

control phonon,[2] photon, electron, and ion interactions with matter; perform multiscale modeling that bridges multiple length and time scales; and use the collective efforts of condensed matter and materials physicists, chemists, biologists, molecular engineers, and those skilled in applied mathematics and computer science.

The importance of the nanoscale was another recurring theme. At the root of the opportunities provided by nanoscience is the fact that all of the elementary steps of energy conversion (e.g., charge transfer, molecular rearrangement, and chemical reactions) take place on the nanoscale. Thus, the development of new nanoscale materials, as well as the methods to characterize, manipulate, and assemble them, create an entirely new paradigm for developing new and revolutionary energy technologies. The five new Nanoscale Science Research Center user facilities, which the BES program recently completed, were conceived because of this, and they have become the signature contribution of the DOE to the National Nanotechnology Initiative.

To become as proficient—or ideally even more proficient—than nature in making and transforming materials will require knowledge that we do not yet have. This challenge cannot be overstated. Even basic concepts elude us. For example, we do not understand the mechanism of high-temperature superconductivity, which was discovered more than 20 years ago; yet without such understanding the rational design of new superconductors is impossible. We have limited ability to conceptualize, calculate, or predict processes far from equilibrium; yet all natural and most interesting human-induced phenomena occur in systems that are away from the equilibrium. All living systems exist far from equilibrium. Quite succinctly, we can articulate the challenges, but today's scientific tools are not sufficient to address them. We are looking for new concepts and theories to understand how nature works. The disciplines supported by the BES program seek a 21st century equivalent to the development of quantum mechanics 100 years ago.

The scientific user facilities that the BES program supports—five Nanoscale Science Research Centers and the world's largest suite of synchrotron radiation light source facilities, neutron scattering facilities, and electron-beam microcharacterization centers—enable the fabrication of new materials and the examination of materials and their transformations at the atomic scale through x-ray, neutron, and electron beam scattering. These facilities derive directly from the needs of the research program. Once the province of a few hundred specialists, mostly physicists, these scattering facilities now are used by nine thousand researchers annually from dozens of disciplines and subdisciplines.

The BES program facilities were driven by the need to correlate the microscopic structure of materials with their macroscopic properties, a topic that long predates our knowledge of the existence of atoms. The visible light microscope, invented about four hundred years ago and based on optics studies dating back one thousand years, gave us an initial glimpse of nature's assemblies. The microscope opened the world of mineral, plant, and animal structures and even showed us individual cells. Although now superbly perfected, the fundamental laws of physics limit the resolution (i.e., the smallest features that can be seen) of visible light microscopes to features equal to the wavelength of visible light, roughly a few hundred nanometers. The typical size of an atom is tenths of a nanometer. Thus, instruments with resolutions one thousand times better than the best visible light microscopes are required to see atoms. The laws of physics, which explain why these first microscopes fail to resolve individual atoms, also point to the solution. To see atoms, we must use substitutes for visible light—probes that are themselves as small as the atoms under investigation. Three such probes are x-rays, electrons, and neutrons. The ability of these probes to teach us about the arrangements of atoms in materials was realized soon after their discovery in the early 1900s.

The resulting facilities for x-ray, electron, and neutron scattering that were planned, constructed, and are now operated by the BES program have revolutionized our understanding of materials. These facilities—and their availability to the broad national and international communities—are one of the great success stories of the BES program and the DOE.

During the past 10 years, the BES program has delivered nearly $2 billion of facilities and upgrades on schedule and within budget. Among others, this includes the Spallation Neutron Source, the complete reconstruction of the Stanford Synchrotron Radiation Laboratory, five Nanoscale Science Research Centers, and numerous instrument fabrication projects. On the drawing board and under construction are future generations of each of these facilities as well as future generations of the instruments used at them. Many of these new facilities will be complex, costly, and time consuming to construct. Billion-dollar-class facilities with construction times of

[2] A phonon is a quantized vibration in the crystal structure of a solid.

six to eight years will not be unusual. As in the past, continued sound planning for them is critical.

In what follows, I provide additional details on the BES program and its subprograms; some likely future priorities for both research and facilities, including the mechanisms for establishing these priorities; and the importance of a program of R&D integration that recognizes the respective roles of discovery, innovation, application, development, and deployment.

Addressing the Nation's Energy Challenges in the New Era of Science

The 21st century has brought with it the recognition of staggering challenges for advanced energy technologies. Finite supplies of fossil fuel resources, uneven distribution of those resources, and the negative global effects of their use demand change. It is unlikely that incremental advances in current energy technologies, many of which are rooted in 19th century discoveries and 20th century development, will meet the need for the projected doubling or tripling of world energy consumption by the end of the 21st century.

BES and its predecessor organizations have supported a program of fundamental research focused on critical mission needs of the Nation for over five decades. The federal program that became BES began with a research effort initiated to help defend our nation during World War II. The diversified program was organized into the Division of Research with the establishment of the Atomic Energy Commission in 1946 and was later renamed Basic Energy Sciences as it continued to evolve as a result of provisions included in the *Atomic Energy Act of 1954,* the *Energy Reorganization Act of 1974,* the *Department of Energy Organization Act of 1977,* and the *Energy Policy Acts of 1992* and *2005.*

Today the research supported by the BES program touches virtually every aspect of energy resources, production, conversion, transmission, storage, efficiency, and waste mitigation. Research in materials sciences and engineering leads to the development of materials that improve the efficiency, economy, environmental acceptability, and safety of energy generation, conversion, transmission, storage, and use. Research in chemistry leads to the development of advances such as efficient combustion systems with reduced emissions of pollutants; new solar photoconversion processes; improved catalysts for the production of fuels and chemicals; and better separations and analytical methods for applications in energy processes, environmental remediation, and waste management. Research in geosciences results in advanced monitoring and measurement techniques for reservoir definition and an understanding of the dynamics of complex fluids, such as oil, flowing through porous and fractured subsurface rock. Research into the molecular and biochemical nature of photosynthesis aids the development of solar photo-energy conversion.

As described above, in 2001 the Basic Energy Sciences Advisory Committee conducted a major study to assess the scope of fundamental scientific research that must be considered to address the DOE missions in energy efficiency, renewable energy resources, improved use of fossil fuels, safe and environmentally acceptable nuclear energy, future energy sources, and reduced environmental impacts of energy production and use. The results of the week-long workshop were published in early 2003 in the report *Basic Research Needs to Assure a Secure Energy Future.* That report inspired a series of ten follow-on *Basic Research Needs* workshops over the next five years, which together attracted more than 1,500 participants from universities, industry, and DOE laboratories. The topics of the ten workshops were: the hydrogen economy, solar energy utilization, superconductivity, solid-state lighting, advanced nuclear energy systems, combustion of 21st century transportation fuels, electrical-energy storage, geosciences as it relates to the storage of energy wastes (the long-term storage of both nuclear waste and carbon dioxide), materials under extreme environments, and catalysis for energy-related processes.

After the first workshop in early 2003, *Basic Research Needs for the Hydrogen Economy,* the BES program issued solicitations for FY 2005 funding for individual investigator and small-group awards in areas of hydrogen production, storage, and use. An astounding 668 qualified pre-applications were received in five submission categories: novel materials for hydrogen storage; membranes for separation, purification, and ion transport; design of catalysts at the nanoscale; solar hydrogen production; and bio-inspired materials and processes. Three of the five focus areas—novel storage materials, membranes, and design of catalysts at the nanoscale—accounted for about 75 percent of the submissions. Following a review, principal investigators on about 40 percent of the pre-applications were invited to submit full applications; 227 full applications were received; and 70 awards were made totaling $21,473,000. Additional funding of $7,205,000 was awarded in subsequent years. BES involved staff from the DOE Office of Energy Efficiency and Renewable Energy (EERE) in the pre-application review process to ensure basic research relevance to technology program goals. Furthermore, BES program staff began participating in the DOE Hydrogen Program Annual Merit Review, which also involved EERE and the DOE Offices of Fossil Energy and Nuclear Energy, to promote information sharing. Beginning in FY 2006, the BES program staff organized parallel sessions at that meeting for the BES principal investigators.

This funding has enabled significant advances in understanding hydrogen-matter interactions. Recent accomplishments include:

- the discovery of atomic-scale mechanisms explaining reversible hydrogen storage within complex metal hydrides;
- the development of novel micro- and nano-patterning syntheses for a new generation of fuel cell membranes with superior power output;
- theoretical predictions and experimental validation of new architectures and compositions of catalyst alloys for efficient hydrogen production from fossil fuels as well as for fuel cell applications;
- the synthesis of mixed metal oxide photoelectrodes for solar hydrogen production;
- the identification of chemical pathways to convert biomass to hydrogen and other fuels; and
- advances in the development of oxygen-tolerant enzymes for bio-inspired hydrogen production.

A number of these accomplishments have led to follow-up developments by the applied research programs. Of particular note is the successful development of electrocatalysts with ultra-low platinum content that are 20 times more active by mass and more stable than pure platinum for converting hydrogen to electricity in fuel cell applications and dramatically reduce the cost of potential future fuel cell systems.

The Energy Frontier Research Centers

Very similar scientific themes emerged from multiple workshops in the *Basic Research Needs* series, and it became clear that in the future we would need broader solicitations than those used to support work in hydrogen production, storage, and use. The workshops also showed that the challenges of energy research transcend any single discipline and very often require many different disciplines to join together. In addition, during the years that the workshops were underway (2001–2007), we saw the advent of energy/environment centers at universities across the Nation and at DOE laboratories. Requests for funding from both the academic sector and the laboratory sector became commensurately larger and more multi-disciplinary as groups of researchers joined together to tackle difficult problems in energy research. This prompted discussions over the past few years about the establishment of Energy Frontier Research Centers to complement the existing single-investigator awards and small-group (but largely single-discipline) awards.

With completion of the final *Basic Research Needs* workshop in late 2007, the BES program was primed to propose and implement an Energy Frontier Research Centers program in the FY 2009 Presidential Budget Request. The Energy Frontier Research Centers should be viewed as a funding mechanism, along with the more traditional single-investigator and small-group grants, rather than a new program. The Energy Frontier Research Centers represents about 15 percent of the total BES research portfolio in FY 2009. Depending on the results of the first solicitation, it is possible that the program might grow to a maximum of perhaps 25 percent of the total BES research portfolio over a period of five to ten years.

The Energy Frontier Research Centers awards are expected to be in the $2–$5 million range annually for an initial five-year period. A 2008 Funding Opportunity Announcement requested applications from the scientific community in a competition open to academic institutions, DOE laboratories, and other institutions as well as to partnerships among them. The Energy Frontier Research Centers are expected to bring together the skills and talents of multiple investigators to enable research of a scope and complexity that would not be possible with the standard individual investigator or small group awards. Up to $100,000,000 will be awarded in FY 2009, pending appropriations, and will support perhaps 25 to 35 individual centers. No building construction will be part of the awards. As the program matures, it is anticipated that competitions will be held every few years and that renewal submissions will be openly competed with new submissions.

General Comments on R&D Integration

As is demonstrated by the *Basic Research Needs* workshop series, the BES program is committed to R&D integration. The workshops and their follow-on solicitations seek to partner the BES program with its counterparts in the DOE technology offices. More broadly, DOE coordinates its basic research efforts in the Office of Science programs with the Department's applied technology offices through a number of processes and mechanisms. These include:

- scientific and technical workshops such as the *Basic Research Needs* series;
- structured, targeted research efforts driven by program manager-level coordination between the basic and applied R&D programs;
- joint program planning and/or program reviews;
- joint funding solicitations or jointly coordinated solicitations;
- shared grantee/contractors meetings and conferences to bring the research communities together;
- portfolio assessment efforts by structured oversight groups (DOE R&D Council); and
- coordination working group efforts guided by senior management (DOE S&T Council).

Coordination between the basic and applied programs is also enhanced through joint programs, jointly funded scientific facilities, the program management activities of the DOE Office of Science Small Business Innovation Research and Small Business Technology Transfer Programs, and the Experimental Program to Stimulate Competitive Research. DOE program managers have established formal technical coordinating committees (e.g., the Energy Materials Coordinating Committee) that meet on a regular basis to discuss R&D programs with wide applications for basic and applied programs. Additionally, co-funding research activities and facilities at the DOE laboratories and using funding mechanisms that encourage broad partnerships are also means by which DOE facilitates greater communication and research integration within the S&T communities. Taken in sum, these coordination activities are widespread and have contributed significantly to DOE's capabilities and success in achieving mission goals.

Basic Energy Sciences Subprogram Details

The Basic Energy Sciences program has two subprograms: Materials Sciences and Engineering, which supports research and all of the facility operations, and Chemical Sciences, Geosciences, and Biosciences, which supports research. The two research components and the facility operations component are described below.

Materials Sciences and Engineering Research

This activity supports fundamental experimental and theoretical research to provide the knowledge base for the discovery and design of new materials with novel structures, functions, and properties.

In *condensed matter and materials physics*—including activities in experimental condensed matter physics, theoretical condensed matter physics, materials behavior and radiation effects, and physical behavior of materials—research is supported to understand, design, and control materials properties and function. These goals are accomplished through studies of the relationship of materials structures to their electrical, optical, magnetic, surface reactivity, and mechanical properties and of the way in which materials respond to external forces such as stress, chemical and electrochemical environments, radiation, and the proximity of materials to surfaces and interfaces. The activity emphasizes strongly correlated materials, which are a wide class of materials that show unusual, often technologically useful, electronic and magnetic properties. Intensively studied strongly correlated materials include the high-temperature superconductors.

In *scattering and instrumentation sciences*—including activities in neutron and x-ray scattering and electron and scanning probe microscopies—research is supported on the fundamental interactions of photons, neutrons, and electrons with matter to understand the atomic, electronic, and magnetic structures and excitations of materials and the relationship of these structures and excitations to materials properties and behavior. Major research areas include fundamental dynamics in complex materials, correlated electron systems, nanostructures, and the characterization of novel systems. The development of next generation neutron, x-ray, and electron microscopy instrumentation is a key element of this portfolio.

In *materials discovery, design, and synthesis*—including activities in synthesis and processing science, materials chemistry, and biomolecular materials—research is supported in the discovery and design of novel materials and the development of innovative materials synthesis and processing methods. Major research thrust areas include nanoscale synthesis, organization of nanostructures into macroscopic structures, solid state chemistry, polymers and polymer composites, surface and interfacial chemistry including electrochemistry and electro-catalysis, synthesis, and processing science including biomimetic and bioinspired routes to functional materials and complex structures.

Chemical Sciences, Geosciences, and Biosciences Research

This activity supports experimental and theoretical research to provide fundamental understanding of chemical transformations and energy flow in systems relevant to DOE missions.

In *fundamental interactions,* basic research is supported in atomic, molecular, and optical sciences; gas-phase chemical physics; ultra-fast chemical science; and condensed phase and interfacial molecular science. Emphasis is placed on structural and dynamical studies of atoms, molecules, and nanostructures, and the description of their interactions in full quantum detail, with the aim of providing a complete understanding of reactive chemistry in the gas phase, condensed phase, and at interfaces. Novel sources of photons, electrons, and ions are used to probe and control atomic, molecular, and nanoscale matter. Ultra-fast optical and x-ray techniques are developed and used to study chemical dynamics.

In *photochemistry and biochemistry,* research is supported on the molecular mechanisms involved in the capture of light energy and its conversion into chemical and electrical energy through biological and chemical pathways. Natural photosynthetic systems are studied to create robust artificial and bio-hybrid systems that exhibit the biological traits of self assembly, regulation, and self repair. Complementary research encompasses organic and inorganic photochemistry, photo-induced electron and energy transfer, photoelectrochemistry, and molecular assemblies for artificial photosynthesis. Photoelectrochemical conversion is explored in studies of nanostructured semiconductors. Biological energy transduction systems are investigated, with an emphasis on the coupling of plant development and microbial biochemistry with the experimental and computational tools of the physical sciences.

In *chemical transformations,* the themes are characterization, control, and optimization of chemical transformations, including efforts in catalysis science; separations and analytical science, actinide chemistry, and geosciences. Catalysis science underpins the design of new catalytic methods for the clean and efficient production of fuels and chemicals and emphasizes inorganic and organic complexes; interfacial chemistry; nanostructured and supramolecular catalysts, photocatalysis and electrochemistry, and bio-inspired catalytic processes. Heavy element chemistry focuses on the spectroscopy, bonding, and reactivity of actinides and fission products; complementary research on chemical separations focuses on the use of nanoscale membranes and the development of novel metal complexes. Chemical analysis research emphasizes laser-based and ionization techniques for molecular detection, particularly the development of chemical imaging techniques. Geosciences research covers analytical and physical geochemistry, rock-fluid interactions, and flow/transport phenomena; this research provides a fundamental basis for understanding the environmental contaminant fate and transport and for predicting the performance of repositories for radioactive waste or carbon dioxide sequestration.

Scientific User Facilities Operations

This activity supports the R&D, planning, and operation of scientific user facilities for the fabrication of materials and for the examination of materials through x-ray, neutron, and electron beam scattering.

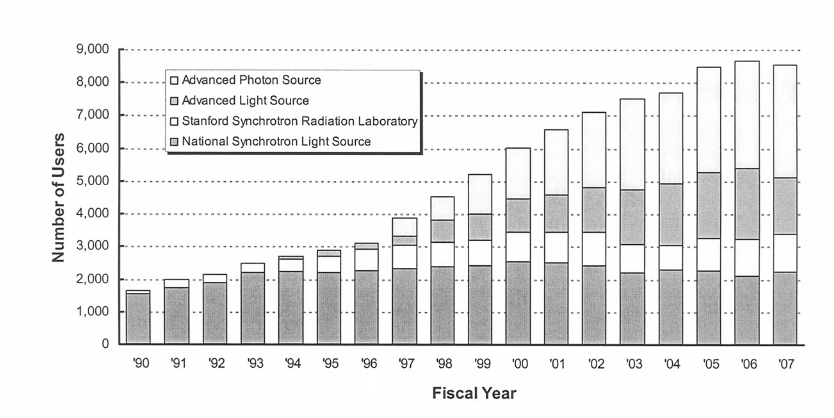
For approved, peer-reviewed projects, operating time is available without charge to researchers who intend to publish their results in the open literature. The synchrotron light sources, producing mostly soft and hard x-rays, examine the fundamental parameters used to perceive the physical world (energy, momentum, position, and time). The unique properties of synchrotron radiation—high flux and brightness, tunability, polarizability, and high spatial and temporal coherence, and the pulsed nature of the beam—afford a wide variety of experimental techniques in diffraction and scattering, spectroscopy, and spectrochemical analysis, imaging, and dynamics. Neutron sources take advantage of the electrical neutrality and special magnetic properties of the neutron to probe atoms and molecules and their assembly into materials. With unique characteristics such as sensitivity to light elements, neutron scattering has proven to be invaluable to polymer and biological sciences. The high penetrating ability of neutrons allows property measurements and nondestructive evaluation deep within a specimen. Neutrons have magnetic moments and are thus uniquely sensitive probes of magnetic species within a sample. The Nanoscale Science Research Centers provide the ability to fabricate complex nanostructures using chemical, biological, and other synthesis techniques, to characterize them, to assemble them, and to integrate them into devices.

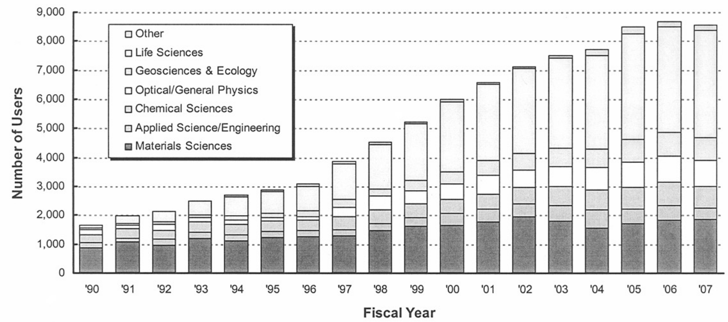
Because of the large numbers of users who visit the synchrotron radiation light sources—nearly half of all users of the Office of Science facilities—the light sources are of particular interest. The size and demographics of the user community have changed dramatically since the 1980s when only a few hundred intrepid users visited the light sources each year.

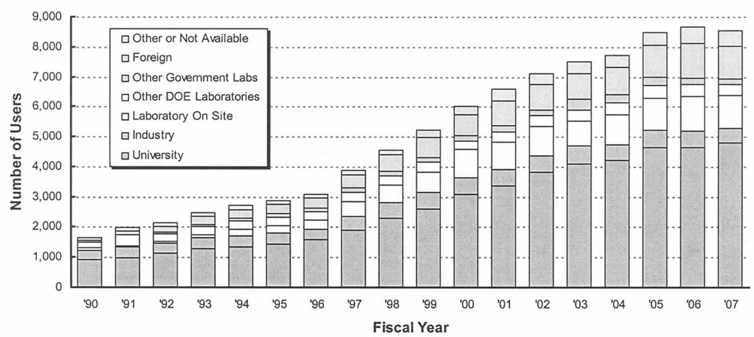
In the charts below, many demographic trends are illustrated. Among other things, the commissioning of the Advanced Light Source at Lawrence Berkeley National Laboratory in 1993 and the Advanced Photon Source at Argonne National Laboratory in 1996 more than doubled the capacity of the light sources. The growth in users was additionally spurred by the influx of new users, notably those who studied macromolecular crystallography. Finally, it is interesting to note that the total number of users reached a maximum in FY 2006. This is largely due to funding limitations during FY 2006 through FY 2008.

The charts below show the numbers of users at the BES synchrotron radiation light sources each year as a function of facility (Chart 1); user discipline (Chart 2); and user home institution (Chart 3). In Chart 1, APS is the Advanced Photon Source at Argonne National Laboratory; ALS is the Advanced Light Source at Lawrence Berkeley National Laboratory; SSRL is the Stanford Synchrotron Radiation Laboratory at Stanford Linear Accelerator Center; and NSLS is the National Synchrotron Light Source at Brookhaven National Laboratory.

In all of the charts below, there is a standard definition of "user." A user is a researcher who proposes and conducts peer-reviewed experiments at a scientific facility or conducts experiments at the facility remotely. A user does not include individuals who only send samples to be analyzed, pay to have services performed, or visit the facility for tours or educational purposes. The term user also does not include researchers who collaborate on the proposal or subsequent research paper but do not conduct experiments at the facility. For annual totals, an individual is counted as one user at a particular facility no matter how often or how long the researcher conducts experiments at the facility during the year.







Several years ago the BES program reevaluated the metrics used to assess effective operation and utilization of the synchrotron light source facilities, looking potentially to broaden the metrics from those used previously in annual reports to Congress: hours of operation of the accelerator complex and numbers of users who annually visit the facilities. With the cooperation of the facilities, new measures were devised that provided quantitative assessments of instrument capability, instrument capacity, and staffing levels. These measures were piloted in FY 2005 and FY 2006, and data were collected for FY 2007 and FY 2008 as well. These pilot studies show that overall effectiveness of operation and utilization of the synchrotron light sources could be improved but that usually such improvements would require additional operations costs, although some improvements could be gained from enhanced strategic planning within and across facilities. These studies supported enhanced funding requests for the facilities in FY 2007 and FY 2008; however, the proposed increases were not funded in the appropriations for those years. Increases have been requested again in FY 2009.

Future Directions

The BES program supports a broad portfolio of work, and planning for the future is an ongoing activity. The first set of *Basic Research Needs* workshops and the report *Directing Matter and Energy: Five Challenges for Science and the Imagination* are complete. Together they describe a continuum of research from the most fundamental questions of how nature works to the "show-stopper" questions in the applied research programs supported by the DOE technology offices. The BES programs' portfolios have been reassessed and restructured as necessary to reflect the results of these workshops. In addition to the work identified in these workshops, other BES priority areas include general support for ultrafast science, chemical imaging, and mid-scale instrumentation. Funding for all of these activities was requested in FY 2007–FY 2009; however, the FY 2007 and FY 2008 appropriations were not sufficient to support many of the new directions.

Planning for the facilities sponsored by the BES program is also an ongoing activity. The BES program has a long tradition of planning, constructing, and operating facilities well. During the past 10 years, the BES program has delivered nearly $2 billion of facilities and upgrades on schedule and within budget. Among others, this includes the Spallation Neutron Source, the complete reconstruction of the Stanford Synchrotron Radiation Laboratory, five Nanoscale Science Research Centers, and numerous instrument fabrication projects for the major scientific user facilities.

The 2003 Office of Science report, *Facilities for the Future of Science: A Twenty-Year Outlook,* describes the long-range plan for the Office of Science facilities. As high priorities, the report includes construction of the Linac Coherent Light Source, which is nearing completion and will begin operations in FY 2009, and the Transmission Electron Aberration-corrected Microscope, which already has delivered an early prototype.

Mid-term priorities include upgrades to the Spallation Neutron Source, which was commissioned in FY 2006. The upgrades consist of an energy upgrade to the linac and the construction of a second target station; the former will undergo cost and schedule baselining this year, and the later is preparing for Critical Decision 0, Approval of Mission Need. Another mid-term priority is the construction of the National Synchrotron Light Source-II. This project moved up in priority owing to elimination of technical impediments, and it is scheduled to begin construction in FY 2009.

Far-term priorities include upgrades to the Advanced Photon Source and the Advanced Light Source. These activities as well as the consideration of next-generation light sources are now under consideration by the BES program. Recently, the Basic Energy Sciences Advisory Committee has been charged to sponsor a Photon Workshop to consider the science drivers for new photon sources. The workshop will identify new grand energy and scientific opportunities in materials, chemistry, biology, medicine, environment, and physics that can be addressed with diffraction, excitation, and imaging by photons. The primary outputs of the workshop will be (1) the evaluation of the impact of each new opportunity in advancing the frontier of science or enabling new approaches to energy challenges, and (2) the definition of the photon attributes required to realize each opportunity. The photon attributes include coherence length, time structure, energy, energy resolution, brightness, intensity, spatial resolution, and polarization. It is expected that this workshop will help set the course for photon science facilities for the next decade.

Five-year BES program planning is consistent with funding profiles proposed by the *America COMPETES Act of 2007* (P.L. 110–69), which would lead to a doubling of funding in the Office of Science in seven years.

Concluding Remarks

Thank you, Mr. Chairman, for providing this opportunity to discuss the Basic Energy Sciences program. This concludes my testimony, and I would be pleased to answer any questions you might have.

BIOGRAPHY FOR PATRICIA M. DEHMER

Patricia M. Dehmer is the Deputy Director for Science Programs in the Office of Science at the U.S. Department of Energy (DOE). In this position, Dr. Dehmer is the senior career science official in the Office of Science, which supports more than $4B in research annually. Dr. Dehmer provides scientific and management oversight for the six science programs, for workforce development for teachers and scientists, and for construction project assessment. The Office of Science supports research at 300 colleges and universities nationwide, at DOE laboratories, and at other private institutions.

From 1995 to 2007, Dr. Dehmer served as the Director of the Office of Basic Energy Sciences in the Office of Science. She built a world-leading portfolio of work in condensed matter and materials physics, chemistry, and biosciences. During this period, Dr. Dehmer also was responsible for the planning, design, and construction phases of more than a dozen major construction projects totaling $3 billion. Notable among these were the $1.4B Spallation Neutron Source at Oak Ridge National Laboratory, five Nanoscale Science Research Centers totaling more than $300M, and the start of two new facilities for x-ray scattering—the Linac Coherent Light Source at SLAC, which is the world's first hard x-ray free electron laser, and the National

Synchrotron Light Source–II at Brookhaven National Laboratory, which will provide the highest spatial resolution of any synchrotron light source in the world.

Dr. Dehmer began her scientific career as a postdoctoral fellow at Argonne National Laboratory in 1972. She joined the staff of the Laboratory as an Assistant Scientist in 1975 and became a Senior Scientist in 1985. In 1992, the Laboratory established a new scientific rank that recognizes sustained outstanding scientific and engineering research, and Dr. Dehmer was among the one percent of the Laboratory's technical staff promoted to that rank, now called Argonne Distinguished Fellow.

Dr. Dehmer received the Bachelor of Science degree in Chemistry from the University of Illinois and the Ph.D. degree in Chemical Physics from the University of Chicago. Her studies of the interactions of electronic and atomic motion in molecules provided fundamental understanding of energy transfer, molecular rearrangement, and chemical reactivity and resulted in more than 125 peer-reviewed publications.

Dr. Dehmer is a fellow of the American Physical Society and the American Association for the Advancement of Science. For the 15 years prior to joining DOE, she served in dozens of elected and appointed positions in scientific and professional societies and on review boards. Dr. Dehmer was awarded the Meritorious Presidential Rank Award in 2000 and the Distinguished Presidential Rank Award in 2003.

Chairman LAMPSON. Thank you, Dr. Dehmer. Dr. Dierker, you are recognized.

STATEMENT OF DR. STEVEN B. DIERKER, ASSOCIATE LABORATORY DIRECTOR FOR LIGHT SOURCES; NATIONAL SYNCHROTRON LIGHT SOURCE II PROJECT DIRECTOR, BROOKHAVEN NATIONAL LABORATORY

Dr. DIERKER. Thank you, Mr. Chairman, and also Congresswoman Biggert for the opportunity to provide testimony on the Basic Energy Sciences Program. I have served as the Director of the National Synchrotron Light Source since 2001 and then more recently as the Associate Lab Director for Light Sources and Project Director for the National Synchrotron Light Source II Project at Brookhaven National Lab, I am pleased to share with you my perspective on the synchrotron light sources operated by the BES Program.

Under BES leadership, the four BES light source facilities have thrived and flourished. They have really become one of the great success stories of the past 25 years. Created by a handful of pioneering physicists, they are now used by more than 8,000 academic, industrial, and government researchers annually from all disciplines and from every state in the United States as well as overseas. My own experience with the National Synchrotron Light Source (NSLS) is representative of the other BES light sources. With close to 1,000 publications per year, the NSLS is one of the most prolific scientific facilities in the world. Each year it attracts about 2,200 scientists from 350 universities and 90 companies to conduct research at 65 beamlines in such diverse fields as biology, physics, chemistry, geology, medicine, environmental, and material science.

The BES light sources give researchers unique capabilities for carrying out basic research that is essential for the development of future energy technologies. For example, using the BES light sources, scientists have studied catalysts that could help improve the performance of hydrogen-powered fuel cells, a key component of future clean car technologies; have studied the electrolytes in lithium ion batteries with the aim of improving their performance; have studied the properties of high temperature superconductors, materials that conduct electricity with almost zero resistance and promise high-efficiency transmission of power for the electric grid; and have studied flame chemistry and combustion leading to more efficient designs for fuel spray nozzles. These are only a few examples of the wide-range, high-impact fundamental and applied research made possible by the light sources.

The goal in operating a major light source facility is to enable world-class science and technology and to operate with maximum effectiveness for all users. Large numbers of users now want to use a very limited number of beamlines, a situation distinctly different from that even 20 years ago. Many beamlines are oversubscribed and cannot meet user demand for beamtime. The light sources truly represent a scarce national resource. As a result of these trends, the BES light source facilities are taking a greater role in constructing and operating the beamlines and instruments in order to better accommodate user needs and to ensure stable, reliable operations.

In selecting the beamlines to be constructed at the facilities, facility management needs to ensure that the appropriate capabilities are present so that it is as productive as possible. Planning needs to prioritize among competing demands and strike the appropriate balance between different communities. All key stakeholders, including the user community, funding agencies, and facility management, actively engage in facility planning through workshops, white papers, advisory committee meetings, and others. This inclusiveness in planning is a hallmark of the DOE selection process and is a key contributor to DOE's successful management of the light sources.

Light sources routinely operate 5,500 hours per year, or about 24 hours per day for 230 days. The accelerators at the heart of the light sources operate very reliably, generally delivering 95 percent of their scheduled time. However, not all of the beamlines are operating at their full potential. It is critically important that today's facilities be provided full support for operations to meet the ever increasing demand for synchrotron facilities. Support for research and development for new instrumentation and detectors is equally important.

The utility of today's light sources have been greatly expanded by technological progress in many areas. However, there is a critical need for even more advanced and powerful storage ring based light sources. The economic and energy security of the United States requires we make major advances in developing alternative energy and pollution control technologies. Achieving this will require basic research leading to scientific breakthroughs and developing new materials with previously unimagined properties.

To realize this promise, it is essential that we develop new synchrotron radiation tools that will allow the characterization of materials with nanoscale resolution, capability that doesn't exist today. In order to fill this, the program is carrying out the design and construction of the National Synchrotron Light Source II which will give this capability. No other synchrotron light source will have the beam characteristics of this facility, and it will be part of a new era of science that is key to America's competitiveness.

The program has outstanding track records successfully constructing large and very productive facilities. The construction plans for facilities are subjected to rigorous series of reviews, and the resulting cost, schedule, and technical baselines establish realistic goals for the construction of those facilities.

As a project director, I have opportunity to work closely with the program management as part of the integrated project team that shares a common goal of constructing the new facility on schedule and within the approved budget. It is a pleasure to work with a DOE team that has such an excellent track record and understanding of the challenges in construction of new facilities.

Thank you, Mr. Chairman, for providing this opportunity to discuss the program.

[The prepared statement of Dr. Dierker follows:]

PREPARED STATEMENT OF STEVEN B. DIERKER

Thank you Mr. Chairman, Ranking Member Inglis, and Members of the Committee for the opportunity to appear before you to provide testimony on the Basic Energy Sciences (BES) Program in the Department of Energy's (DOE's) Office of Science (SC). I have worked in industry, in academia, and, since 2001, in the DOE national laboratory system, first as Director of the National Synchrotron Light Source and most recently as the Associate Laboratory Director for Light Sources and the Project Director for the National Synchrotron Light Source II Project at Brookhaven National Laboratory. I am pleased to share with you my perspectives on the synchrotron radiation light sources operated by BES.

Synchrotron radiation light sources

Under BES leadership, the four BES light source facilities, the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory (BNL), the Stanford Synchrotron Radiation Laboratory (SSRL) at the Stanford Linear Accelerator Center (SLAC), the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (LBNL), and the Advanced Photon Source (APS) at Argonne National Laboratory (ANL), have thrived and flourished. They have become one of the great success stories of the past 25 years. Created by a handful of pioneering physicists, they are now used by more than 8,000 academic, industrial, and government researchers annually from all disciplines and from every state in the U.S. as well as foreign countries.

My own experience is with the National Synchrotron Light Source, which is representative of the other BES light sources. With close to 1,000 publications per year, the NSLS is one of the most prolific scientific facilities in the world. Each year, it attracts about 2,200 scientists from 350 universities and 90 companies to conduct research at 65 beamlines in such diverse fields as biology, physics, chemistry, geology, medicine, and environmental and materials sciences.

The BES light sources give researchers unique capabilities for carrying out basic long-term research that is essential for the development of future energy technologies. For example, using the BES light sources, scientists:

- have studied catalysts that could help improve the performance of hydrogen-powered fuel cells, a key component of future clean-car technologies;
- have studied electrolytes in lithium-ion batteries with the aim of improving their performance;
- have studied the properties of high-temperature superconductors, materials that conduct electricity with almost zero resistance and promise high efficiency transmission of power for the electric grid; and
- have studied flame chemistry and combustion, leading to more efficient designs for fuel spray nozzles.

These are only a few examples of the wide-ranging high-impact fundamental and applied research made possible by the synchrotron radiation light sources.

User Access and Facility Management

The goal in operating a major light source facility is to enable world-class science and technology and to operate with maximum effectiveness for all users. Large numbers of users now want to use a very limited number of beamlines, a situation distinctly different from that even 20 years ago. Many beamlines are oversubscribed and cannot meet user demand for beamtime. The light sources represent a scarce national resource. As a result of these trends, the BES light source facilities are taking a greater role in constructing and operating the beamlines and instruments in order to better accommodate user needs and to ensure stable, reliable operations.

In selecting the beamlines to be constructed at the light source facilities, facility management needs to ensure that the appropriate capabilities are present at the facility so that it is as productive as possible. Facility planning needs to prioritize among competing demands and strike the appropriate balance between different scientific communities. All key stakeholders, including the user community, funding agencies, and facility management, are actively engaged in facility planning through workshops, whitepapers, advisory committee meetings, and other means. This inclusiveness in planning is a hallmark of the DOE selection process and is a key contributor to DOE's successful management of the light source facilities.

BES light sources routinely operate about 5,500 hours per year, i.e., 24 hours per day for about 230 days, with the remainder required for necessary maintenance and upgrades. The accelerators at the heart of the light sources operate very reliably, generally delivering 95 percent or more of their scheduled operating hours. However, not all of the beamlines are operating at their full potential. It is critically important that today's facilities be provided full support for operations to meet the ever increasing demand for synchrotron radiation facilities. Support for research and development for new instrumentation and detectors is equally important to take maximum advantage of today's facilities.

Advances in Synchrotron Light Sources

The utility of today's light sources has been greatly extended by technological progress in many areas that has resulted in spectacular gains in source performance. Nevertheless, there is a critical need for even more advanced and powerful storage ring based light sources.

The economic and energy security of the United States requires that we make major advances in developing alternative energy and pollution control technologies—such as the use of hydrogen as an energy carrier; the widespread, economical use of solar energy; or the development of the next generation of nuclear power systems. Achieving this will require basic research leading to scientific breakthroughs in developing new materials with previously unimagined properties. Examples include catalysts that can split water with sunlight for hydrogen production, materials that can reversibly store large quantities of hydrogen, materials for efficient power transmission lines, materials for solid state lighting with 50 percent of present power consumption, and materials for reactor containment vessels that can withstand fast-neutron damage and high temperatures. The National Nanoscience Initiative is predicated on the promise of exploiting the remarkable changes in properties of materials when structured on the nanoscale to develop new materials with enhanced properties.

To realize this promise, it is essential that we develop new synchrotron radiation tools that will allow the characterization of the atomic and electronic structure, the chemical composition, and the magnetic properties of materials with nanoscale resolution, capabilities that are beyond today's light sources. In order to fill this capability gap and to further the accomplishment of its mission, the BES program plans to construct the National Synchrotron Light Source II (NSLS–II) facility as a replacement for NSLS. NSLS–II will enable the study of material properties and functions, particularly materials at the nanoscale, at a level of detail and precision never before possible. No other synchrotron light source worldwide will have the beam characteristics and advanced instrumentation of NSLS–II. It will be part of a new era of science that is key to America's competiveness, where material properties can be sufficiently well understood to be predictable and ultimately tailored to specific applications.

Construction Project Management

The BES program has an outstanding track record, successfully constructing some of the largest and most productive facilities within the Office of Science. The so-called "Lehman Reviews" ensure that the lessons-learned within SC inform the plans for new facilities. The NSLS–II facility construction plans were subjected to a rigorous series of these SC Lehman reviews and the resulting cost, schedule, and technical baseline that was approved by the Deputy Secretary of Energy is robust, establishing realistic goals for the construction of the facility.

As the NSLS–II Project Director, I have the opportunity to work closely with the BES program management and the DOE Brookhaven Site Office as part of an Integrated Project Team that shares the common goal of constructing NSLS–II on schedule and within the approved budget. It is a pleasure to work with a DOE team that has such an excellent track record and understanding of the challenges encountered in the construction of new facilities.

In what follows, I provide additional details on these topics.

Synchrotron radiation light sources

Synchrotron radiation light sources are large and complex facilities for accelerating electrons to nearly the speed of light and then storing them in a circular orbit using a storage ring consisting of hundreds of large magnets and other components. At controlled points around the storage ring, the electrons are made to emit high intensity narrow beams of light at wavelengths that span the range from the infrared, through the visible, to soft, and hard x-rays. This synchrotron radiation light is a natural phenomena, similar to the starlight we see at night, but a synchrotron radiation light source produces much more intense and narrow beams and at many locations around the storage ring. These light beams are transported down "beamlines" to experiment stations containing sophisticated apparatus that allows researchers to use the light to study the properties of materials.

The information obtained in experiments carried out at synchrotron light sources often cannot be obtained any other way. A synchrotron radiation light source may have 60 or more of these experimental beamlines, all operating simultaneously. The facility can thus host a large number of research groups, all carrying out different experiments at the same time.

The wealth and variety of experimental techniques available at synchrotrons is characterized by the very wide photon energy range they can offer, from the far infrared to the very hard x-ray. Most techniques, and the instruments that enable these techniques to be performed, are associated with a particular photon energy range. Thus, the wide energy range offered to users is served by a wide variety of experimental techniques. While each of the beamlines is different and complementary, they can be grouped into the following four major categories:

Diffraction and scattering techniques make use of the patterns of light produced when x-rays are deflected by the closely spaced atoms in solids and are commonly used to determine the structures of fully ordered or partially ordered materials, from ferroelectrics for use in electronics to new superconductors for possible power applications.

Macromolecular crystallography is the most powerful method for the determination of the three-dimensional structure of large biological molecules (macromolecules). This technique can be used to design therapeutic drugs and determine the structure and mechanisms of enzyme, nucleic acids, viruses, and numerous other molecules in order understand life processes and how to better diagnose and treat disease.

Imaging techniques produce pictures with fine spatial resolution of the sample being studied, for use in research ranging from visualizing plaque formation in Alzheimer's disease patients to the environmental analysis of soils.

Spectroscopy is used to study the energies of particles that are emitted or absorbed by samples that are exposed to a light-source beam. It provides unique information on the composition of a sample and the chemical nature of the bonding. Experiments include measuring the concentration and chemical nature of impurities in systems, from soils to silicon solar cells, or measuring the excitations of magnetic systems to develop better performing nano-magnetic memory devices.

User Access and Facility Management

Users of the facilities include academic, industrial, and government scientists and engineers. The results of the vast majority of user research are made available in the public domain by publication in the open literature. There is also a limited need for access to carry out proprietary research that utilizes these unique facilities to benefit the national economy. Proprietary research is the only mode of user access for which there is a charge for beam time.

The facilities have adopted policies for user access that are designed to achieve the following objectives:

- ensure open and fair access by the scientific community at large;
- sustain the highest standards of scientific and technical excellence; and
- respond and adapt to varying user needs and funding realities

The key to delivery of outstanding science and technology is rigorous peer review that is fair, clear, expedient and sensitive to the needs of users. Various external independent advisory committees play key roles in providing this.

Users access the facilities by submitting proposals as either General Users or as Partner Users. General Users are individuals or groups who need access to beam time to carry out their research using existing beamlines. They typically only supply samples, but can also provide custom instrumentation or end-stations for the duration of their experiments. General Users apply for access by submitting a scientific proposal that is evaluated by an independent review panel. The amount of beam time allocated to the proposal depends on the rating of the proposal relative to other proposals requesting beam time and on beam time availability.

In some cases, users have a need to obtain experimental results on an expedited schedule. This is often the case when the synchrotron measurement can be done in a short amount of time and is only one step of an overall experimental program. Examples include high throughput measurement of properties of materials grown using combinatorial synthesis techniques, screening of protein molecules to identify large, well diffracting crystals, or the solution of many time critical analytical problems studied in industry. To serve this need, "Rapid Access" proposals receive an expedited review and can usually be scheduled for beamtime within a week or two.

Partner Users are individuals or groups who carry out research at beamlines and also enhance the beamline capabilities and/or contribute to its operation. Partner Users typically develop instrumentation in some manner, either bringing external financial and/or intellectual capital into the evolution of the beamlines, or by making an external contribution to the operation of the beamlines. Partner User contributions have to be made available to the General Users and so benefit them as well as the facility. To encourage involvement and in exchange for making these contributions available to General Users and the facility, Partner Users may be recognized for their investments by receiving a specified percentage of beam time on one or more beamlines for a limited period, typically several years, with the possibility of renewal.

Various models have emerged for allocation of beamline resources, i.e., for determining who specifies, builds, owns, operates, maintains, and uses the beamlines. Beamline allocation models range from Facility Owned and Operated Beamlines (FOOBs) that are built, owned, and operated by the facility for general users to Participating Research Teams (PRTs) and Cooperative Access Teams (CATs) in which consortia of outside users build, own, and operate the beamlines. PRTs and CATs are a special case of a Partner User group in which the PRT/CAT has brought in external funds to independently and wholly build, maintain, staff and operate a beamline. The PRT/CAT is required to provide some fraction of beamtime—typically 25 percent—to General Users and to provide training and assistance to General Users who are allocated beam time on their beamline. In exchange, the PRT has complete control over the beamline and manages its scientific program for the remaining available beam time of up to 75 percent for a renewable term of typically three years.

Many facilities have a mixture of FOOBs, PRTs, and/or CATs. The BES light source facilities are currently evolving their access models to emphasize FOOBs in most cases in order to better accommodate user needs and to ensure stable, reliable operations.

Construction Project Management

The DOE has extensive experience with effectively managing large scale construction projects to deliver the mission need safely, on time, and within budget. The requirements for projects to achieve this have been stated in the DOE Order 413.3A, *Program and Project Management for the Acquisition of Capital Assets,* and its implementation manual, DOE M 413.3–1, *Project Management for the Acquisition of Capital Assets.* All projects costing more than $20M are carried out in accord with these requirements.

DOE Order 413.3A defines five Critical Decisions, or "CDs"—formal determinations or decision points in a project life cycle that allow the project to proceed to the next phase and commit resources. Each decision constitutes a work authorization for a specific phase of the project. The Deputy Secretary of Energy serves as the Secretarial Acquisition Executive (SAE) for the Department and approves site selection and Critical Decisions for Major System Project.

CD–0, Approve Mission Need, authorizes preparation of a Conceptual Design Report, Acquisition Strategy, Risk Management Assessment, and Safety Documentation. CD–1, Approve Alternative Selection and Cost Range, authorizes the expenditure of Project Engineering and Design funds to proceed with Title I (preliminary) and Title II (final) design. CD–2, Approve Performance Baseline, establishes the technical, schedule, and cost performance baseline for the project. CD–3, Approve Start of Construction, authorizes the project to start full-scale construction. CD–4, Approve Project Completion, is accomplished when the project scope has been delivered and demonstrated to be functioning properly and safely and the facility is ready to begin operations.

An essential element of project management systems is the control of changes to the performance baseline. Changes to project execution are evaluated in terms of baseline impacts. Through a graduated hierarchy of change control authority, appropriate levels of management become involved in decisions regarding project changes.

Real-time monitoring of a project occurs through established mechanisms among project participants. Progress reviews of the project are conducted by SC, typically at semiannual intervals, with results of these reviews provided to the Under Secretary for Science. Quarterly Progress Reviews are conducted between the Under Secretary for Science and the Federal Project Director. Formal project reporting, including monthly data submissions into the DOE Project Assessment and Reporting System (PARS), is in effect for the duration of a construction project. The monthly PARS report also serves as the basis for the NSLS–II Project's input to the Office of Engineering and Construction Management (OECM) Monthly Project Status report to the Deputy Secretary of Energy.

The safety and security of all staff, guests, contractors, vendors, and the environment is a primary priority in construction projects. It is expected that all staff and contractors will plan, manage, and execute their respective duties consistent with the requirements of the tenets of Integrated Safety Management to ensure that the facility is designed, constructed, and operated in a safe and environmentally sound manner to ensure the protection of the workers, the public, and the environment.

Concluding Remarks

Thank you, Mr. Chairman, for providing this opportunity to discuss the Basic Energy Sciences program. This concludes my testimony, and I would be pleased to answer any questions you might have.

BIOGRAPHY FOR STEVEN B. DIERKER

Steven Dierker is the Associate Laboratory Director for the Light Sources Directorate and the Director of the National Synchrotron Light Source II (NSLS–II) Project at Brookhaven National Laboratory (BNL). As NSLS–II Project Director, he has overall line management responsibility and authority for carrying out the NSLS–II Project, including the design, construction, and transition to operations of the NSLS–II facility to ensure all mission requirements are fulfilled in a safe, cost-efficient, and environmentally responsible manner. In addition to the NSLS–II Project, the Light Sources Directorate also includes the National Synchrotron Light Source (NSLS), which reports to Dr. Dierker.

After earning B.S. degrees in both physics and electrical engineering in 1977 from Washington University, Dierker earned both an M.S. and Ph.D. in physics from the University of Illinois, Urbana-Champaign, in 1978 and 1983, respectively. His Ph.D. research involved the first observation of Raman scattering from superconducting gap excitations, which has now become a widespread and powerful technique for investigating the physics of superconductors.

In 1983, he joined the Semiconductor and Chemical Physics Research Department at AT&T Bell Laboratories and carried out research using light scattering and neutron scattering to study problems in soft condensed matter, most notably the hexatic phase of freely suspended liquid crystal films and activated dynamics of binary fluids in porous media.

In 1990, he joined the University of Michigan, where he was Professor of Physics and Applied Physics. At Michigan, he pioneered the development of the new technique of X-ray Photon Correlation Spectroscopy (XPCS) and carried out the first convincing demonstration of the feasibility of this technique in a study of Brownian motion of gold colloids. Dierker helped to plan the design, construction, and operation of beamlines at the APS, with funding from the U.S. Department of Energy and the National Science Foundation.

In 2001, Dierker joined BNL to become Director of the NSLS, which has a $37M annual operating budget, a staff of 200, and serves more than 2,200 users per year. He became the Associate Laboratory Director for the Light Sources Directorate at BNL when that Directorate was created in 2003. He also continued to serve as the Chair of the NSLS until he stepped down from that position to become the Director of the NSLS–II Project in December, 2005.

Chairman LAMPSON. Thank you, Dr. Dierker. And Dr. Hall, you are now recognized.

STATEMENT OF DR. ERNEST L. HALL, CHIEF SCIENTIST, CHEMISTRY TECHNOLOGIES AND MATERIALS CHARACTERIZATION, GE GLOBAL RESEARCH

Dr. HALL. Thank you, Mr. Chairman, acting Ranking Member Biggert. Good afternoon, and thank you for inviting me to address the Committee and provide GE's perspective on the Department of Energy's Office of Sciences Basic Energy Science Program.

I am a Chief Scientist at GE Global Research, GE's central research and development organization. We are arguably the largest and most diversified industrial research lab in the Nation, if not the world with a proud heritage of innovation spanning more than 100 years.

GE researchers have a proven record of delivering meaningful technology from breakthrough developments that include medical X-rays in the early 1900's and the first U.S. jet engine in the 1940's to advancing new energy sources today such as solar and wind.

The mission of GE Global Research is the same as it was at the time of our founding in 1900, to drive innovations that create new and better GE products that meet the need of our customers and society.

I have 36 years of experience in advanced methods of materials characterization and for the past 17 years have managed a group of scientists at GE Global Research who use the most advanced tools for the analysis of structure and composition of GE materials including significant usage of the DOE synchrotron and neutron facilities.

Today I would like to share my views on the DOE's Office of Sciences BES Program and what it means to research conducted at GE. In short, access to national synchrotron, neutron, and electron beam facilities managed by BES is critical to the development of new technologies by GE. GE primarily uses DOE synchrotron facilities at Brookhaven and Argonne National Labs, and has used the NIST and Argonne neutron facilities, and electron microscopy at Lawrence Berkeley and Oak Ridge National Labs. The research we perform at these national facilities is critical to GE's technology and product development and addresses some of the most important national needs. We use the synchrotron X-ray sources to provide us with higher energy, higher resolution, and higher throughput experimentation than we can achieve in our own labs. For example, we can achieve a 30X reduction in the time required for some experiments using the synchrotron. These more intense x-ray sources also allow us to conduct experiments in environments that better approximate those encountered when the materials are used in applications such as gas turbines or aircraft engines.

Examples of our research at the synchrotron facilities include the measurement of chemical processes occurring during the operation of advanced batteries for hybrid vehicles; the determination of the atomic mechanisms by which materials store and release hydrogen for hydrogen-powered cars; development of nanotechnology; fuel cell development; and measuring stresses and strains in a non-destructive way to predict the life of turbine parts associated with our gas turbine business in South Carolina and our aircraft engine business in Ohio and Massachusetts. We have used the Intense Pulsed Neutron Source at Argonne to study new phosphor and detector materials for higher-resolution medical imaging equipment, homeland security devices, and higher-efficiency lighting. While GE is a significant user of the synchrotron light source facilities, we could never fully utilize our own synchrotron, making access to DOE facilities essential. In addition, the regional strategy put in place by DOE is a favorable model, with GE using the Brookhaven site most frequently given its proximity to our R&D center in upstate New York.

While we have found ways to effectively utilize these facilities, there are some potential improvements that I wish to highlight on behalf of the industrial user community. We would urge these facilities to make availability to industrial users a top priority. We understand this will need to be properly balanced with outstanding fundamental research, which is currently the main priority. Industrial research has a unique set of needs and requirements, including the need for prompt access, reliable operation, and the ability to conduct repeated experiments on large numbers of samples for process development and validation which is vital to developing robust and reliable commercial technology. We would advocate the creation of a system that would make facility time available to industry with minimum bureaucracy and cost. If DOE wishes to impact the broadest spectrum of industrial users, then it is important to provide more than just access to the facility. Particularly for smaller companies, it will be important to provide access to facility researchers who can assist with set-up of experiments, data collection, and data processing and interpretation.

We are very supportive of the recent shifts by the DOE that gives funding for the construction and maintenance of beamlines or endstations to the facility. This increases availability and standardization.

Finally, we urge that simple and cost-effective mechanisms be put in place for industry to conduct proprietary research. This is particularly important when industry is using the facility as a characterization tool rather than conducting fundamental research.

Mr. Chairman, I want to thank you and the other Members of the Committee for the opportunity to provide testimony. We have strong collaborations in place with many agencies, especially the Department of Energy. It is our hope that we can continue to make these industry-government partnerships even stronger so that we can deliver real technologies to the marketplace that solves some of the world's most pressing challenges. Thank you.

[The prepared statement of Dr. Hall follows:]

PREPARED STATEMENT OF ERNEST L. HALL

Mr. Chairman, Ranking Member Inglis, and Members of the Committee: good morning and thank you for inviting me to address the Committee and provide GE's perspective on the Department of Energy's Office of Science's Basic Energy Sciences program.

I am Ernie Hall, a Chief Scientist in the Chemistry Technologies and Materials Characterization labs at GE Global Research, GE's centralized research and development organization. We are arguably the largest and most diversified industrial research lab in the Nation, if not the world, with a proud heritage of innovation spanning more than 100 years. This is my official statement and has been entered into the record.

From breakthrough developments that include medical x-ray in the early 1900s and the first U.S. jet engine in the 1940s, to advancing new energy sources today such as solar and wind, GE researchers have a proven record of delivering meaningful technology. The mission of GE Global Research is the same as it was at the time of our founding in 1900—to drive innovations that create new or better GE products that meet the needs of our customers and society.

In my current role, I am expected to provide a broad, technical vision to all of the global technology organizations at GE Global Research, our GE businesses and our end customers. I have 36 years of experience in advanced methods of materials characterization and I have authored more than 175 external technical publications. For the past 17 years I managed a group of scientists at GE Global Research who use the most advanced tools for analysis of the structure and composition of GE materials, including significant usage of DOE's synchrotron and neutron facilities.

Today, I would like to share my views on the DOE's Office of Science's Basic Energy Sciences program and what it means to research conducted by GE. In short, access to national synchrotron, neutron, and electron beam facilities managed by BES is critical to the development of new technologies by GE. GE primarily uses DOE synchrotron facilities at Brookhaven and Argonne National Labs, and has used the NIST and Argonne neutron facilities, and electron microscopy at Lawrence Berkeley and Oak Ridge National Labs.

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Examples of our research at the synchrotron facilities include measurement of chemical processes occurring during operation of advanced batteries for hybrid vehicles; determination of the atomic mechanisms by which materials store and release hydrogen for hydrogen-powered cars; development of nanotechnology, including ceramic membranes for industrial sensors; fuel cell development; and measuring stresses and strains in a non-destructive way to predict the life of turbine parts associated with our gas turbine business in Greenville, South Carolina and our aircraft engine business in Cincinnati, Ohio and Lynn, Massachusetts. We have used the Intense Pulsed Neutron Source at Argonne to study new phosphor and detector materials for higher-resolution medical imaging equipment, homeland security devices, and higher-efficiency lighting.

While GE is a significant user of the synchrotron light source facilities, we could never fully utilize our own synchrotron, making access to DOE facilities essential. In addition, the regional strategy put in place by DOE is a favorable model, with GE using the Brookhaven site most frequently given its proximity to our R&D center in upstate New York.

While we have found ways to effectively utilize these facilities, there are some potential improvements that I wish to highlight on behalf of the industrial user community. We would urge these facilities to make availability to industrial users a top priority. We understand that this will need to be properly balanced with outstanding fundamental research, which is currently the main priority. Industrial research has a unique set of needs and requirements, including the need for prompt access, reliable operation, and the ability to conduct repeated experiments on large numbers of samples. This process development and validation is vital to developing robust and reliable commercial technology, yet is often in competition with the drive for unique, cutting-edge academic research taking place at the national resources.

GE enjoys a strong, collaborative relationship with the DOE. However, because industrial research utilizing the synchrotrons is not a top priority, it is my team's experience that gaining access to sufficient beam time on a timely basis can be challenging. We would advocate the creation of a system that would make facility time available to industry with minimum bureaucracy and cost.

Based on my own experience as a researcher, I would like to make an additional point. If DOE wishes to impact the broadest spectrum of industrial users, then it is important to provide more than just access to the facility. We are fortunate at GE to have outstanding scientists on our research staff, some of whom have worked at the national facilities as graduate students or post-doctoral associates. This will not be true for all companies, especially smaller businesses. In addition to beam time, it is important to provide access to facility researchers who can help with experiment set-up, data collection, and data processing and interpretation. I have been involved with the Shared Research Equipment (SHaRE) program at Oak Ridge National Laboratory, providing access mainly to electron microscopes and administered by DOE BES, and in my mind this is a good model for access to advanced instrumentation for both academic and industrial researchers.

Another area that I would like to call attention to is the need for available end-stations for specific experiments. As you may know, while the synchrotron or neutron facility produces the x-rays or neutrons needed for experimentation, it is also necessary to have experimental stations to receive the beams and conduct the experiments. Many of these are specialized for specific experiments. In the past, most of these end stations were built by Participating Research Teams, mainly from universities, which received government funding for their construction. Over time, these stations may or may not have been well-maintained, or available to industrial use. In recent years, the DOE has switched to giving the funding for end-station construction to the facility directly. We applaud this change since it makes these stations available for other users, standardizes hardware and software use across the facility, and allows the facility to continue to maintain and modernize these end-stations.

The final point that I wish to make concerns proprietary research. The competitiveness of U.S. industry relies upon proper patent protection of the technology that we have invested to develop. There needs to be proper protection in place for the situation where an industrial researcher conducts an experiment on a proprietary material at a national facility. At present, the national facilities have a "total cost recovery" option for proprietary research, but the high cost of this option again seems to put priority on basic, publishable research. We of course recognize that research conducted jointly by national facilities and industry should be considered as a separate category, but urge a re-examination of the case where an industrial scientist wants to run an experiment on a material under development in an industrial lab. GE has not used the "total cost recovery" option extensively, since most of our research is on the structure of engineering materials, and we can often publish these more general results. However, it is our understanding that proprietary issues can be particularly problematic for the chemical and pharmaceutical industries.

Mr. Chairman, I want to thank you and Members of the Committee for the opportunity to provide testimony. We have strong collaborations in place with many agencies, especially the Department of Energy. It is our hope that we can continue to make these industrial-government partnerships even stronger so that we can deliver real technologies to the marketplace that solve some of the world's most pressing challenges. This concludes my testimony and I would be pleased to answer any questions.

Thank you.

Biography for Ernest L. Hall

BS, Massachusetts Institute of Technology, 1973, Metallurgy and Materials Science

Ph.D., Massachusetts Institute of Technology, 1977, Materials Science and Engineering

Dr. Ernest L. Hall joined GE Global Research in 1979. He is presently Chief Scientist for Chemical Technologies and Materials Characterization, where he is responsible for shaping the technical vision and strategic technology direction of his organization and GE Global Research. From 1991 until 2008 he was manager of the Microstructural and Surface Science Laboratory, which provides capabilities for micro- and nano-scale imaging, surface analysis, x-ray diffraction and crystallography, nano-property measurement, and quantitative image analysis. His particular areas of expertise include the techniques and applications of analytical transmission electron microscopy in materials science. In his role as a technical contributor he has conducted microstructural investigations of a wide variety of different materials, including semiconductors, superconductors, and nickel and titanium-based alloys for aircraft engine and aerospace applications.

Ernie is author or co-author of over 175 technical publications, one book chapter, and has edited four books on the methods and applications of analytical electron microscopy and other advanced characterization methods in materials research. From 1984 to 1990 he served as an adjunct professor in the Materials Engineering Department at Rensselaer Polytechnic Institute. Prior to joining GE, he spent two years as a Research Associate/IBM Postdoctoral Fellow at MIT.

In 1984 Ernie was awarded the Alfred H. Geisler Award by the Eastern New York chapter of ASM for his metallurgical research and, in 1989, was named a Coolidge Fellow, the highest honor awarded by GE Global Research, for his outstanding and sustained research contributions. He has served as past Chairman of the Hudson-Mohawk chapter of TMS, as National Program Vice Chair and Chair for the Microscopy and Microanalysis annual meeting, on the editorial board of Metallurgical Transactions, as Chair of GE's Teacher Industrial Fellowship program, and as coordinator of the both the Coolidge Fellows and the Lab Manager Council at GRC. He has served on the governing Boards of both the Microscopy Society of America and the Microbeam Analysis Society.

Ernie has also served on the scientific advisory board of the DOE–BES Shared Research Equipment (ShaRE) program at Oak Ridge National Lab, as an invited participant in the "Nanoscience Opportunities at NSLS–II" workshop at Brookhaven National Lab, and as Session Chair at the 2007 DOE–BES roadmap/grand challenges workshop on Future Science Needs and Opportunities for Electron Scattering.

Chairman LAMPSON. Thank you, Dr. Hall. Dr. Russell, you are recognized.

STATEMENT OF DR. THOMAS P. RUSSELL, SILVIO O. CONTE DISTINGUISHED PROFESSOR, POLYMER SCIENCE AND ENGINEERING DEPARTMENT, UNIVERSITY OF MASSACHUSETTS–AMHERST; DIRECTOR, MATERIALS RESEARCH SCIENCE AND ENGINEERING CENTER; ASSOCIATE DIRECTOR, MASSNANOTECH

Dr. RUSSELL. Chairman Lampson, acting Ranking Member Biggert, thank you for the opportunity to testify. I am speaking to you as a scientist with 16 years of experience at the IBM Almaden Research Center as well as an academician at the University of Massachusetts at Amherst in the Department of Polymer Science and Engineering.

I think from an academic perspective, it is critical to be able to assess the directions or how the Department of Energy assesses the directions as to where they are going to be funding research. They have done this very effectively by study groups and workshops and have derived five grand challenges that are facing the scientific community, and these grand challenges transcend specific disciplines and they address problems that relate to anything from photovoltaics to solid-state lighting.

One must also be critical in terms of asking about technology transfer, and I would like to give you three personal examples of research that was supported by the Department of Energy, Basic Energy Sciences, in my own research, and this is dealing with block copolymer materials and thin films. This has led to recent air gap technology that IBM is currently employing which will allow chips to operate faster and more efficiently.

A second example is flash memory whereby using a similar type of technology, the longevity of your memory sticks actually can be increased significantly.

A final example is in magnetic storage whereby we have developed technology where we can get 10 terabits of information per square inch, and for your own perspective, what this means is that you will be able to put 25 DVDs on a disk the size of a quarter. Actually, it is 250 DVDs on a disk the size of a quarter. That, in my opinion, is something that truly addresses the issue of American Competitiveness.

Another area that the DOE must involve themselves in is as stewards of these facilities. As an academician, I have students and post-doctoral fellows who are actively conducting research, and they conduct research at these eight facilities. It is essential that these facilities be available and that they be reliable. I could not have said this 15 years ago, but yet under the stewardship of the Department of Energy, in particular, under guidance of Dr. Dehmer actually, what has been done is that these facilities have been transformed into being very reliable and available so that when my students or post-doctoral fellows go to these facilities, they will be able to do the experiments that they were planning to do.

Another issue concerns the number of facilities, and there is an issue associated with overlap and the facilities may be doing similar things. That is true, they do. There is also an issue associated with regionality, and Dr. Dierker has already addressed the issue of oversubscription of these facilities; and it is essential that these facilities be available to the academic community in order to execute the research. These tools in my opinion are indispensable, and they become even more critical as we move to smaller and smaller structures. We hear a lot about nanostructured materials, and these facilities are ideally suited to address problems on the nanoscale. That also is going to be essential in terms of American Competitiveness.

As a professor, one thing that has not been addressed is that these facilities are a tremendous educational tool for both students and post-doctoral fellows; and for the future of the United States in terms of the scientists that are being trained. Having the ability to gain experience at these facilities and learn the science these facilities enable is absolutely essential.

I would also like to address these Energy Frontier Research Centers. Energy is the number one problem that is facing the United States and all of mankind. We have a situation now where we must be able to develop routes by which we can access or generate energy from any of a variety of means. It in my opinion is essential to involve the academic community. There is a tremendous amount of research, fundamental research, that needs to be done, and this can be done very effectively in the academic community. The industrial sector also can perform such research but we are in a situation whereby more research right now, fundamental research, is imperative in addition to the development that can be provided by the industrial sector.

I would finally like to address one other thing. Everything sounds rosy, and it is not and the reason it is not rosy is that the single most critical problem for me in dealing with the Department of Energy is the budgets and budget reductions. This does not seem like a big issue to some extent, but let me give you one example. As an academician, we need to write proposals. Proposals take several months in order to write. Last year we were in a situation where I would say that approximately 300 proposals that were written and submitted to the Department of Energy addressing energy issues, issues that are the most critical problem facing us right now. At the end of all of this, after all the proposals were written, ranked, et cetera, the funding was cut from this initiative. For me as an academician, this is truly frustrating. It takes a huge amount of effort and energy in order to write these proposals, in order to fund the research and students and post-doctoral fellows that work with me. So for me, budget reductions are probably one of the single most critical problems that we are facing right now from the academic sector.

With that, Chairman, I would like to thank you for the opportunity to present to you an academic perspective with a little bit of industrial perspective thrown in.

[The prepared statement of Dr. Russell follows:]

PREPARED STATEMENT OF THOMAS P. RUSSELL

I am in the unique position of having received support as an individual investigator from the Department of Energy, Office of Science, Basic Energy Science for the past 25 years both as an industrial scientist and as an academician. I have served on the Committee of Visitors who reviewed the research portfolio that the Office of Science, Basic Energy Science, supports and the processes used to make funding decisions. In addition, I have also been involved with the national synchrotron and neutron facilities that the Department of Energy stewards, as a user, as a member of research team efforts, as a member of proposal review panels, and as a member of advisory boards for the facilities. I have also served on panels that have mapped out the course of x-ray and neutron sciences in the United States. While I have actively used the facilities within the United States, I have also used facilities in Europe and in Asia and am in a position to assess the performance of the Department of Energy in the operation of these facilities in comparison to other countries.

Research Portfolio

The research portfolio of the Department of Energy, Office of Science, Basic Energy Science encompasses and exceptionally large range of topics. Due to the breadth of the programs that span from soft to hard materials including synthetic and natural (biological) materials as well as a suite of national user facilities, it is truly a daunting task to cover every research area in sufficient detail with the budget limitations that are common to any funding agency. Infinite resources would, of course, solve all problems. However, due to the limitations in the budget, it is reasonable, in fact mandatory, to ask the question as to whether BES is allocating its resources properly. Guidance for research directions, in general, are established via reports from workshops wherein expertise from around the world are brought together to review the current state of affairs in a particular area and where the future directions of a field lay. The results of these studies are balanced with the potential impact that a given area will have on society and American Competitiveness.

One such study group led to five grand challenges in basic science. These grand scientific challenges strike at the essence of the fundamental science stifling advances in many disciplines. Take, for example, the topic of non-equilibrium phenomena. Everyday we are exposed to and use materials that are in a state that is very far removed from their most preferred or, in other words, lowest energy state. Virtually processes that industry uses to generate materials are trapped in a non-equilibrium state. Yet, processes have been developed, more often than not by trial and error, to produce materials to meet end-user (consumer) needs. However, if we really understood exactly how the materials got to their final state, then we would have predictive capabilities in being able to optimize the structure and properties of a material. While this may seem like an obvious example, glassy materials, glass that is used for windows and drinking or grains of sand or powder passing through a funnel or rush hour traffic are situations where materials are tapped in a state far removed from equilibrium. Each of these examples represents objects that are really fluid-like in nature but are jammed or trapped in state where they are essentially frozen. Yet, can we control the state of these jammed materials or even develop routes by which the materials can be unfrozen without leading to catastrophic events. Think, for example, of mud slides or earthquakes where systems are trapped and the sudden release of the snag restraining the system and event that is highly desirable (as in traffic of in powder flow through a constriction) or highly undesirable (as in mud slides or earthquakes). As of yet, we still do not have a fundamental understanding of systems that are trapped in these highly non-equilibrium states.

The five grand challenges that have been put forth by a panel of renowned scientists represent a superb platform that BES will use to guide future funding directions. These are challenges that transcend any one discipline but will have far reaching consequence to society and American Competitiveness. How different disciplines will address all or some of these challenges will be discipline-dependent, yet these challenges provide BES with excellent guidance for resource allocations. Does this mean that all research must fall under one of these grand challenges? Absolutely not! This raises another aspect of BES program managers that is critical. As a member of the Committee of Visitors reviewing the process by which funds were allocated, in general, the peer-review process was adhered to. Proposals from researchers in academia, industry and laboratories were reviewed and the program officer would make decisions based on these recommendations. However, there were instances where the program officer would fund a risky proposal. In most cases, these risks paid off, leading to new areas of science that clearly advance American technology. One case in point is combinatorial chemistry which led to start-up companies like Affymax, Affymetrics and Symyx Technologies where libraries of materials, generated by performing literally thousands of reactions in parallel, are used to uncover materials with unique properties or drugs with exceptional response. This flexibility is, in my opinion, extremely valuable and it has been used effectively, albeit with discretion and care.

Is there evidence that the decision to fund basic science leads to true advances in American technology? This is the age-old question of whether there has any value in supporting basic research. Are there concrete examples where the funding of basic science has led to technological developments? To address this question, I would like to provide a brief description of the funding of my own research by BES. When I was at the IBM Almaden Research Center I had submitted a proposal to examine the behavior of polymers (plastics) at the interface with another polymer. From IBM's perspective, this research was of importance, since it addressed issues of delamination, where two adjoining layers of materials separate. If this occurs, this would lead to a failure of the device or chip or, in the least, degradation in the performance of a material. From a basic science point of view, fundamental questions concerning the behavior of a polymer molecule at an interface were never asked. These studies led to the development of processes and materials to control such delamination problems while using non-propriety materials and processes to uncover the fundamental science.

One type of material that was intensively studied was block copolymers, two different polymers that are tied together at one end. These materials are like soap, where you have two components that simply do not mix and separate from each other. In the case of soap, there is a part that is oily or hydrophobic and one part that will dissolve in water or hydrophilic. Now polymers are about 10 nm in size. So, if I have a copolymers, we have two parts that are about 10 nm in size that want to separate from each other and, like in the case of soap, the size of the molecule and the fact that they are tied together limits how far apart the sections can get from each other. The consequence of this is that these molecules form domains that are tens of nanometer or less in size. The basic research that BES supported allowed us the opportunity to develop routes to control how these domains are arranged in thin films that can be generated by routine spin-coating processes that the microelectronics industry is using every day. In addition, we learned how to remove one of the domains, producing films that had nanoscopic holes. This seemingly simple process has had a tremendous impact on the microelectronics industry already and, soon, in the magnetic storage industry.

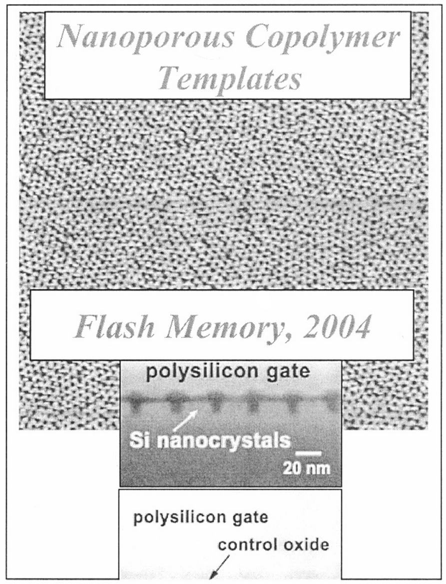
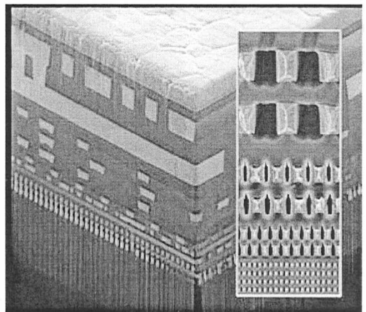


Figure 1. Floating gate technology

By using these films with the nanoscopic holes, silicon can be evaporated in the holes and, with subsequent processing, tiny islands of silicon can be produced where each of the islands are separate from each other by either the remaining polymer or the polymer can be replaced with an electrically insulating material, like silicon oxide. Researchers at IBM used this very simple technology to increase the lifetimes of flash memory devices (memory sticks), since a critical component in the device is a floating gate where electrons are stored. However, the process of transferring electron from a source to the gate is destructive over time. So, if one has a single piece of silicon acting as the gate, with time the source will short-out with the gate. However, by using the copolymer technology describe above, the gate is broken up into a large number of smaller pieces that are insulated from each other and, if one of these pieces shorts-out, it does not cause a failure of the device, since we have a large number of smaller pieces left. The figure shows a side view of one of these gates where the copolymer templating process has resulted in a significant increase in the longevity of the device.



This permits chips to run faster and use less energy….significant advance in exploiting nanotechnology…enhances the competitiveness of US companies in this critical industry. According to Dr. John Kelly, IBM's senior vice president of research and development, "To our knowledge, this is the first time anyone has used nanoscale self-assembled materials to build things that machines aren't capable of doing."

Figure 2. IBM's air gap technology

This simple concept of copolymer templating has led to yet another technological breakthrough. In a microelectronic circuit the speed that the electrons travel in the circuit depends on the dielectric constant of the materials surround this wires. Ideally, you would like to have the wires suspended in air, but this, of course, is impossible, since the elements of the circuit must be solid to support a multi-layered structure. If, though, you use the polymer film with nanoscopic holes, as described above, and you place this on the existing insulating material between the wires on the circuit, then you can use the film with holes as a template to etch or drill into the insulating materials. Subsequently, you can cover the tops of the holes in the insulator, trapping air pockets in the insulator. The consequence of this is that the dielectric constant is significantly decreased, allowing faster and more efficient transport of electrons through the device. An example of a multilayered circuit is shown in the figure and IBM is adopting this strategy in the manufacture of devices beginning in 2009.

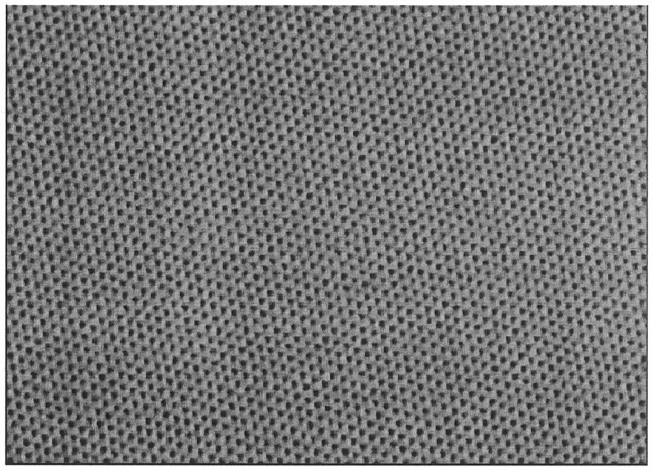


Figure 3. Bock copolymer template with long-range lateral order with 15 nm pores that can be use for a one terabit magnetic data storage. This technology will lead to 10 Tbit capable of a 100 DVDs on disc the size of a quarter.

We can go even one step further. Let's consider this polymer film with the nanoscopic holes. Any of a variety of standard processes can be used to fill the holes with a material that is magnetic. If we could address each of these magnetic elements and force the spin of each tiny magnet to be up or down (this is a typical process that is used for magnetic storage in current computers) and, if we could read each of these tiny elements, then we could far exceed the predictions of Moore's law that governs the magnetic storage industry. Now with the copolymers, we can control the size and separation distance between each of these elements by controlling the size of the molecule. Recently, laboratories across the United States learned how to control the ordering of arrays of these elements and, in the no-to-distant future, we will be able to produce storage media that is so dense that we could put 100 DVD or a disc that is the size of a quarter! An example of an array of elements produced by this copolymer templating technology is shown in the figure. Here, each of the little holes is ~8 nm, about 100,000 times smaller than a human hair! This will represent an incredible breakthrough in the storage density far exceeding that predicted by Moore's Law, and will revolutionize everything magnetic storage and, I dare to say, the life of the average American. In addition, this storage density will impact numerous technologies and significantly impact American Competiveness.

There are other applications where these simple templates are having impact in the biological arena, as for example in the separation of virus particles or in the generation of surfaces that can promote or retard cell proliferation. However, the developments that have been made using copolymer templates are extensive. This represents just one particular project that BES had supported where the objective was a fundamental scientific question, i.e., basic research, that have had significant impact on technology and, by default, American Competitiveness. It should be noted that the time scale over which the current technological advances are being made is on the five- to ten-year time frame. For all intents and purposes, this time scale was fairly rapid. Another additional factor that has direct impact on the "turn-around" time is that the processes that are required for the copolymer templating processes are non-disruptive, i.e. these materials could be integrated into the existing fabrication processes. If an entire new process was required to enable the use of these templates, the chance of them seeing the light-of-day in an industrial process would be slim or, at least, delayed by another 5-10 years. Fabrication lines are simply so expensive to build, that introducing new processes is getting progressively harder.

Facilities

The Office of Science, BES, is the steward of the national user facilities located at national laboratories across the country which includes synchrotron x-ray facilities, reactor-based neutron sources, spallation neutron sources, electron microscopy facilities and ignition laboratories. I am most familiar with the x-ray and neutron facilities constitute essential tools for the execution of my research. I have also been a member of the Kohn Panel, which documented the state of neutron sources and made recommendations to BES to ensure the vibrancy of neutron science in the United States, and the Birgenau Panel, which documented the state of synchrotron x-ray facilities (both hard and soft x-rays) and made recommendations to BES on the operation and future directions for national x-ray sources in the United States. In addition, I also chaired two panels to establish the design and operation criteria for the spallation neutron source. When I was a member of the Basic Energy Science Advisory Committee, neutron and x-ray facilities were undergoing major revamping, the Advanced Neutron Source (a reactor source) was put on indefinite hold (essentially canceled due to extensive costs), the foundations were laid for the construction of the Spallation Neutron Source, now operational at the Oak Ridge National Laboratory, and the Advanced Photon Source was just being commissioned. As a general statement, these facilities should be considered as jewels of the national laboratories that provide an invaluable resource to science and technological advances in the United States and hold significant promise for the future.

Does the Department of Energy manage these facilities well? With the resources available to BES, I feel that the DOE BES does an exceptional job. While these facilities have required substantial investment to design, construct and operate, BES has made every effort to ensure that the facilities operate in a manner where the reliability and availability of the sources exceed the criteria established by the Kohn panel. This requires that the facilities operate in a dedicated "user-facility" mode, not being parasitic to other sources. The Stanford Synchrotron Radiation Laboratory and the Los Alamos Neutron Scattering Center were, at one time, parasitic to the Stanford Linear Accelerator Center and the Los Alamos Meson Production Facility. When operated in this mode, the ability for a user to perform experiments was impaired. However, at present time, all the x-ray and neutron scattering facilities are dedicated to the users. In addition, the ability to use these sources relies on a peer-review process where the highest ranked proposals are granted appropriate levels of time to execute the proposed studies. This means that both small, individual investigator efforts can be accommodated, along with much larger efforts. At the National Synchrotron Light Source at the Brookhaven National Laboratory and the Advanced Photon Source at Argonne National Laboratory, Private Research Team and Collaborative Access Team efforts were introduced where teams of investigators could propose, plan, finance and commission a specific beamline. In return for this investment, these investigators were guaranteed a certain percentage of the beam time, while the remainder was made available to outside users. These were novel concepts to instrument these facilities allowing researchers to secure funding from government or industrial sources to establish a particular capability in x-ray science. Neutron sources have not implemented this mode of operation due, primarily, to the limited number of beamlines that can be accommodated by the sources.

Whether the beamlines are provided by the DOE BES or via the PRT or CAT routes, the operation of the facilities has been excellent and have provided routes by which industrial, academic and government laboratory scientists could perform research that they were not capable of doing in there own laboratory. For industrial scientists, if the research is proprietary in nature, a full cost recovery of the operation of the beamline during the experiments is required and this, in my opinion, is as it should be. Proprietary research cannot be reviewed in a peer-review manner and, as such, the investment the industrial laboratory is required to make to do the experiments is appropriate to circumvent the normal review process and, in a sense, is akin to a review process, since this investment would not be made unless it was cost effective. As an academic scientist and as a former industrial scientist interested in performing basic research, the allocation of beam time have been and is done in an objective and effective manner.

Does this mean that the operation of the facilities cannot be improved? Absolutely not! Perhaps the major problem that I see with the operation of the facilities is the insufficient number of staff scientists or beamline scientists. These facilities operate 24/7 and it is virtually impossible for these scientists to operate in this manner. This is not an unusual level of staff support. Yet, these scientists are expected to accommodate the user community, maintain the operation of the beamline and maintain an active, independent research effort. In addition, the staff scientists tend to get burned-out and it is most difficult to attract and retain first-class researchers to these positions. I feel that this problem could be alleviated with a higher level of personnel support. Nonetheless, the beamline scientists perform an extraordinary service to the scientific community by interacting with seasoned users and those users who are new to either x-ray or neutron science.

Are there too many facilities? In the United States there are three BES-maintained neutron sources currently operational: the Spallation Neutron Source and the High Flux Isotope Reactor at the Oak Ridge national Laboratory, and the Los Alamos Neutron Scattering Center at the Los Alamos National Laboratory. In addition, there is the Center for Neutron Research at the National Institute of Standards and Technology that is operated by the Department of Commerce. The Intense Pulsed Neutron Source at the Argonne National Laboratory is scheduled for closure. In comparison to European or Asian scientists, the availability of neutrons in the United States falls far behind. As an academician, this means that the competition for beam time at these facilities is stiff. There are three hard x-ray synchrotron sources: the Stanford Synchrotron Radiation Laboratory, the National Synchrotron Light Source and the Advanced Photon Source. Geographically, these sources are located on the western, eastern and central United States. Consequently, these facilities have taken on a regional character with many of the users coming from the respective parts of the United States. There is not question that there is overlap in the capabilities for the facilities, yet each facility offers unique capabilities that are used by scientists across the country. From the soft x-ray perspective, there are source at the National Synchrotron Light Source and the Lawrence Berkeley National Laboratory and, as such, the user-base is far less regional in character. These facilities are operated 24/7 and it is still difficult to get time on the instruments. Should there be more sources made available? While one can easily give a quick response based on the full-time use, I would only concur with this after an in-depth study, since the demand-surpassing-the-supply situation ensures that only the highest quality science is performed on these invaluable resources. The cost for the design, construction and operation of a single facility demands that the scientific or technological case be solidly made before considering taking this step.

Do these facilities contribute to American Competiveness? The example that I cited about on the use of copolymers a templates for insulating and gate materials in microelectronics and the generation of ultrahigh density magnetic storage media represent on a small number of examples where these sources were key in understanding the fundamental science underpinning the processes used to generate these structures. Numerous other examples can be cited where these facilities have been essential in enabling a scientific advance that, in turn, led to a technological breakthrough or development. One example where these sources will be key to American Competiveness lies in the unique ability of these sources to characterize materials on the nanoscopic level over macroscopic distances. To understand this, in Figure 3 is an array of nanoscopic dots that are present over the entire surface of a disc that may be several centimeters in diameter. To be suitable as a magnetic storage medium we must know the exact position of each of the elements to within a nanometer. Industry is currently pushing to a goal of 10 terabits or 1013 magnetic elements per square inch. If we could read one element in a nanosecond, it would take us three hours to scan (which we cannot with any accuracy) a one-inch square just to characterize the surface. X-ray scattering, though, has the ability to sample an entire surface at once and provide information on the nanometer to subnanometer level in seconds. Consequently, I feel that these intense x-ray sources will play a key role in establishing metrics to characterize nanostructured materials with any degree of certainty. Such capabilities will be essential as the size of structure gets smaller and smaller.

Aside from the scientific importance of the experiments that can be done on these facilities, they also provide an important tool for educating young scientists, not just in terms of the science that underpins the technique but, also, in the science that forms the basis of their own research and the research of others. At these facilities there are numerous scientists performing experiments on different beamlines and it is difficult not to interact with others during the course of the experiments. These facilities provide a beautiful setting in which the next generation of scientists can receive a basic education in their own discipline but, also, a fertile ground in which science, over a much larger spectrum, can be learned. This is, in my opinion, vital to the future of science and technology in the United States. I must, also, add that many of the facilities offer short courses where students from across the country travel to a particular source and receive a practical training on the theory and use of these facilities. I have personally sent numerous students to attend these courses where travel and accommodations are covered by the hosting facility. These short courses have been invaluable and beautifully augment the formal training that the students receive in the classroom.

Frontier Energy Research Centers

The single-most important problem facing the United States and mankind in general is the identification of a reliable energy source that will, at some point, overcome our dependency on fossil fuel. Fossil fuel resources are finite in nature and where the resources will exhausted in 20 years or one hundred years, the "writing is on the wall." A reliable, cost-effective energy source or sources must be found before we, as a nation, or as a species are forced in to a corner. I will not argue whether solar is better than hydrogen, hydroelectric or wind. Regardless of the method, a solution must be found. This is one of the DOE BES grand challenges. Last year, the DOE BES had a call for single to multiple investigator proposals that addressed this critical energy need. Even though hundreds of proposals were submitted, only a handful was supported. This was not a result of the quality of the proposals. On the contrary, based on peer review, many more proposals should have been funded but the funding cutbacks precluded supporting many of these proposals. This year we are faced with a similar situation. The DOE BES had been allowed to proceed with a call for Energy Frontier Research Centers (EFRCs) with a proposed total budget of $100M. The scientific community was very pleasantly surprised by this call, given the events of the previous year. These EFRCs are intended to support multi-investigator and/or multi-institutional efforts that bring together scientists from different disciplines to attack this energy problem in a novel manner. The EFRCs are similar in ilk to the Materials Research Science and Engineering Center and will provide a beautiful framework in which significant advances can be made in resolving the impending energy crisis.

The academic community is now faced with a possible repeat scenario of last year that must, in my opinion and in the opinion of many academic scientists across the country, be corrected! The academic community received the news of this call with great enthusiasm. It is very clear that the academic community, in general, must be involved, in some manner, in addressing the energy crisis. While national laboratories, like the National Renewable Energy Laboratory or the Lawrence Berkeley Laboratory, have established track records in energy science and some industrial laboratories have expertise in designing and fabricating energy devices, I can cite the recent developments at the University of Virginia where scientists succeeded in making a photovoltaic device with 50 percent efficiency. This is a tremendous advance in the field and demonstrates the key role that academic laboratories can play in this area of critical need. Currently, the Senate has removed this item from the budget of DOE BES, transferring it to EERE. This was done after the House of Representatives left the EFRCs in as a line item in the budget. The reasoning behind this is not obvious. Nonetheless, the person power that academic laboratories can bring to bear on this problem and the diversity in the research portfolio of the Department of Energy forces us to the conclusion that a peer-reviewed proposal process for EFRCs that is open to academic and industrial scientists and where expertise at the DOE-supported national laboratories is the logical route to follow. Not only will this lead to advances in resolving this critical problem but it will also serve to educate the next generation of scientists in problems associated with energy which, in turn, will ensure a retention of expertise and competitiveness of the United States in energy.

Ramifications of Budget Reductions

Perhaps the most frustrating experiences that I have had with both facilities, specifically neutron sources, and the energy initiatives are budget reductions. Sometimes these reductions are known in advance and other times they occur rather rapidly. I fully realize that these reductions are outside the control of BES but that does not make them any less frustrating. For example, last year (2007) BES had a major initiative on renewable energy, soliciting proposal across the entire spectrum, ranging from hydrogen storage to photovoltaics. The response of the community was overwhelming, with over 300 proposals submitted. I happened to be involved in several of these proposals as a co-principal investigator. These proposals were peer reviewed and, in fact, the priorities for funding were established. After a significant delay, a continuing resolution was established for the federal budget with the funds promised to support this initiative, never materializing. The sum and substance of this was a massive waste of time. I assure you that most of the individuals involved in these proposals are under severe time constraints and I can also assure you that there were many investigators who were less than pleased. Aside from the investigators proposing research, the peer review process itself consumes a significant amount of time on the part of the referees. We can add to that the significant amount of time that was expended by the program managers at BES. It was also not an easy task to turn to the investigators and to the scientific community in general and announce that the funding to support research in the most important problem facing the United States, although promised, was not going to be there. This budget shortfall dumbfounded, surprised, frustrated, and irked everyone involved in this effort.

With the EFRCs we are again faced with a similar situation that we must, in any way possible, prevent from happening again. Specifically, there was a call for EFRCs that was to be supported by $100M enabling the establishment of 20–40 EFRCs across the United States in academic, industrial and government laboratories. The House of Representatives approved this initiative while the Senate removed this from the BES budget, transferring the funds to EERE. This will essentially place the funds in the hands of NREL and/or industrial laboratories. While superb research can be done at these laboratories, as I mentioned above, engaging the entire scientific community, as BES is quite capable of doing, is essential. So, now we have a situation where the call for EFRCs has a proposal deadline of October 1. Putting together a competitive proposal for an EFRC that will involve multiple institutions will require several months of effort. With the recommendation made by the Senate and the budget being debated in committee the inevitable question arises as to whether one should write an EFRC proposal? Putting these proposals together is a massive effort. Not writing the proposal ensures losing an opportunity to bring your expertise to bear on a scientific engaging, societally important ad technologically challenging topic. Yet, there are absolutely no guarantees that if a proposal is written that there will be funds to support the effort. Do you take the chance that the funds will appear? Don't forget that the deadline is October 1 and proposals simply do not materialize out of thin air. I have decided to take this chance and I am gambling on the wisdom of our Congress to reinstate these funds to the BES budget.

Let's move to the neutron facilities, both the reactor-based and accelerator-based (spallation) neutron sources. In the United States there are two reactors currently operational as user facilities: the Oak Ridge High Flux Isotope Reactor (DOE supported) and the Cold Neutron Research Facility at NIST (DOC supported). Both are superb instruments where researchers (faculty member, students, post-doctoral fellows, industrial scientists and government laboratory scientists) can perform experiments on a peer review basis. Reactor sources, particularly cold neutron sources which these facilities are, enable experiments on large objects (approaching microns in size) which is essential for the study of biological systems, plastics, colloids and metals. Through a combination of safety issues, budget reductions and bad publicity, the High Flux Brookhaven Reactor was decommissioned and the Advanced Neutron Source never materialized. Losing two facilities may not seem to be a major disaster. However, the paucity of neutrons has resulted in a loss in the number of scientists who have expertise with neutrons. This has deleteriously impacted nearly every scientific discipline and, therefore, technological advances that would have been enabled by studies using neutrons. Academicians were simply fearful of having doctoral theses reliant on the availability of neutrons. Funding agencies were reluctant to support research that relied on the availability of neutron Loss of funding for individual PI grants translates in to a further reduction in the number of students and so we go spiraling down. So many opportunities were lost by American scientists during this time. Even though an idea may have theoretically emanated from research in the United States, American scientists simply had to sit back while their European counterparts executed the studies. I experienced this anguish on several occasions, but there was imply nothing that could be done, so you move on.

The situation with accelerator-based (spallation) sources was not that much better. At the time, the Intense Pulsed Neutron Source at the Argonne National Laboratory was operating like the Every Bunny (it kept on going and going). However, despite its name IPNS was not a high flux facility and only through the innovative and creative efforts of scientists at the IPNS were scientific and technological advances possible. Indeed, given the flux of the facility, it is amazing to see the number of outstanding contributions made by IPNS scientists. The Los Alamos Neutron Scattering Center, while being much more intense than IPNS, had seemingly incurable problems with availability and reliability of neutrons. As a result, the user base at Los Alamos deteriorated and, as an academic, I was reticent in establishing a research effort where students' theses relied on experiments at Los Alamos. As an industrial scientist, I was content to take my chances at Los Alamos, though there were numerous experiments that never occurred due to the unreliability of this facility. I do want you to appreciate the fact that to do experiments at these facilities is far more than the actual time you are at the facility. Sample preparation begins weeks to months ahead of the scheduled beam time. Second, you have to travel to the facility. Los Alamos, by design and intent, is not an easy facility to get to. The same holds true for Oak Ridge. You finally arrive at the facility, ready to do experiments 24 hours a day for three to four days and then the system fails. Why? Since the facilities are so complex, no one is really certain but "We think it will be operational in a half an hour." I sympathize with the operators of the facilities, since they are trying their level best to get the facility back on line and want to be optimistic. However, after you hear this numerous times throughout the night, it becomes a little thin when the sun is rising and you are sleep deprived. But still, you do not leave, since maybe the facility will be back on line shortly and you may finally begin to do experiments that are key to your research. At the time, Los Alamos was operating in a parasitic mode. I can relate similar horror stories about my experiences at the Stanford Synchrotron Radiation Laboratory when it was operating in a paratistic mode.

So, you can conclude that scientists who use the neutron and x-ray facilities are masochistic. This, however, is far from the truth. Rather, tolerating these abysmal conditions demonstrates the importance and unique capabilities of these facilities in addressing scientific and technologically important questions. This situation, however, does not exist at present and the efforts of Patricia Dehmer, lie at the solution to these problems. Through a series of workshops and panel reports, initiated by Dehmer and the late Iran Thomas, BES identified the sources of the problems and placed stringent conditions on the continued support of the facilities which led to a suite of x-ray and neutron facilities, including the spallation neutron source, that are available to the user in a reliable manner. I must also add that during the course of the renovations and new construction projects, Dehmer used the expertise of Daniel Lehman to scrutinize the planning and construction projects which resulted in tremendous cost savings, reductions in project cost overruns, and timely completion of the projects. Again, this reflects the attention that Dehmer has placed on detail and her commitment to the scientific community. These improvements are now paying off with a growth in the community and a return in competiveness of the United Stated in neutron science. As an academic scientist, I have no qualms in having students use these facilities and base a large fraction of their theses on results that emanate from these facilities.

From my experiences on the Basic Energy Science Advisory Committee, and Steering and Advisory Committees of several facilities, an ever-appearing problem that arises is budget reductions to the requested BES budget. Facilities represent only one component of the portfolio of responsibilities of BES. When the BES budget is passed down from Congress, BES is expected to fulfill all its commitments and, as such, budget reductions invariably impact all aspects of BES' portfolio. If budgets were inflated, a reduction would have minimal impact. However, this is clearly not the case. For example, the Advanced Light Source at Berkeley is shutting down for two months as a consequence of a budget reduction. This translates into a stall on all research that relies on the use of soft x-rays for research. Scientific research is intensely competitive and delays of this nature can make or break primary ownership of a discovery. If this were only a matter of the prestige or glory of a scientist, it really would not be of tremendous consequence. However, discoveries lead to intellectual property which, when viewed in terms of American Competitiveness, can have far reaching consequences.

BIOGRAPHY FOR THOMAS P. RUSSELL

Thomas P. Russell is the Silvio O. Conte Distinguished Professor of Polymer Science and Engineering at the University of Massachusetts Amherst, the Director of the Materials Research Science and Engineering Center on Polymers, the Associate Director of MassNanoTech, Director of a Multi-University Research Initiative on Hierarchically Ordered Materials, an Associate Editor of *Macromolecules,* and on the Advisory Board of the *Journal of Chemical Physics,* the *Journal of Polymer Science, Soft Matter* and *Macromolecular Chemistry and Physics.* He was a Research Staff Scientist at the IBM Almaden Research Center in San Jose, CA for 16 years before moving to the University of Massachusetts in 1996. He has over 400 publications in peer-reviewed journals in the field of polymer science, nanostructured materials, and self-assembly of synthetic and natural nanoparticles and has eight patents in the field. He is a fellow of the American Physical Society, the American Association for the Advancement of Science and the Neutron Scattering Society of America. He has served on and chaired the Solid State Science Committee of the National Research Council, the Executive Committee of the Division of Polymer Physics of the American Physical Society, the Basic Energy Science Advisory Committee of the Department of Energy, the Steering Committee of the Spallation Neutron Source in Oak Ridge Tennessee, the Advisory Committee of the Intense Pulsed Neutron Source at the Argonne National Laboratory, the Advisory Committee for the Los Alamos Neutron Scattering Center and the Advisory Committee for Neutron Research at the National Institute of Standards and Technology. He is a lead investigator in the Global Research Laboratory on Energy at Seoul National University in Korea and in the World Premier Institute, Advanced Institute of Materials Science at Tohoku University in Sendai, Japan. He has received awards from the American Chemical Society, the American Physical Society and the Dutch Polymer Society and was elected to the National Academy of Engineering for his research accomplishments.

DISCUSSION

INVESTIGATION OF RESEARCH AND DEVELOPMENT ACROSS THE DEPARTMENT OF ENERGY AND OTHER AGENCIES

Chairman LAMPSON. Thank you very much, Dr. Russell. I happen to believe very much in what your last comment was about. We have truly taken away the opportunity to grow the knowledge that we need to solve the problems that we face, and it seems an awful lot of times. Hopefully we will be able to change some of that. Hopefully it will be quick enough to make the difference that all of us would like to see made, particularly those of us on this Committee.

Let me start with Dr. Dehmer, and I will recognize myself for five minutes after which time I will pass to the next Member of Congress. Dr. Dehmer, in your testimony you note a number of ways that energy research and development is coordinated across the Department of Energy. However, we still hear significant issues of stovepiping at the Department. Do you agree and how can this coordination be improved, particularly between the Office of Energy Efficiency and Renewable Energy and the Office of Science?

Dr. DEHMER. Well, I have also heard a lot of talk about stovepiping. I think a couple of things have happened in recent years that are working to change that. The first is this entire series of workshops that have really energized the scientific community. In all of my years in science, and it is quite a lot of years now, I have never seen the scientific community so energized as I have over the problems of energy. And this is real. Tom Russell said that 300 proposals were turned down. It was actually 700, Tom.

Dr. RUSSELL. My chances were less.

Dr. DEHMER. Your chances were less. But something else has happened in the Department, and that is the creation of the Under Secretary for Science position. When Ray Orbach was confirmed as Under Secretary of Science, the first thing that he did was a DOE-wide assessment of basic and applied research. He had all of the technology offices come in and speak to him about what they were doing, and he specifically asked the Office of Science how could it help the various programs. As a result of those assessments, which took several months, Dr. Orbach came up with about two dozen areas that were ripe for R&D integration. Many of these actually appeared in the budget and will continue to appear in the budget in future years. These are areas that not coincidentally were topics of the basic research in the workshop series and areas where the technology offices and the Office of Science are coming together much more closely to devise road maps and planning scenarios, to integrate their performers in the field to hold joint workshops, to hold joint contractor meetings, to advise one another on how calls for proposals ought to be written and to help one another review the proposals.

I have seen a change. I have been in the Department of Energy for 13 years, and I have seen a dramatic change in the last three, and I would like to see that continue.

Chairman LAMPSON. An Interagency Biomass Research and Development Board was recently created that includes representatives from both the Office of Science and EERE within DOE as well as those from NSF, USDA, EPA, and several other relevant agencies. Do you think it is a good model to coordinate other energy research that is fostered by multiple programs and agencies like solar energy and advanced battery research?

Dr. DEHMER. Yes, I have served on a large number of interagency working groups, and I am familiar with the biomass board; and in general, they are successful. I have particular experience with interagency working groups for the large-scale facilities, the Synchrotron Light Source and the Neutron Scattering Facilities and they have been very successful.

Chairman LAMPSON. The Senate Energy and Water Appropriations Subcommittee has proposed cutting solar research out of the Basic Energy Sciences Program and shifting $60 million to the solar program in the Office of Energy Efficiency and Renewable Energy. Does this make sense to you and if not, then why should the Office of Science be the steward of the kind of solar research it currently oversees?

Dr. DEHMER. Well, the Basic Energy Sciences Program has had the largest solar photochemistry program in the Nation for decades, and I am personally very proud of that. As a result of the workshops, that solar photochemistry program has become integrated with the photosynthesis program so that plant photosynthesis and inorganic solar photochemistry are now completely integrated. It is a wonderful program. Of the 250 letters of intent that the Basic Energy Sciences Program received for the Energy Frontier Research Centers, by far the largest number were in solar energy. Basic Energy Sciences is known for its fundamental research in solar energy. We support the activities in the Office of Energy Efficiency and Renewable Energy, and we note with great pride that some of the things that they are working on now were actually discovered in the Basic Energy Sciences Program and not very long ago. In my opinion, both the Office of Energy Efficiency and Renewable Energy and Basic Energy Sciences ought to be robustly funded for photochemistry and solar energy conversion.

Chairman LAMPSON. Dr. Russell, will you comment on that as well, please?

Dr. RUSSELL. I think by removing or shifting the funds from BES to EERE, one of the things that will inevitably happen is that the amount of funds that will be going into the academic community is going to be much less. If you look at some of the advances that have been made and if I look at photovoltaics, the most efficient photovoltaic device is above 50 percent efficient. That was actually discovered in the academic community. If I look at some of the results that have been coming out in terms of the all organic type photovoltaic devices, advances have been made in the academic sector. I fear that if monies are shifted from BES to EERE, then that is going to remove those funds from the academic sector where I think a lot of basic research can be done. Development work clearly needs to be done as well, and that having the industrial sector involved as well is important. However, by removing this to EERE, the amount of funds that will be put into the academic sector is going to be much less. I think that is a mistake.

Chairman LAMPSON. Thank you very much. Ms. Biggert, you are recognized for five minutes.

RETAINING THE ENERGY SCIENCE WORKFORCE

Ms. BIGGERT. Thank you, Mr. Chairman. I am going to continue with Dr. Dehmer and probably Dr. Russell. Hopefully we will have another round if we don't get—Dr. Dehmer, I think we are aware that the major facilities have struggled with an adequate operating budget, and we certainly had to add something into the supplemental budget for the labs to continue in 2008. But now we are worried about the 2009 budget and whether that will really go back to the 2007 budget. So we certainly aren't out of the woods as far as dealing with that budget. Are you concerned, and I think this ties in a little bit to the budget, about the expertise in the energy science going to foreign countries or our ability to attract scientists from abroad as we once did? Do you see that as a connection to the economic competitiveness?

Dr. DEHMER. Yes, so let me talk for a second about the scientific user facilities. Those facilities should be funded probably 10 to 15 percent above where they are funded right now; and in 2007, 2008, and 2009, the BES budget request includes that funding. When the funding was not appropriated, those facilities survived largely by cannibalizing funds that they would normally use for routine maintenance, upgrades, spares, and so forth. Although the facilities for the most part continue to run at the 5,500 hours a year that Steve Dierker mentioned, they are really strained to do so; and a very bad outcome could happen if they don't get increased funding. So that is the situation with the scientific user facilities.

In terms of attracting scientists to energy, U.S. scientists and foreign scientists, the scientific community is like herding cats. You can't herd them but you can move the food, and the large amount of money that was included in the BES budget in 2007, 2008, and 2009 for basic research and energy was certainly an attractor to the scientific community. And I mentioned a moment ago that we had to turn down 700 peer-reviewed proposals when the funding didn't come through. But like cats, the scientific community learns and after three times, they learn pretty well that they won't go after that food again.

So the answer to your question, although somewhat jocularly, is yes, I am concerned about retaining not only U.S. scientists but foreign scientists in fundamental research related to energy. If we cannot do this, as a country we will have been diminished; and as

I said a moment ago, I have never seen the level of enthusiasm in the scientific community as I have seen as a result of these workshops. I don't want to lose that enthusiasm. I don't want to lose these scientists.

Ms. BIGGERT. Thank you. Dr. Russell, how would you compare our national user facilities to those in other countries?

Dr. RUSSELL. I think what Pat Dehmer said is correct, that the facilities that the American scientists have available to them are absolutely world class. These facilities are as good as any facilities that you would get anywhere in the world and that would include Europe as well as Asia.

Ms. BIGGERT. Thank you. Dr. Hall, if you can't get access to the user facilities when you need it, what are the repercussions to your research and are there other viable options for GE and other industrial users?

Dr. HALL. We do have reasonably good access to these user facilities. The question often comes up as to the many different types of access that we need, and very much as you think about these facilities, they play two really important roles. One is as tools for fundamental research and the second is as probably the best characterization tools in the world. And what we generally are seeking is access in the latter category where we need to characterize materials. And so we are looking at trying to get better access on a number of timeframes, in some cases longer-range research where we can use the proposal system but also in a sort of a rapid access mode where we can investigate issues that occur during technology development. If we can't get access to these facilities since these are such superb facilities for materials characterization, it will definitely slow our programs. We will try to find alternatives. We can sometimes use in-house resources, but really, access to these superb facilities is critical and can be very problematical if as we have said the resources aren't there for both the facilities and the researchers at the national facilities.

Ms. BIGGERT. Thank you. I yield back.

Chairman LAMPSON. Thank you, Ms. Biggert. Dr. Bartlett, you are recognized for five minutes.

ALTERNATIVE TRANSPORTATION FUEL

Mr. BARTLETT. Thank you very much. I appreciate very much your testimony today. I have here an Energy News Roundup, and it notes that there were three editorials in The Hill today relative to energy. It notes that the Senate is working on an energy bill that nobody seems enthusiastic about. They have to get 60 votes there to pass something. The House is struggling to find an approach to an energy bill that can get the requisite 218 votes. There is an interview with Charles Maxwell who very correctly predicted the high price of oil now and just recently even higher who says that by I think 2015 oil will be $300 a barrel. I am very interested in your testimony and the potential that could come from this basic research that is being done, and I notice that most of that potential would result in the production of electricity. But the real crunch in the near-term and mid-term and far-term actually is not going to be for electricity because with a lot of solar and wind and much more nuclear and true geothermal where you tap into the molten core of the Earth and with microhydro that might produce as much as macrohydro without the environmental degradation, we could probably produce as much electricity as we ought to be using, maybe not as much as we would like to be using. But there is no such rosy outlook for liquid fuels. There is just no silver bullet out there. Two bubbles have already broken, the corn ethanol bubble which was destined to break because simple, back-of-the-envelope computations said that that was never going anywhere and it didn't; the hydrogen bubble broke before the corn ethanol bubble; and finally people figured out that hydrogen is not an energy source, it is simply a battery if you will that carries energy from one place to another. Now our hopes are on a third bubble which will shortly break because there is irrational exuberance about cellulosic ethanol. You will never get more energy from cellulose if you simply burned it. And it is inconceivable to me that we are going to get much more energy from a wasteland not good enough to grow anything on than we could get from all of our corn and all of our soybeans where you know the National Academy has said that we might displace 2.4 percent of our gasoline if we use all of our corn for ethanol and 2.9 percent of our diesel if we use all of our soybeans for soy diesel.

What kind of prospects—and I am a scientist. I am one of three in Congress, and I know you do basic science, not because of any societal benefit because you want to advance knowledge, and there will be societal benefit if you advance knowledge. But what are we looking at that could possibly provide the quantity and quality of energy that we are getting from the 84 or 85 million barrels of oil that we produce today, 21 or 22 of which are used by the United States, and each barrel has the energy equivalent of 12 people working all year? What is there in the future that could come even close to the quality in terms of density and quantity, quality and quantity that we get from oil?

Dr. DEHMER. Are you asking me, sir?

Mr. BARTLETT. Any of you.

Dr. DEHMER. Okay. Sir, you are absolutely right in everything you say. I agree with you completely. In the short-term for transportation, we only have fuel switching as an option, and the fuel switching, corn ethanol, is not the answer. In the short-term, cellulosic ethanol may be a partial answer. There is also fuel switching to different kinds of petroleum-based products, oil shale, tar sands, and so forth. Again, a short-term solution but a solution nevertheless. What we really need is a long-term, sort of decades-to-century strategy here for transportation. It may well be that it involves a combination of ethanol produced, not cellulosically but perhaps biometrically combined with electric. So there may be some hybrids but right now, we have to do a transition from where we are today to a 10-, 20-, 30-year solution and ultimately to a 50- to 100-year solution. But I agree with all of the assessments that you just stated.

Mr. BARTLETT. Mr. Chairman, the real tragedy is that we knew of an absolute certainty 28 years ago that we were going to be here today because 28 years ago we could look back to 10 years prior to that, 1970, where M. King Hubbert's prediction about oil production in the United States came true. We reached our maximum production. Today, in spite of drilling more oil wells than all of the rest of the world put together and finding oil in Alaska and the Gulf of Mexico which he had not included, today we produce half the oil that we did in 1970. It is really quite a shame that we are here today. Thank you very much.

Chairman LAMPSON. We were also told in 1945 by the United States Army to diversify away from our dependence on fossil fuels, and we ignored that as well.

Mr. BARTLETT. Mr. Chairman, we are into ignoring things. Our government has paid for four studies in the last several years, two of them in '05, one of them the Hirsch Report, the second report by the Corps of Engineers, two of them last year, one by the Government Accountability Office, another by the National Petroleum Council. All four of them said the same thing. The peaking of oil is a certainty. It is either present or imminent with potentially devastating consequences, and nobody in leadership in our country has recognized any of these reports and the challenge that it provides us. So we are into ignoring things.

Chairman LAMPSON. Well, unfortunately you are right, and it is going to take the scientific community to fix it for us. So we need to be about—you want to make a comment, Dr. Russell? Help yourself.

Dr. RUSSELL. We are in a situation now where it is inevitable and we can't ignore.

Mr. BARTLETT. I believe, sir, that we are in a situation where as predicted by the Hirsch Report that said that unless you anticipated the peaking of oil by a decade, to have no economic consequence, you have to anticipate it by two decades. To have meaningful but maybe manageable economic consequences, you need to precede it by a decade. It is here I believe, and we have done nothing.

Dr. RUSSELL. I agree with you completely, and the only point I am making is that we can't ignore this anymore because it is inevitable and I think that——

Mr. BARTLETT. We shouldn't but I am afraid that politicians can.

INDUSTRIAL USE OF FACILITIES

Chairman LAMPSON. We better find a way. Let us start with Dr. Hall again. I did note that in your team's experience, "gaining access to sufficient beamtime on a timely basis can be challenging." Does GE have experience with the rapid access system that Dr. Dierker described in his testimony, and how would you recommend it be improved?

Dr. HALL. I think we do have experience with that, and I do want to make it clear that the researchers at the Department of Energy labs certainly are as accommodating as they can be in many cases to meeting our needs. I think that my testimony really focused on sort of a philosophical shift as we think about these facilities, and this is again something that really needs to be considered at a policy level as to how these facilities would be best utilized. And we know as we heard about the history of these facilities and read about the history of these facilities that they came from a philosophy of doing basic science. I am here to say that they are also incredibly important tools for characterization and for moving technology forward as industry tries to solve the most important challenges. And so as we think about that, we need to think about what the priorities should be, how the Department of Energy should set priorities relative to basic research versus use of these facilities as characterization tools, and whether, for example, certain amounts of time should be set aside for industrial use, additional time set aside for rapid access use; and again, this is sort of a policy question that we are certainly very happy to—I am sure many of the industrial users are very happy to partner with DOE. I am not here to propose, you know, specific solutions but only to raise the question of how we want to best utilize these incredibly important facilities; and of course, much of the availability of both beamtime and researchers goes back to the budget question and the need to properly fund these facilities.

Chairman LAMPSON. Dr. Dierker, would you comment?

Dr. DIERKER. The provision for rapid access is one that is becoming more common at the facilities as the need that Dr. Hall described has become more apparent. Often the kind of industrial characterization measurements that he is referring to I believe are ones that can be done very quickly, even as short as 10 minutes of access to beamtime can give a very important answer for industry.

The challenge is getting access quickly and having the facility have the staff and the instrumentation to have a very high through-put of these kind of characterization measurements to serve the needs of industry. And so I think the facilities have established user access that is going in this direction even more and more and with proper support for staffing and operating the kinds of high through-put characterization facilities that are especially important to industry. I think that we can meet that need.

Chairman LAMPSON. Thank you. In addition to scientific merit, do you think it would make sense to take American Competitiveness into account when reviewing proposals for time on the facilities and should this be a separate competition or would a separate user fee structure be justified for industrial research that doesn't need intellectual property protection? And I would like for Dr. Dierker and Dr. Hall to respond.

Dr. DIERKER. I think that the criteria used in evaluating proposals need to give proper recognition to the impact of research on industry so that both scientific impact and technological innovation that comes from the results of the measurements have to be equally recognized. I do believe that the peer-review process and open competition is proven to guarantee the best work is done, whether its goals are pure science or technological innovation. And so I believe that that kind of a process with proper guidance to the evaluation criteria is the best path for having the best work done, and I think that a ticket system would compromise that competitive peer-review process.

ENERGY FRONTIER RESEARCH CENTERS

Chairman LAMPSON. Dr. Dehmer, I think we all appreciate your efforts to identify and prioritize your research in areas that can have the most impact on our future energy options. I do have a few questions on your proposal to create 25 to 35 Energy Frontier Research Centers.

You note in your testimony that they, "should be viewed as a funding mechanism" and that "no building construction will be part of the awards." Given this, does it even make sense to call them centers which implies some kind of a permanence? Maybe they should be called Energy Frontier Research Awards or Collaborations. Your thoughts?

Dr. DEHMER. Well, first of all, I didn't fully appreciate the ramifications of the word "center." We had no intent to associate construction with these, and we also did not have any intention to continue them in perpetuity. They would be stood up for five years, and they would undergo regular peer-review competition; and I would envision, although I am no longer director of the Basic Energy Sciences Program, I had envisioned something like calls for proposals every, say, two to three years, and those centers or those collaborations that were completing their five-year term would be competed with new ones. So I would envision rotation in and out with the best of ideas and the best collaborations being successful.

Chairman LAMPSON. Thank you. Dr. Russell, do you view this as a good proposal to get the best minds in the academic community more involved in tackling these issues?

Dr. RUSSELL. Yes, but I would like to address the issue of centers. I run a Materials Research Science and Engineering Center. That does not require a building and nor is there any permanence to this, and there are other precedents in that the National Science Foundation has science and Technology Centers and Engineering and Research Centers; and none of these requires you to have a building or any sort of structure that is going to have any permanence to it.

In terms of these EFRCs that you are mentioning, 25 to 40 of these, I think it is imperative that this be made available to the academic community, and this is a means by which one can get some of the best minds in the country working on these problems and being funded to work on these problems in a manner that they can actually conduct the research in a viable way.

Chairman LAMPSON. Thank you. Ms. Biggert, you are recognized for five minutes.

PROPRIETARY INFORMATION

Ms. BIGGERT. Thank you. Dr. Hall, in your written testimony you talked about that there were concerns of proprietary research. Could you expound on that?

Dr. HALL. Yes. Certainly you know, I can speak for some segment of the industrial user base. You should recognize that in the chemical and pharmaceutical industries which also heavily use these facilities, in some cases proprietary issues are even more significant, and I encourage you to explore their needs as well. I would like to just encourage us to have a mechanism since we need to on occasion bring materials to the facilities where we are trying to answer some questions about the structure and chemistry of these materials, materials that have been developed in our own labs; and we need, in order to do that if these are proprietary materials, we need proper protection to ensure that we own the results of those investigations. Again, they may be the types of investigations that Dr. Dierker was talking about where we may only need a very short amount of time on these facilities in order to get the answers that we need. So my encouragement here is that we have systems in place where we can very simply execute proprietary agreements that are clear and straightforward and that can enable us to do this. Again, I think this is key to moving American technology forward.

Ms. BIGGERT. What do you mean by the total cost recovery option?

Dr. HALL. There is a system in place and certainly probably Dr. Dierker can speak to this even more extensively than I can, there is a system in place where when an industry brings proprietary research to the facility that a fee is charged, and that is based on a total cost recovery. This is separate from the proposal process which generally involves non-proprietary work. I will tell you that in GE's case, most of the work that we actually do with the synchrotron is non-propriety and collaborative in partnership with the scientists at the facility. But speaking for industry as a whole, proprietary concerns when using these facilities are certainly large and important.

Ms. BIGGERT. Is this materials that are patented? Is that——

Dr. HALL. Patented or patentable, yes. Yes. Certainly once a material is fully patented, then we have the protection we need. These would be materials under development.

Ms. BIGGERT. Dr. Dierker, would you like to add anything to that?

Dr. DIERKER. Yes. We do have procedures for proprietary work to be carried out which does not require the industry to review any proprietary information, and the total cost recovery you are referring to is a quite nominal fee I believe. Since the facility operates for so many hours per year and there may be dozens of beamlines operating at the same time, the operating costs are divided by the number of beamline hours; and so in a case of the National Synchrotron Light Source, for example, I think it is about $110 per hour as a proprietary fee. So I don't think it is any impediment to the industrial research, and there are safeguards in place that permit the work to be done and patents protected.

SUPPORTING BES FACILITIES

Ms. BIGGERT. Thank you. Dr. Dehmer, what is the right balance between the important new facilities such as NSLS–II and the continued operation of the very successful existing facilities such as the Advanced Photon Source?

Dr. DEHMER. That is a difficult question that comes up all the time. You constantly have to work to be at the forefront of science and technology and that means making some difficult choices, perhaps with facilities that are past their time. We have a number of facilities in the Basic Energy Sciences Program that are very new and very modern, and all of those need to be supported. And at some point the new Director of Basic Energy Sciences may have to make some hard choices about the older facilities. But the ones that you mentioned, the Advanced Photon Source, the Spallation Neutron Source, the facility under construction that Steve Dierker is Chair of, these are cutting-edge facilities that will keep the United States at the forefront of the physical sciences and technology—and they will be supported.

Ms. BIGGERT. I assume any time from the Department of Energy and what the top projects are, you know, the top 20, and we start talking about those, and then all of a sudden it changes. Do you see that these will remain the top priority?

Dr. DEHMER. Yes, actually the Facilities for the Future, a brochure that was put out probably five years ago now, rank-ordered a number of facilities. The ones in the top tier actually all have gone forward. There were a couple of changes; but over a five-year period, you would expect that you would have a few changes. Some facilities fell off the map, and a couple of other facilities rose in priority. But I can say that the ones in the top tier all have gone forward and have been very successful.

Ms. BIGGERT. Okay. Just go back for a minute to the budget. We have tried and tried to double the funding for the Office of Science and so many opportunities, and it always seems that somehow it gets cut out. How can we, as Congress, and what we have tried to do is inform the other Members of the importance of this but from your point of view, what could we do really to impress upon the Congress that it really is our charge to ensure that we are going to be competitive through the use of basic science research?

Dr. DEHMER. Well, I think perhaps if there has been a failure, it is a multi-point failure; and it is partly a failure of the scientific community and the agencies. We have not made the case clearly enough, that there is a link between fundamental research, discovery, innovation, and competitiveness. And I think that that link has to be made much more strongly. We have heard examples here today of it; but this is real, and I have seen from Congress a strong sense that doubling the physical sciences, doubling the budgets of these three agencies including the Office of Science, is critical. If other Members are not convinced, I think it is the responsibility of all of us to make the case more strongly.

Ms. BIGGERT. Would anyone else like to add to that? Dr. Hall?

Dr. HALL. I would only say that one important point once again is that to solve the most pressing problems that we are facing as a Nation, it is going to be critically important that we have strong industry-government-university partnerships around these technology areas. The availability of these types of facilities is a key part of that partnership.

Ms. BIGGERT. Thank you. Thank you and I yield back.

Chairman LAMPSON. Thank you. Dr. Bartlett, you are recognized.

Mr. BARTLETT. Thank you very much. Dr. Dehmer, when you mentioned failure, you were referring to what as failure?

Dr. DEHMER. I personally strongly believe in the link between fundamental research, discovery, innovation and technology development. I spent the last six to eight years of my life leading these workshops to demonstrate that and to energize the basic research community so that they would be part of the common cause. If the message hasn't gotten through to those who make the decisions, then I think that is a failure on our part.

BASIC RESEARCH AND LONG-TERM SCIENTIFIC CHALLENGES

Mr. BARTLETT. Okay. Okay. When I first came to the Congress about 16 years ago, there was a proposal that we should fund only basic research that would have societal benefits, and I asked them, how were they going to do that because I am sure that Madam Curie had no idea what societal benefits would accrue to her early discoveries in radiation. They asked me, then what? I said, well, you just provide an adequate amount of money, which we do not, to support an adequate number of basic researchers, which we do not, and I will assure you that if you just leave them free to pursue their interest in discovering new information, that there will be societal benefits. I gather that, Dr. Hall, you are primarily interested in developmental things that will ultimately have societal benefits?

Dr. HALL. I am here speaking on behalf of General Electric, and in my role, technology development is very critical. But I clearly said in my testimony that this needs to be particularly for these facilities, the characterization or technology development piece clearly needs to be balanced with the need for outstanding fundamental research.

Mr. BARTLETT. The rest of you are primarily interested in fundamental research, I gather from your testimony and your positions. I would hope that you would stoutly resist any attempt to try to direct you into basic research, fundamental research pursuits that are likely to have societal benefits; and I trust that you will do that. Yes, sir?

Dr. RUSSELL. Can I trust that you could speak to the funding agencies? And the reason why I say that is every academician, when they are writing a proposal to get funding for basic research, there must be a section of that proposal that discusses or treats what sort of societal impact that may potentially evolve from that research.

Mr. BARTLETT. That is too bad.

Dr. RUSSELL. Well, that is reality.

Mr. BARTLETT. That is too bad, and Mr. Chairman, we should strive to remove that requirement because no one knows when there will be societal benefits that comes to basic research.

Dr. RUSSELL. I agree with you wholeheartedly, and it would be wonderful if that could be removed.

Mr. BARTLETT. There are several of us in Congress, three scientists and several others that agree with us, and we will try. This hearing is focused on energy, and one of the things that I have supported and it is now the law, although not being implemented by the Administration who didn't like that law, and that is the creation of ARPA–E. I gather you are all familiar with DARPA. Their customer, of course, is the Department of Defense and they have been enormously successful because what they do is to fund far out things that the Board of Directors couldn't justify funding with their stockholders' money because the payoff is far too distant and the probability of a payoff is small, and ARPA–E of course would be a DARPA-like thing for energy. Do you think that there is a reasonable role for that as we tackle a problem we should have been tackling at least 28 years ago?

Dr. DEHMER. Well, as you correctly pointed out, ARPA–E was in the Authorization Act but has not been funded. And so I am not going to comment on the Administration's position because I think you know that. But perhaps I can speak to one other thing that talks about way-out, fundamental, long-term, high-risk research. After 11 basic research needs workshops in different areas of energy, I was hearing the same kinds of things over and over again, that we need to control the movement of electrons and materials, that we need to be able to assemble from the atomic level up. However, I got the sense from the community that they were too skewed toward the end product which was an energy technology. And so I was the one who empaneled a final workshop to look at grand challenges in science that had nothing to do with energy technologies and that were stripped of disciplinary labels. And that is the workshop that Tom Russell talked about in his opening remarks.

I want to keep the Basic Energy Sciences research community as focused on long-term scientific challenges that may not have an immediate payoff as they are on the energy needs of the Department. And I can tell you, it is a very difficult challenge because as Tom said, researchers are programmed to put in the opening paragraph of their proposals the societal relevance; and in the case of the Department of Energy, the energy relevance. But from someone who stewarded a basic research program for 12 years, I know that you have to keep this community focused on long-term discovery science, and I have worked very hard to do it but it is a struggle.

Mr. BARTLETT. That requirement of course indicates the naivety and the ignorance of the general public and Congress, and we have truly representative government about basic research, what it is and how it should be conducted.

Thank you all very much for your testimony and your service.

Chairman LAMPSON. Thank you, Dr. Bartlett. I want to thank all of you. This has been fascinating. I have probably another dozen questions that I would like to ask. We will take a different track at this point, though. I will express my appreciation for your appearing before the Committee this afternoon and say that under the rules of the Committee, the record will be held open for two weeks for Members to submit additional statements and any additional questions such as mine that they might have for the witnesses. We appreciate your coming. Have a good day, and this hearing is now adjourned.

[Whereupon, at 3:15 p.m., the Subcommittee was adjourned.]

Appendix:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Patricia M. Dehmer, Deputy Director for Science Programs, Office of Science, Department of Energy

Questions submitted by Chairman Nick Lampson

Q1. In your testimony, you note that "we are looking for new concepts and theories to understand how nature works" and you are seeking "a 21st century equivalent to the development of quantum mechanics 100 years ago." The importance of more emphasis on theoretical research is another area highlighted in your recent "Grand Challenges" report. Do you believe the current support for research into new theories and concepts in materials and chemical sciences is adequate?

A1. Theoretical research in materials and chemical sciences to understand how nature works is a key component of the research activities supported by Basic Energy Science (BES). The shortfall in appropriations compared to the FY 2007 and FY 2008 President's requests did not allow BES to provide support for new research in these critical scientific areas or for promising theoretical studies.

The importance of theoretical research was emphasized not only in the BES Advisory Committee "Grand Challenges" report, but also in the recent series of *Basic Research Needs* workshop reports. The resulting increased emphasis on theoretical research has been reflected in the BES budget requests in the past three years. For example, over $80 million of new funding was requested in FY 2007 and FY 2008 to increase research in solar energy utilization, hydrogen research, advanced nuclear energy systems, and mid-scale instrumentation, highlighting the need for theoretical approaches.

The FY 2009 BES budget request contains funding increases to initiate new basic research to address the grand science and energy challenges, in line with the goals of the *America COMPETES Act.* The BES request includes funding for the proposed Energy Frontier Research Centers ($100 million) as well as funding for increased opportunities for single investigator and small group research awards in the BES core program (approximately $60 million). The development of new theories and concepts is at the core of most of these new research opportunities. If funded, these new research efforts would significantly enhance the current theoretical research activities supported by BES and would bring the total theoretical research effort in BES to a level that would adequately support BES program needs.

Q2. A recent National Academics report has promoted biomaterials as an exciting new area of research without a real home. These can have some very useful properties like self-healing and the ability to detect hazardous substances, would it make sense for BES and the Office of Science's Biological and Environmental Research program to establish a joint initiative in this area?

A2. The report, *Inspired by Biology: From Molecules to Materials to Machines,* is the product of a study by the National Research Council (NRC) of the National Academy of Sciences (NAS) co-sponsored by BES and the National Science Foundation (NSF). We support the findings and recommendations of this report which recognizes that biology offers an extraordinary source of inspiration for the development of new materials, devices, and processes.

BES and the Office of Science's Biological and Environmental Research (BER) program have several joint initiatives in the area of biomaterials. For example, BES and BER, along with NSF and the National Institutes of Health, are currently co-sponsoring an NRC study entitled *Forefronts of Science at the Interface of Physical and Life Sciences.* This study seeks to identify large-scale, complex problems at the interface of the physical sciences and life sciences that could produce unprecedented advances and breakthroughs in both areas. We anticipate the report will provide valuable insight into the scope of scientific opportunities spanning programs in BES and BER (as well as other federal agencies) and may help form the basis for new activities in these Offices.

Q3. Corrosion is a major issue in both our transportation and military infrastructure, how significant is the attention to corrosion of materials in the BES program, and is there any integration with research efforts at the Department of Defense?

A3. The BES program is working with the Department of Defense through two studies by the National Research Council (NRC) of the National Academy of Sciences (NAS) on corrosion. BES is currently co-funding a study with the Department of Defense by the NRC entitled *Research Opportunities in Corrosion Science* *and Engineering.* This study is designed to identify the science opportunities which have arisen from recent advances in the field of fundamental corrosion research to further advance scientific understanding of the mechanisms of corrosion processes, materials degradation, and their mitigation. The study will prioritize a set of research grand-challenge questions to fill identified scientific gaps and will make recommendations on a national strategy for fundamental corrosion research to gain critical understanding of materials degradation and mitigating technologies. The resulting strategy is also expected to include recommendations on how to maximize dissemination of the results of corrosion research, so that results of this research can be incorporated into corrosion mitigation. BES also participated in the recently completed NRC study on *Assessing Corrosion Education* which the Department of Defense sponsored.

Q4. In your testimony, you mention pilot studies on ways to improve the operation and utilization of the light sources, but budget restrictions did not allow you to implement them this year. Could you describe in greater detail what you would have done to better manage these facilities if you received the funds you requested?

A4. Operational costs for the light sources have increased significantly in recent years, largely because of increases in the cost of the electric power needed to operate these facilities. Yet appropriations in FY 2007 and FY 2008 were below the levels requested. These reductions forced us to reduce some operating hours and user access at the light sources; but, we were able to hold these reductions to a minimum by using funds that had been intended for accelerator maintenance and instrument upgrades, which have been deferred. So, there has been a cost. Also, present staffing levels are not sufficient to provide optimum utilization of the facilities. The FY 2009 budget request, if provided in full, would allow full operation of the light sources, increased staffing of the user beamlines, and some mitigation of the impact of deferred maintenance and upgrades. The DOE light sources are the "crown jewels" of our user facilities, and we are in danger of significantly damaging them if budget reductions continue.

To better manage these facilities, given the recurrent budget shortfalls the BES program re-evaluated the metrics used to assess effective operation and utilization of the synchrotron light source facilities, looking to broaden the metrics from the previously used "hours of operation of the accelerator complex and numbers of users who annually visit the facilities." With the cooperation of the facilities, DOE devised new measures that provide quantitative assessments of instrument capability, instrument capacity, and staffing levels. These measures were piloted in FY 2005 and FY 2006, and data were collected for FY 2007 and FY 2008 as well. These pilot studies show that overall effectiveness of operation and utilization of the synchrotron light sources could be improved, but that usually such improvements would require additional operating costs, although some improvements could be gained from enhanced strategic planning within and across facilities.

The BES program initiated the pilot study to develop two factors for assessing effective utilization of DOE light source capabilities. First, BES commissioned the classification of light source beamlines that resulted in twelve categories of instruments, four in each of the three major categories of spectroscopy, scattering, and imaging. Classifying the instruments at the light sources in this way revealed some of the differences among the facilities. For example, the APS, a hard x-ray light source, emphasizes scattering, while the ALS, a soft x-ray light source, emphasizes spectroscopy and imaging.

Once all the beamlines were uniformly categorized, new data were collected for two assessment factors: quality of beamlines in operation and number of staff—including all relevant support staff—dedicated to the use of the beamlines versus an assessment of optimal staffing needed for each beamline.

The quality factor data in FY 2005 indicated that only 18 percent of the beamlines at the four DOE facilities are operating at optimal performance. An equal number of operating beamlines required major upgrades or are marginally useful. The majority of beamlines, 64 percent, required minor or moderate upgrades. Across the four DOE facilities, 46 beamlines (27 percent) were rated as "best in class" as benchmarked against similar capabilities worldwide.

These data have been collected by the four DOE light sources annually since the initial pilot study and are used by facility management to assess utilization. The FY 2008 data will be available late in 2008, and BES will use the multi-year data to assess the trends for instrument and facilities utilization of the four DOE light sources during these recent years of constrained budgets.

Question submitted by Representative Bob Inglis

Q1. Dr. Dehmer, in your testimony, you discuss the Basic Research Needs *workshops, one of which was the* Basic Research Needs for the Hydrogen Economy. *Can you discuss how work on the basic sciences of hydrogen matter is helping to improve our ability to tap into this valuable energy source?*

A1. As an energy carrier—not an energy source, hydrogen holds the potential to significantly transform the ways in which we use energy. The *Basic Research Needs for the Hydrogen Economy* workshop, held in 2003, served as a basis for the first BES solicitation in the hydrogen program. As a result of that solicitation BES now funds hydrogen research under five categories, including Novel Materials for Hydrogen Storage; Membranes for Separation, Purification and Ion Transport; Design of Catalysts at the Nanoscale; Solar Hydrogen Production; and Bio-inspired Materials and Processes. In each of these five categories substantial progress has been made in understanding the issues that are "show stoppers" in the technology programs.

This work has enabled significant advances in understanding hydrogen-matter interactions. Recent accomplishments in BES-supported research include the discovery of atomic-scale mechanisms explaining reversible hydrogen storage within complex metal hydrides; the development of novel micro- and nano-patterning syntheses for a new generation of fuel cell membranes with superior power output; theoretical predictions and experimental validation of new architectures and compositions of catalyst alloys for efficient hydrogen production from fossil fuels as well as for fuel cell applications; the synthesis of mixed metal oxide photoelectrodes for solar hydrogen production; the identification of chemical pathways to convert biomass to hydrogen and other fuels; and advances in the development of oxygen-tolerant enzymes for bio-inspired hydrogen production.

A number of these accomplishments have led to follow-up developments by the applied research programs. Of particular note is the successful development of electrocatalysts with ultra-low platinum content that are 20 times more active by mass and more stable than pure platinum for converting hydrogen to electricity in fuel cell applications dramatically reducing the potential cost of future fuel cell systems.

The connection of basic research results with the applied technology needs is ensured by close collaboration between BES and the technology offices within DOE that are part of the hydrogen program, as well as with other government agencies that perform research and development on hydrogen and fuel cells. In order to further strengthen collaborations with the applied technology programs, BES program staff began participating in the DOE Hydrogen Program Annual Merit Review, which also involved the DOE Offices of Energy Efficiency and Renewable Energy, Fossil Energy, and Nuclear Energy, to promote information sharing. Beginning in FY 2006, the BES program staff organized parallel sessions at the Merit Review meeting for the BES principal investigators. Results from long-term research in hydrogen storage, fuel cells, and hydrogen production will allow continued cost reductions as ongoing scientific advances in areas like photochemical hydrogen production reach technological readiness. DOE and industry representatives have stated that fundamental science breakthroughs are needed to meet the 2015 technological readiness requirements.

Questions submitted by Representative Daniel Lipinski

Q1. Both the National Academies and DOE's own "Grand Challenges" report recently identified materials synthesis as an area that needs much more attention if we're to come up with solutions for a broad range of our energy problems. Do you agree, and if so how should we address this? Are the new nanotechnology centers all we need?

A1. The discovery of new materials with superior properties is essential to energy-relevant areas such as superconductors for energy transmission, photovoltaics and batteries for energy storage, and thermoelectrics for power generation. The design, discovery, and growth of novel materials represent a national core competency, which is required for scientific progress and long-term economic growth. Currently, the U.S. infrastructure in materials synthesis is insufficient due in part to the decline of traditionally strong industrial expertise in synthesis and to the relatively small number of synthesis scientists being trained in U.S. universities and national laboratories.

The Energy Frontier Research Centers (EFRCs) proposed in the Office of Science's FY 2009 budget request ($100 million) and the corresponding increased opportunities for single investigator and small group research awards in the BES core program (+ ~ $60,000,000) will address this deficiency. The design, discovery, and synthesis of new materials and molecular assemblies through atomic scale control are prevailing themes in these efforts. Further, BES has a core research activity in Synthesis and Processing Science focused on atomic- to nanoscale scientific understanding using physical principles to enable reliable, reproducible, and innovative production of novel materials. We also expect that materials synthesis work done in the EFRCs will be coordinated and prioritized within this BES research activity.

The DOE Nanoscale Science Research Centers are an integral part of the BES materials synthesis effort. Their specialized synthesis capabilities as well as their complementary analytical and computational tools are expected to be utilized by the EFRCs and also by the new single investigator and small group research investigators.

Q2. Nanotechnology promises to yield significant advancements in many fields, perhaps most notably in the development of new energy technologies. Would you elaborate on your experiences with nanotechnology and how you envision it aiding in the fight to develop advance energy technologies that will wean us off fossil fuels and reduce emissions of climate changing gases?

A2. The relationship of nanoscale science and technology to the Nation's energy future was detailed in the report of an interagency workshop sponsored by DOE and the other member agencies of the Nanoscale Science, Engineering and Technology Subcommittee of the National Science and Technology Council in March 2004. The report (*http://www.sc.doe.gov/bes/reports/files/NREN_rpt.pdf*) contains many examples indicative of outcomes and expected progress in a broad range of research targets. Six foundational nanoscience research themes were highlighted: catalysis by nanoscale materials; using interfaces to manipulate energy carriers; linking structure and function at the nanoscale; assembly and architecture of nanoscale structures; theory, modeling, and simulation for energy nanoscience; and scalable synthesis methods.

At the root of the opportunities provided by nanoscience and nanotechnology to impact our energy security is the fact that all the elementary steps of energy conversion take place at the nanoscale. There are many recent examples where quantum confinement in nanomaterials has produced unexpected phenomena exploitable for energy technologies. These examples include highly selective nanocatalysis for hydrogen fuel cells; quantum dots for high efficiency solid-state lighting; nanostructured electrodes for batteries and ultra-capacitors with higher energy and power densities; radiation-tolerant nanomaterials for next generation nuclear applications; and nano-layered high-temperature superconductor wires for low-loss transmission lines.

Q3. Major facilities have struggled with adequate operating budgets. How has reduced operating time at facilities like the Advanced Photon Source (APS) affected work like yours? What are the long-term impacts of inadequate funding?

A3. Despite requested increases in FY 2007 and FY 2008, the operations of BES major user facilities—the synchrotron radiation light sources, the neutron scattering facilities, the electron beam micro-characterization centers, and the nanoscale science research centers—have been nearly flat funded since FY 2006. As a result hours of operation were reduced, service to users was reduced, staffing levels were less than optimal, and staff layoffs occurred. We have, however, taken steps to mitigate as much as possible the impacts on facilities' operations and user access. To keep facilities operating at the highest possible levels, despite limited funding, we have deferred planned maintenance of the accelerators and instruments, as well as needed upgrades to the beamlines. Such compromises, however, are placing the facilities—especially the light sources that either operate or conduct maintenance 24 hours a day, seven days a week—in very difficult situations which will eventually have adverse effects on our research communities and their results.

The Advanced Photon Source (APS) in Illinois illustrates the negative impacts of prolonged inadequate funding. The APS is the largest light source in the U.S.; it employs about 450 researchers and technicians and serves over 3,000 users annually. Total cost of maintaining the staff in FY 2009 is estimated to be $82 million. Fixed costs for central charges like servicing the experiment hall and providing electricity are $18 million; this includes a machine power bill of $8.5 million and a house power cost of $2 million. The cost of annual software licenses at the APS is more than $1 million, and liquid nitrogen alone costs about $300,000 annually. Moreover, electricity costs have increased 25 percent this year. Such rising fixed costs and salaries for on-board staff, coupled with flat budgets, leave scant funds for needed maintenance, materials, and supplies. Yet a prolonged lack of maintenance, materials, and supplies will eventually negatively impact safe reliable operations at the APS and could even result in a full shutdown. Obviously, this would severely impact users and their science output.

Under a flat budget in FY 2009, the APS would likely have to layoff 50–60 staff in April 2009, to allow funding for enough materials and supplies to operate at a reduced scope. The APS would operate only about 4,000 hours in 2009 and would lose about 15 percent of its users. This strategy would allow the APS to continue operating in a safe, reliable manner, though at reduced levels, and would retain key staff and users until budgets improve at some future time. The situation is similar at other BES facilities, and is unsustainable in the long-term.

Q4. How do you compare U.S. investments in science and user facilities with those of other countries that you are familiar with?

A4. The question is a broad one, and I will limit my response to investment trends in two areas where BES has national stewardship responsibilities—synchrotron radiation light sources and high-flux neutron sources.

One quantitative comparison of U.S. and international advanced capability and capacity comes from a consideration of these third generation synchrotron light sources and, in particular, from a consideration of the numbers of usable beamline ports. In general, the number of ports is a good indicator of the corresponding instrument capacity of a facility. Currently, the U.S. has about 30 percent of the total ports on third generation light sources. By 2010, that percentage will likely drop to 15 percent. The rate of investment in new synchrotron light sources with advanced capability and significant capacity is far greater internationally than within the U.S.

A few years ago, BES upgraded the Stanford Synchrotron Radiation Laboratory at the SLAC National Accelerator Laboratory by completely rebuilding the magnetic lattice and control systems. Very recently, BES began funding for the National Synchrotron Light Source II project at Brookhaven National Laboratory. While these are very important contributions towards maintaining U.S. competitiveness in the field, there has also been significant growth of synchrotron radiation facilities worldwide. At the end of this decade, there will be 12 intermediate energy (2.5–4 GeV, or billion electron volt) sources in the world, of which eight will have commenced operations between 2005 and 2010. The U.S. will have only two of these.

The state of neutron scattering facilities in the U.S. has improved in the past five years through the upgrade of the High-Flux Isotope Reactor and construction of the Spallation Neutron Source, both at Oak Ridge National Laboratory. The High-Flux Isotope Reactor provides the world's highest flux reactor-based neutron source, and the Spallation Neutron Source is the world's most intense pulsed accelerator-based neutron source. However, there are more neutron sources—both reactor- and spallation-based—in operation in Europe than in the U.S. As a result, the U.S. is outnumbered in instruments available to users by almost a factor of three.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Steven B. Dierker, Associate Laboratory Director for Light Sources; National Synchrotron Light Source II Project Director, Brookhaven National Laboratory

Question submitted by Chairman Nick Lampson

Q1. Most R&D in accelerators, which are the backbone of the major BES facilities, is now conducted by the high energy physics program. Do you think a joint program with a greater contribution from BES would be beneficial?

A1. A large number of outstanding and highly talented scientists and engineers with specialized knowledge and skills are supported by the BES program to design, construct, and operate the accelerators that form the backbone of the major BES user facilities. They represent a critical human resource that can be effectively leveraged by engaging them in R&D programs to advance the state of the art in accelerator science and technology. Such advances are essential to enable the next generation of scientific user facilities to be conceived and built in order to maintain U.S. leadership in this internationally competitive area of science and technology. Funding to enable the BES program to expand its present program would be very beneficial. Continuing to coordinate the R&D efforts in the different programs of the Office of Science would also be beneficial.

Question submitted by Representative Bob Inglis

Q1. Dr. Dierker, you remark that the Basic Energy Sciences facilities have a regional character; for example, two-thirds of the users at the National Synchrotron Light Source are from the northeast. In your opinion, should BES develop outreach mechanisms to attract academic users from the United States at large? If so, how might they go about that?

A1. While the usage of the BES facilities does have a regional character, it is important to note that they nevertheless do serve large numbers of users from throughout the United States. The BES user facilities do engage in significant outreach programs to attract academic users from throughout the United States and I believe that additional outreach efforts would be unlikely to change the present regional character of the user base of the facilities. This usage pattern primarily results from the nature of the research carried out at such facilities, which often requires frequent, hands-on access which is most practical for the users that are relatively nearby the facility. The facilities do try to support remote users by collaborating with them, acting as their local "hands and eyes" on the experiment. Not all experiments lend themselves to being controlled remotely, but those that do still require a local person to install the sample, etc. At present, the facilities are chronically understaffed, and the shortage of staffing limits the amount of support they can provide to remote users. Additional operating funds would enable the facilities to hire the staff necessary to support more remote users.

Questions submitted by Representative Daniel Lipinski

Q1. Major facilities have struggled with adequate operating budgets. How has reduced operating time at facilities like the Advanced Photon Source (APS) affected work like yours? What are the long-term impacts of inadequate funding?

A1. Reductions in operating time at the BES facilities directly translate to reduced scientific productivity by the academic, industrial, and government laboratory user community that depends on these facilities to carry out its research. If inadequate operating budgets persist, the long-term impact will be that U.S. researchers fall further behind researchers overseas, who have ready access to competing facilities in other countries, directly threatening the economic and technological competitiveness of the U.S. The additional funds needed to fully operate and utilize the BES facilities represent a small marginal investment that capitalizes on the significant investment in constructing and operating the facilities.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Ernest L. Hall, Chief Scientist, Chemistry Technologies and Materials Characterization, GE Global Research

Questions submitted by Chairman Nick Lampson

Q1. In your testimony, you praise the Shared Research Equipment program at Oak Ridge National Laboratory as "a good model for access to advanced instrumentation for both academic and industrial researchers." Can you explain in more detail what you find useful about this program, and how easy you think it would be to replicate in BES's larger facilities?

A1. I specifically mentioned the DOE/BES SHaRE program at Oak Ridge National Laboratory (which deals primarily with electron beam and atom probe instrumentation) since I have personal experience with that program, and it contains many of the attributes that I feel would comprise a successful external-user program. I have also been able to observe the impact of this program on the research of both academic and industrial users over the past 30 years. Some of the key aspects of SHaRE are:

- A very clear and user-friendly website interface *http://www.ms.ornl.gov/share/index.shtml,* which specifically invites faculty and students of U.S. accredited universities, industrial researchers, and scientists at national laboratories to participate.
- Easy access to information about the capabilities that are available, and an excellent on-line proposal application.
- Proposals can be submitted and considered at any time.
- Submitted proposals are assigned a senior researcher who works to understand the technical needs of the applicants and ensure scientific value and applicability. If the proposal is accepted, this ONRL staff member will be the host and key collaborator for the research, and will help with experiment set-up, execution, and interpretation. This maximizes the potential for success for the visiting scientists.
- Although I do not currently see mention of this, I believe at one point there was modest funding to help defray travel and living costs for academic researchers.
- ORNL ShaRE researchers are very active at major U.S. technical meetings in presenting scientific results from the collaborative ShaRE projects, and promoting the program to external scientists.

There may be other similar programs at DOE's major facilities that I am not aware of. It would seem to me that it would be possible to incorporate the aspects listed above into successful user outreach programs at any facility.

Questions submitted by Representative Bob Inglis

Q1. Dr. Hall, you remark in your testimony that DOE should give industry preferential access to their facility time. Can you explain your position and elaborate on how DOE can better balance the need for industrial research and fundamental academic research?

A1. In my written statement, I asked that DOE consider giving higher priority than at present to the needs of industrial users. I also indicated the need for a proper balance between outstanding fundamental or basic research, and the use of these facilities as materials characterization tools in the development of new technologies by industry. It seems to me that basic energy science will continue to be the dominant use of the very large facilities. If we look to Europe and Asia, where some synchrotron and neutron facilities have aggressively worked to increase access by industry, we see that perhaps 20 percent of the usage is devoted to industrial needs. That may be a good benchmark. In my written testimony, I also argue for several aspects that would benefit U.S. industry: a mechanism for rapid short-term access; good maintenance and reliability of the source and end-station beamlines; access to expert facility staff; and an easy, clear, and cost-effective method to deal with proprietary concerns.

Last March there was a three-way meeting between the APS (DOE, U.S.), ESRF (Europe), and SPring-8 (Japan) synchrotron communities. In reporting about the meeting, *Synchrotron Radiation News* wrote: "SPring-8 Director General Akira Kira delved into the "Socialization of SPring-8." This is a continuation of a move to develop a more inclusive user base: bringing in not only synchrotron radiation experts, but also non-experts, and providing more assistance and user-friendly equipment for the industrial as well as academic users." This would seem to be a good model for increasing industrial impact.

Questions submitted by Representative Daniel Lipinski

Q1. Nanotechnology promises to yield significant advancements in many fields, perhaps most notably in the development of new energy technologies. Would you elaborate on your experiences with nanotechnology and how you envision it aiding in the fight to develop advance energy technologies that will wean us off fossil fuels and reduce emissions of climate changing gases?

A1. At GE Global Research, we have a large nanotechnology effort. We view nanotechnology as a key enabler in the drive for new materials that will impact solar energy, energy storage systems including batteries for hybrid vehicles, stronger and lighter materials for higher-efficiency engines and turbines, catalysts for waste gas reduction, membranes for CO_2 separation, and many other technologies. We have already used the existing U.S. synchrotron and neutron facilities in many of these projects. In addition, we have been working with the National Synchrotron Light Source at Brookhaven National Lab in the design of the NSLS–II, which has some specific features designed to extend capabilities to the nanoscale. High source brightness, combined with x-ray optics and new imaging techniques, should allow studies at the sub-10 nanometer scale. We look forward to utilizing this capability. However, at the same time, it is important to maintain the flexibility for studies at the micro and even macro-scale. At GE, many of our products in the energy field are physically large compared, for example, to microelectronics. A key question is, "can we maintain nanoscale structure and properties uniformly in a large part?" The synchrotrons and neutron facilities are very well suited to answer that question.

Q2. How do you compare U.S. investments in science and user facilities with those of other countries that you are familiar with?

A2. As I'm sure you are aware, there has been a significant increase in the number of synchrotron and neutron facilities in Europe and Asia that are in operation or under construction. Among other facilities, we are familiar with the FRM–II neutron facility on the campus of the Technical University of Munich, Germany, which is close to our European Research Center adjacent to the campus. In China, the government is building the Shanghai Synchrotron Research Facility across the street from our China Technology Center. We have done some limited technical work with the former, and anticipate a good working relationship with the latter. From GE's point of view, with our current U.S. group of synchrotron and neutron sources, and new facilities such as the Spallation Neutron Source at Oak Ridge and the National Synchrotron Light Source II at Brookhaven coming on line in the future, we feel that our research needs, and those of other U.S. industries, can be met. As I have stated previously, the key is to invest in the maintenance, upgrading, and staffing of existing and future planned facilities so they can be fully and optimally utilized. It is critical that we have world-class scientists working on the staff of the U.S. facilities.

Since my particular areas of expertise also include electron beam instrumentation, I would also urge DOE to continue to think broadly about investment in advanced materials characterization facilities such as electron microscopes and atom-probe instruments. In the cases where this instrumentation becomes sufficiently specialized, sophisticated, and costly, it is difficult for U.S. industry, especially smaller businesses, to have all of the needed instruments in house. DOE has recently invested in the TEAM program for advanced transmission electron microscopy, and these types of facilities are also extremely important, especially for nanotechnology and micro/nano electronics.

Finally, I wanted to again mention the benefits from the regional approach currently used by DOE in terms of better access for U.S. researchers. Investment in advanced facilities in different regions of the U.S. makes utilization much easier.

Q3. Are you concerned about loss of expertise in energy science to foreign countries at our research institutions, or our ability to attract scientists from abroad as we once did? Do you see a connection to economic competitiveness?

A3. We have discussed above the investment that foreign governments are making in major tools for the conducting of advanced research. In keeping with the purpose of this hearing, I think a case can be made that in order to maintain and grow our world-class expertise in energy science in academia, government, and industry, and to be able to develop technically superior products, U.S. scientists need access to the best research tools in the world. As I've said previously, this means world-class facilities staffed by top researchers with sufficient funding and good access models for external users.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Thomas P. Russell, Silvio O. Conte Distinguished Professor, Polymer Science and Engineering Department, University of Massachusetts–Amherst; Director, Materials Research Science and Engineering Center; Associate Director, MAssNanoTech

Questions submitted by Representative Daniel Lipinski

Q1. As a former college professor and student of engineering, I believe it's critical that we strongly support our research institutions that help train the next generation of scientists. Without ample funding support, young researchers will not be interested in pursuing degrees in areas that appear to have no future or very little reward. And without these young students filling up the pipeline, we will effectively cede scientific progress to other countries.

As I'm sure you would agree, we need to capture the imagination of our students who are the future of our scientific enterprise. What are you doing at the University of Massachusetts to attract students to the field and keep them there? What additional efforts do you believe we could be doing to better assist in this effort?

A1. I have the good fortune of being a faculty member in the top-ranked Polymer Science and Engineering Department in the country. This ranking has come about from the excellence in the curriculum, the success of the faculty in achieving support for their research, the diverse research culture in the department (similar to what I enjoyed at IBM), and the forefront research that is ongoing in the department. Performing forefront research that is exciting, publishing in the top-ranked journals, providing a quality research infrastructure, and advertising this via the World Wide Web are perhaps the keys in attracting students who are interested in pursuing a career in materials science. Quite honestly, I, personally, do not have a problem in recruiting superb students and post-doctoral fellows to my group and other faculty members share a similar luxury.

With that said, I should also say that I have a large number of foreign students and postdoctoral fellows in my group. This is not uncommon. In fact, if I look at the overall trends, the number of American students who are assuming a career in materials or polymer science is decreasing. The same can be said for our European colleagues where they are experiencing similar types of decreases. The difference, of course, has been made up by an increasing number of oriental students, Korean and Chinese, in particular, who are aggressively pursuing careers in these areas. These individuals see the benefits in pursuing careers in materials science and are not afraid to put in long hours that may be required to be successful. Perhaps this arises from a scientific "pipeline" that has been established throughout their educational system where students are given the support and nurturing in the sciences that allow them to succeed. Perhaps this is where the American system is failing. An effective pipeline, where students are thoroughly trained in the sciences has been falling off in the United States and we need to re-invigorate this for the benefit, well-being and competitiveness of the United States on a global level.

At the University of Massachusetts we have active educational programs, outreach programs, designed to reach out to students across all grade levels. The most important age group, in my opinion, is the middle school. It is this age group where students are really making up their minds or, perhaps, can be most easily influenced or excited by materials science. A very effective route to bring across an excitement about research is through their teachers. Exciting the teachers about research can have significant impact. Over the years we have had a Research Experience for Teachers program that has been supported by the National Science Foundation (NSF), where teachers are brought into the laboratories, work with graduate students and post-doctoral fellows, perform research and can, actually, obtain publishable results. More importantly, the teachers get a true flavor for research and become invigorated themselves. This excitement and vigor is then brought back into the classroom where the teachers can convey this excitement to nearly 125 students every day. The teachers are the ones who have the most influence with the students. They work with the students and know how to reach the students. If they can excite a couple of students in each class to pursue a career in the sciences, I am certain the number of career scientists would increase. In addition to the excitement, these research experiences inject confidence into the teachers and, in my opinion, improve the level and quality of their teaching. As part of this program, the teachers can also develop curricula that they can use in their classes. In addition, the teachers can also recommend their students to participate in outreach efforts that we provide for students at this level. This includes a program where students can come to the university, learn about polymers and some advanced instrumentation, and actually use these instruments to do mentored experiments. These latter programs are run by graduate students and the entire experience is an "eye opening" experience for middle and high school student and the participating graduate students.

So what happens to the students when they go to college? At this point is more effective to bring the students into the laboratories to perform research. The National Science Foundation has supported a Research Experience for Undergraduates (REU) programs where students are brought into the laboratory and work with students and post-doctoral fellows to perform meaningful research. This program provides a mechanism by which the students interested in a research career can be engaged in a research activity over the course of eight to ten weeks. This truly allows the students to get a good sense of a research career and serves as an excellent venue by which the students can make a decision about a specific research direction or whether they want to pursue research in the future. From my own personal experience, I participated in an REU program at Brown University for two summers and this experience convinced me that I had the ability to do research. It instilled a confidence in my own abilities and it excited me about pursuing research for a career. I must add that I was attending a four-year college designed to train teachers where there were really no research activities. It made a huge difference in my life and I am certain the same happens to others.

While it is wonderful to reach out to students and teachers we, as scientists, must also reach out to the public. There is, in my opinion, a disconnect between the general American public and the world of materials research. With space exploration, NASA has done a superb job in educating the public about space. This, of course, has come at a reasonable expense, but is has been effective to say the least. As materials scientists we have, in my opinion done a terrible job in educating the public and in the government about the excitement and importance of materials science. During the Cold War it was easy to make the argument to make that materials science was important for the security of the country and there was a much larger number of people who assumed careers in science and, though there was still mysticism about science in general, the public knew that it was important to have a cadre of people who were doing complex thing for the good of the country. Times have changed, though the importance of materials science as certainly not diminished in importance. It is, quite frankly, difficult to compete with other career choices that may be much more rewarding financially. The appeal of intellectual reward is not what is used to be. Nonetheless, we, as scientists, must do a much better job in educating the public and conveying the importance of the work in which we are involved. This should not be an easy task, though we appear to have failed. We are beginning to come out of our ivory towers and to reach out to the public sector. At the University of Massachusetts, in particular in the NSF Materials Research Science and Engineering Center, we have a program called VISUAL where images taken in the laboratory during the course of actual experiments are framed and hung for viewing. Along with the image comes a description, in plain English, of the science underpinning the image. These images are stunning, eye-catching and audience capturing. We have had hangings at museums, galleries, hospitals, coffee houses and even the Department of Motor Vehicles. They have uniformly received a tremendous reception and have made a very small inroad in educating the everyday person about some of the science that is going on in the laboratories at the Center. In a sense, this is just what NASA did with space. The images from space are truly stunning and draw you in. On the way in you receive information about stars, galaxies, black holes, etc. We need much more of this in materials science, since, if the public is won over, it will be far easier for the funding agencies to argue for support and, in turn, far easier for us to get funding to support the research we want to do. Once this ball got rolling, I am certain the interest in individuals assuming careers in science and technologically related areas would increase.

As the Director of the Materials Research Science and Engineering Center at the University of Massachusetts Amherst I have been a very strong proponent of all of these efforts. I honestly believe that we must continue to promote research on all levels, establish a research pipeline for the overall good of the United State and to ensure competitiveness of the United States in the future. This, however, also requires the support from the government. These programs do require a financial commitment and, if the programs are executed effectively, the return on the investment will be substantial.

Q2. Nanotechnology promises to yield significant advancements in many fields, perhaps most notably in the development of new energy technologies. Would you elaborate on your experiences with nanotechnology and how you envision it aid-

ing in the fight to develop advance energy technologies that will wean us off fossil fuels and reduce emissions of climate changing gases?

A2. Many areas of research that are being pursued to solve the energy problem rely, in some form or other, on nanoscopic structures to enable a specific function. With fuel cell, the membranes that are used consist of nanoscopic channels to transport protons. With hydrogen, membranous materials with nanoscopic features will be required for storage. Catalysts, used in fuel cells and hydrogen based systems, are classic examples where nanoscopic size is crucial, since it is the surface area of the catalyst that is important and, as the size of the particle gets smaller and smaller, the surface to volume ratio increases, i.e., there is more surface area available for the catalysts to function. In photovoltaic devices light excites a molecule, generates an exciton (an electron-hole pair) that moves through the material. The exciton diffuses about 5–10 nm before the electron and hole recombine and it is essential to extract the electron before this occurs. This forces the structures in a photovoltaic device to be nanoscopic in size. Even if we go to microbial fuel cells, the microbes rely on the transport of electrons from the microbe to an electrode surface through nanoscopic tubes, called pili. So, nanoscience, and by default, nanotechnology pervade the science that will underpin the solution to the energy problem, relieve our dependency on oil and lead to lower emissions and the generation of carbon dioxide. I do not know whether one or a combination of routes will be the solution, but I am certain that objects on the nanoscopic level will play a key role. When we are considering the mass production of material for general use, fabricating these structures will require advances in nanotechnology, our understanding and fabrication of nanostructured materials. I must add, at this point, that the neutron and synchrotron x-ray facilities that are operated by the Department of Energy are ideally suited to characterize materials on this level and, hence, will be instrumental in advancing nanoscience and nanotechnology.

Q3. How do you compare U.S. investments in science and user facilities with those of other countries that you are familiar with?

A3. I can only reiterate the statement that I made and that Dr. Patricia Dehmer made at the hearing. The facilities in the United States are best-in-class facilities. The Spallation Neutron Source (SNS) in Oak Ridge is (will be) the most intense source of neutrons in the world. While the Europeans can claim bragging rights with the most intense reactor source, the Institut Laue-Langevin (ILL) in Grenoble, the SNS will be able to perform as well, if not better, in all areas of scattering science. The U.S. had plans for an intense reactor source, the Advanced Neutron Source, but the cost to build the facility and issues associated with the Uranium core, prevented the continuation of the project. The SNS is certainly a part of the solution to this problem. The SNS is also complemented by the less intense spallation source at the Lujan Neutron Scattering Center at the Los Alamos National Laboratory. Also at Oak Ridge is the High Flux Isotope Reactor, though not being as intense a source as the ILL, is certainly competitive in several areas of neutron scattering science. The Department of Commerce, through the National Institute of Standards and Technology operates a reactor in Gaithersburg and, with the NSF, U.S. scientists have access to the National Center for Neutron Research. Like HFIR, NCNR has been a tremendous resource to research in many disciplines and has operated with very high availability and reliability. NCNR has been a source that has operated continuously while other neutron sources were being renovated or built. In terms of synchrotron radiation sources, the U.S. has the Advanced Photon Source (APS) at the Argonne National Laboratory which is as intense as the European Synchrotron Radiation Facility (ESRF) in Grenoble. In addition, there is the National Synchrotron Light Sources (NSLS) and the Stanford Synchrotron Radiation Laboratory, affectionately termed generation-1 light sources, which afford the U.S. scientific community with intense sources of x-rays. The Brookhaven National Laboratory has plans to construct a third generation source, NSLS II, which will surpass the capabilities at APS and ESRF. These hard x-ray sources are complemented by the soft x-ray sources that are available at the Brookhaven National Laboratory and the Advanced Photon Source at the Lawrence Berkeley National Laboratory. These facilities provide the users with the capabilities of doing spectroscopy with an intense source of radiation. So, whether one wants to consider the availability of neutron and x-ray sources of varying intensities, the United States is certainly competitive. The Department of Energy has done a tremendous service to the American Scientific community as stewards for these facilities, providing the American scientific community with these capabilities. There is a significant amount of science, ranging from individual investigator to larger scale efforts that required either short-term or long-term efforts that these facilities enable.

Q4a. Are you concerned about loss of expertise in energy science to foreign countries at our research institutions........

A4a. I do not think there is a simple answer to this problem. Am I concerned about a loss of expertise in energy science? Not as long as there is funding to support the scientific enterprise in this country. Last year we experienced a situation where the funding for an energy initiative was removed from the DOE budget. There was a tremendous effort by the scientific community to propose a large range of science. The removal of the funds was alarming, to say the least. In my testimony, I referred to the frustration that I experienced personally with this and this could be multiplied by a factor of 700 where both seasoned scientists and young investigators were left out in the cold. We face a similar situation this year with the Energy Frontier Research Center initiative. The deadline for submission of these proposals was October 1. I do not know the exact number of proposals that were submitted. However, the academic community submitted these proposals even though the funding of this effort was removed by the Senate. We all are hoping that better judgment will prevail and that the funds will be reinstated in the DOE Basic Energy Science budget. There are no guarantees, we know. However, the American scientific community is energized to perform research in this area and the lack of funds will certainly be a blow to the community in this area. Dr. Dehmer stated it properly. The scientific community is like a group of cats. You cannot corral them, but you can move the food. If the food is not provided in this country, then the community will be forced to look elsewhere. We realize the importance of this problem and science does not have boundaries. If it happens that the funding is not in the federal budget, then I am very concerned about the loss of expertise and leadership in energy research in the United States.

Q4b. ...., or our ability to attract scientists from abroad as we once did?

A4b. At present, I am not concerned with our ability to attract some of the best minds from abroad to perform research in energy science. There is no question that other countries have competitive, if not more advanced efforts than that found in the United States. We will certainly run into problems if the funding for energy research is not increased. In Europe and in Asia, the importance of energy is clearly reflected in the funds that the governments of these countries are placing into this area. This is simply to important an area for the United States not to support. So, yes, I am concerned with our abilities in the future to attract some of the best minds in this area and with our ability to retain some of the best minds in the United States. Already we are seeing situation where, in some of the Arabian countries, large sums of monies are being offered to academicians to establish research institutes in energy related areas. Some scientists have already accepted these offers and, quite frankly, it is understandable. If you have ideas to pursue that may potentially lead to a solution to the energy problem, whether this is in photovoltaics or fuel cells, and is only logical. Is this unpatriotic? Absolutely not! Energy is a problem facing all mankind and finding a solution should be nation-independent. However, leading the effort is, in my opinion, important and the United States must play a lead role. Energy is just one area of science and where the best minds go will invariably influence other areas of science as well.

Q4c. Do you see a connection to economic competitiveness?

A4c. While the problem of energy transcends borders, the economic impact of finding a solution to the energy problem does have boundaries. We would be foolish and myopic to think otherwise. Whoever is first in on the solution will clearly have a competitive advantage. The advance in science will lead to a technology transfer and whoever is there first will have the technology first.

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