Office of Science Priority Research Areas for SCGSR 2014 Solicitation

The applicants to the SCGSR Program must be pursuing graduate research in an area that is aligned with one or more of the Priority Research Areas for the SCGSR 2014 Competition. The applicant's proposed SCGSR research project to be conducted at DOE laboratory must address stated aims in at least one of the priority areas listed below.

Applicants will need to identify in the online application system which Office of Science priority research area their proposed SCGSR research project is aligned with. Applications with a proposed research project that does not address an Office of Science research priority area and does not make specific reference to the stated aims of one the listed areas will not be considered.

It is recommended that applicant's become familiar with the Office of Science research program(s) most closely aligned with their graduate thesis research and the priority research area(s) below that are most closely aligned with their research objectives as they begin to formulate ideas for a SCGSR research proposal. A short overview of the Office of Science is available at: http://science.energy.gov/wdts/scgsr/how-to-apply/priority-sc-research-areas/about-sc/. Program descriptions for the Office of Science's six research program offices are summarized below to provide the context for the scientific and technical areas of priority interest to the Office of Science. Specific areas excluded in their research portfolios, and thus the SCGSR program, are also noted.

I. Advanced Scientific Computing Research (ASCR)

(a) Computer Science
(b) Applied Mathematics

II. Basic Energy Sciences (BES)

(a) Accelerator and Detector R&D
(b) Heavy Element Radiochemistry
(c) Neutron Scattering Research and Instrumentation
(d) Predictive Materials Science and Chemistry

III. Biological and Environmental Research (BER)

(a) Computational Biology and Bioinformatics
(b) Plant Breeding Science for Sustainable Bioenergy
(c) Environmental System Science

IV. Fusion Energy Sciences (FES)

(a) Burning Plasma & Magnetic Fusion Energy Science
(b) Discovery Plasma Science

V. High Energy Physics (HEP)
(a) Theoretical and Computational Research in High Energy Physics
(b) Advanced Technology Research and Development in High Energy Physics

VI. Nuclear Physics (NP)
(a) Medium Energy Nuclear Physics
(b) Heavy Ion Nuclear Physics
(c) Low Energy Nuclear Physics
(d) Nuclear Theory
(e) Nuclear Data and Nuclear Theory Computing
(f) Accelerator Research and Development for Current and Future Nuclear Physics Facilities
(g) Isotope Development and Production for Research and Applications
(h) Applications of Nuclear Science and Technology
(i) Advanced Detector Technology Research and Development in Nuclear Physics

I. Advanced Scientific Computing Research (ASCR)

The mission of the Advanced Scientific Computing Research (ASCR) Program is to deliver forefront computational and networking capabilities to extend the frontiers of science. A particular challenge for this program is fulfilling the science potential of emerging multi-core computing systems and other novel "extreme-scale" computing architectures, which will require significant modifications to today's tools and techniques.

Program Website: http://science.energy.gov/ascr/

ASCR mission areas:

- To develop mathematical descriptions, models, methods, and algorithms to accurately describe and understand the behavior of complex systems involving processes that span vastly different time and/or length scales.
- To develop the underlying understanding and software to make effective use of computers at extreme scales.
- To transform extreme scale data from experiments and simulations into scientific insight.
- To advance key areas of computational science and discovery that further advance the missions of the Office of Science through mutually beneficial partnerships.

- To deliver the forefront computational and networking capabilities to extend the frontiers of science.
- To develop networking and collaboration tools and facilities that enable scientists worldwide to work together.

The computing resources and high-speed networks required to meet Office of Science needs exceed the state-of-the-art by a significant margin. Furthermore, the algorithms, software tools, the software libraries and the distributed software environments needed to accelerate scientific discovery through modeling and simulation are beyond the realm of commercial interest. To establish and maintain DOE's modeling and simulation leadership in scientific areas that are important to its mission, ASCR operates Leadership Computing Facilities, a high-performance production computing center, and a high-speed network and implements a broad base research portfolio in applied mathematics, computer science, computational science, and network research to solve complex problems on computational resources that are on a trajectory to reach well beyond a petascale within a few years.

The ASCR's research priority areas for SCGSR program include:

(a) Applied Mathematics

This program supports basic research leading to fundamental mathematical advances and computational breakthroughs across DOE and Office of Science missions. Applied Mathematics research includes and supports efforts to develop robust mathematical models, algorithms and numerical software for enabling predictive scientific simulations of DOE-relevant complex systems. Topic areas of interest include:

1. Innovative mathematics research to improve the fidelity and predictability of continuous and/or distributed complex systems that accurately capture the physics and/or subcomponent interactions across vastly different time and length scales. This includes numerical partial differential equations, multiscale, multiphysics and multicomponent methods and models, optimization techniques, stochastic systems and uncertainty quantification.
2. Scalable solvers for next-generation high-performance computing. Solver research opportunities include new classes of algorithms such as: communication/synchronization hiding and reducing algorithms; mixed-precision-arithmetic algorithms; fault-tolerant and resilient algorithms; energy-efficient algorithms; stochastic algorithms; and algorithms with reproducibility.
3. Rigorous mathematical, statistical and computationally efficient approaches for analyzing and extracting information and insight from large-scale datasets relevant to the DOE missions.

EXCLUSIONS: Development and/or implementation of existing numerical methods to a specific application is not within the scope of this program, no matter how challenging the application.

(b) Computer Science

This program supports research to advance the development, operation, and systems management of Leadership Class and production high performance computing facilities at DOE National Labs, application software development for scientific modeling and simulation at petascale to exascale, high performance computing systems architecture and software, and scientific data management and analysis at scale. Topics of interest for this solicitation are focused on the following key research challenges for exascale platforms, namely:

1. Resilience for extreme-scale scientific applications in the context of leadership-class computing platforms, including research aimed at improving understanding of the causes, frequency, and impact of various types of hard and soft faults and the detection and mitigation thereof;
2. Correctness and debugging tools that complement exascale software stack solutions currently being developed;
3. Programming models, language constructs, compilers and runtime systems that address the challenges of programming applications which are characterized by computations on irregular data structures and with unstructured and dynamic communication patterns;
4. Scientific data management, analysis and visualization, including knowledge representation to facilitate scientific data management, integration, and analysis; data provenance representation, capture, and analysis; data interoperability across scientific disciplines and platforms; scientific workflow systems that support data triage or down selection, data analysis and visualization for petabyte to exabyte data sets from simulations and/or experimental platforms, including visualization of HPC system behavior and/or software visualization for highly parallel HPC codes; and methods to support creation of skeletal versions or mini-apps of data management, analysis and visualization applications for the purposes of extreme-scale system modeling and codesign.

Proposals must explain their relevance to current and future high performance computing platforms as well as their relevance to the mission of the Office of Science and the Advanced Scientific Computing Research programs.

EXCLUSIONS: Topics that are **out of scope** for this program area include all aspects of quantum computing, networking, computer-supported collaboration, social computing, natural language processing/understanding/generation and/or analysis, generalized research in human-computer interaction, discipline-specific data analytics and informatics, research focused on the World Wide Web and/or Internet, and research that is only applicable to hand-held, portable, desktop, embedded or cloud computing.

II. Basic Energy Sciences (BES)

The mission of the Basic Energy Sciences (BES) program is to support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support other aspects of DOE missions in energy, environment, and national security. The portfolio supports work in the natural sciences by emphasizing fundamental research in materials sciences, chemistry, geosciences, and physical biosciences. BES-supported scientific facilities provide specialized instrumentation and expertise that enable scientists to carry out experiments not possible at individual laboratories.

Program Website: http://science.energy.gov/bes

BES mission areas:

- To design, model, fabricate, characterize, analyze, assemble, and use a variety of new materials and structures, including metals, alloys, ceramics, polymers, bioinspired and biomimetic materials and more-particularly at the nanoscale-for energy-related applications.
- To understand, model, and control chemical reactivity and energy transfer processes in the gas phase, in solutions, at interfaces, and on surfaces for energy-related applications, employing lessons from inorganic and biological systems.
- To develop new concepts and improve existing methods to assure a secure energy future, e.g., for solar energy conversion and for other energy sources.
- To conceive, design, fabricate, and use new scientific instruments to characterize and ultimately control materials, especially instruments for x-ray, neutron, and electron beam scattering and for use with high magnetic and electric fields.

The BES' priority research areas for SCGSR program include:

(a) Accelerator and Detector R&D

Basic Energy Sciences (BES) supports accelerator and detector research and development in support of its current and future x-ray and neutron sources. These facilities give students the opportunities to work side-by-side with accelerator and instrument scientists that are operating some of the world's cutting edge facilities and also developing advanced technology for next-generation facilities. Accelerator physics has always relied on inventing, developing, and adapting advanced technologies to enable state-of-the-art research. With the adoption of particle accelerator and detector technologies by many scientific fields, the demand for skilled practitioners in these areas has grown significantly. As the scale of particle accelerators and their associated detectors has grown, very few universities have been able to maintain the infrastructure needed to provide such practical training, and students typically have to rely on short residencies at accelerator laboratories to receive such experience. BES is particularly interested in the training of students in radio frequency (rf) engineering, magnet design, beam diagnostics instrumentation, nonlinear beam dynamics analysis, beam optics design, and detector technology.

(b) Heavy Element Radiochemistry

This priority research area involves basic research on the chemistry of the elements beyond actinium (atomic number greater than 89), typically uranium, neptunium, plutonium, americium, and curium. The unique molecular bonding of these elements is explored using experiment and theory to elucidate electronic and molecular structure as well as reaction thermodynamics. Topics include resolving the f-electron challenge; the chemical and physical properties of these elements to determine solution, interfacial and solid-state bonding and reactivity; fundamental transactinide chemical properties; and the fundamental science underpinning the extraction and separation of the actinides.

Research pursued to resolve the role of the f-electrons is particularly well aligned with current BES research and is one of the three grand challenges identified in the Basic Energy Sciences report *Basic Research Needs for Advanced Nuclear Energy Systems* (August 2006), and echoed in the Basic Energy Sciences Advisory Committee report *Science for Energy Technology: Strengthening the Link between Basic Research and Industry* (August 2010).

<u>EXCLUSIONS:</u> Based on programmatic priorities, topics of research that will not be considered are: the processes affecting the transport of subsurface contaminants, the form and mobility of contaminants including wasteforms, projects aimed at optimization of materials properties including radiation damage, device fabrication, or biological systems; which are all supported through other DOE programs.

(c) Neutron Scattering Research and Instrumentation

Neutron scattering is a powerful tool for conducting DOE mission-critical research. It is also one of the major thrust areas of the BES scientific user facilities and core research program. As a unique research tool, it makes invaluable contributions to the physical, chemical, magnetic, biological, and nanostructured materials sciences. Based on the importance of neutron scattering research, DOE constructed the Spallation Neutron Source (SNS) at Oak Ridge National

Laboratory (ORNL), which has the highest pulsed neutron flux in the world and a broad range of neutron scattering instruments. BES also operates the High Flux Isotope Reactor (HFIR) at ORNL for users to conduct state-of-the-art research using neutron diffraction, reflectivity, inelastic scattering, and imaging instruments.

Under the core program BES supports a range of fundamental science projects, many focused on renewable energy, at universities and national laboratories that utilize neutron scattering as a major tool, primarily at BES-supported user facilities. Major topics include quantum materials, high temperature superconductors, frustrated magnetism, thermoelectrics, multiferroics, heterostructured thin films, spintronic materials, high performance materials for hydrogen storage and carbon capture, nanoconfined water, quantum liquids, matter at extreme conditions, and multi-component complex materials. Also supported is science-driven development of next-generation instrumentation concepts, advanced techniques, innovative neutron optics and in-situ capabilities to accelerate the discovery of advanced materials for future energy challenges.

(d) Predictive Materials Science and Chemistry

There is a growing need for materials and chemical scientists with expertise in predictive theory and modeling. This is driven by the realization that the time to develop and deploy new materials and chemical processes can be substantially reduced through a combination of new algorithms, high-end computing, data repositories, and experimental validation. BES is a partner in the Materials Genome Initiative (MGI), a multi-agency program which supports research aimed at halving the time to deployment of new materials. BES activities in support of the MGI include the development of new software tools that can catalyze a fully integrated approach from material discovery to applications, with an emphasis on research that will provide the foundations for new energy technologies. Researchers have traditionally been trained in theoretical or experimental science. They now need specific training in computational science and in data management and must acquire the ability to participate in a cycle of discovery through modeling, synthesis, and experimental characterization and validation. Databases increasingly contain a mixture of experimental and computed data and researchers must be familiar with both. BES supports research to advance ab-initio methods for materials and chemical processes, provide user friendly software which captures the essential physics and chemistry of relevant systems, and harness the power of modern experimental techniques from free electron lasers, x-ray and neutron scattering facilities, and electron microscopy centers.

III. Biological and Environmental Research (BER)

The mission of the Biological and Environmental Research (BER) program is to support fundamental research and scientific user facilities to achieve a predictive understanding of complex biological, climatic, and environmental systems for a secure and sustainable energy future. The program seeks to understand how genomic information is translated to functional capabilities, enabling more confident redesign of microbes and plants for sustainable biofuels production, improved carbon storage, and understanding the biological transformation of materials such as nutrients and contaminants in the environment. BER research also advances understanding of the roles of the earth's biogeochemical systems (the atmosphere, land, oceans, sea ice, and subsurface) in determining climate in order to predict climate decades or centuries into the future to provide information that will inform plans for future energy and resource needs.

Program Website: http://science.energy.gov/ber

BER mission areas:

- To obtain new molecular-level insight into the functioning and regulation of plants, microbes, and biological communities to provide the science base for cost-effective production of next generation biofuels as a major secure national energy resource.
- To understand the relationships between climate change and Earth's ecosystems, develop and assess options for carbon sequestration, and provide science to underpin a fully predictive understanding of the complex Earth system and the potential impacts of climate change on ecosystems.
- To understand the behavior of DOE-relevant contaminants in subsurface environments, enabling prediction of their fate and transport in support of long term environmental stewardship and development of new, science-based remediation strategies.
- To make fundamental discoveries at the interface of biology and physics by developing and using new, enabling technologies and resources for DOE's needs in climate, bioenergy, and subsurface science.

The BER program is organized into two divisions, the Biological Systems Science Division (BSSD), and Climate and Environmental Sciences Division (CESD):

Biological Systems Science

Biological Systems Science division integrates discovery- and hypothesis-driven science with technology development on plant and microbial systems relevant to DOE bioenergy mission needs. Systems biology is the multidisciplinary study of complex interactions specifying the function of entire biological systems—from single cells to multicellular organisms—rather than the study of individual components. The Biological Systems Science subprogram focuses on utilizing systems biology approaches to define the functional principles that drive living systems, from microbes and microbial communities to plants and other whole organisms.

Key questions that drive these studies include:

- What information is encoded in the genome sequence?

- How is information exchanged between different subcellular constituents?
- What molecular interactions regulate the response of living systems and how can those interactions be understood dynamically and predictively?

The division builds upon a successful track record in defining and tackling bold, complex scientific problems in genomics—problems that required the development of large tools and infrastructure; strong collaboration with the computational sciences community and the mobilization of multidisciplinary teams focused on plant and microbial bioenergy research. The approaches employed include genome sequencing, proteomics, metabolomics, structural biology, high-resolution imaging and characterization, and integration of information into computational models that can be iteratively tested and validated to advance a predictive understanding of biological systems from molecules to mesoscale.

The division supports operation of a scientific user facility, the DOE Joint Genome Institute (JGI), and use of structural biology facilities through the development of instrumentation at DOE's national user facilities. Support is also provided for research at the interface of the biological and physical sciences and instrumentation for radiochemistry to develop new methods for real-time, high-resolution imaging of dynamic biological processes

Climate and Environmental Sciences

The Climate and Environmental Sciences division supports fundamental science and research capabilities that enable major scientific developments in climate-relevant atmospheric-process and ecosystem research and modeling, in support of DOE's mission goals for basic science, energy, and national security. This includes research on clouds, aerosols, and the terrestrial carbon cycle; large-scale climate change and earth system modeling; the effects of climate change on ecosystems; and integrated analysis of climate change impacts on energy and related infrastructures. It also supports subsurface biogeochemical research that advances fundamental understanding of coupled physical, chemical, and biological processes controlling the environmental fate and transport of energy byproducts. This integrated portfolio of research from molecular level to field-scales emphasizes the coupling of multidisciplinary experimentation and advanced computer models and is aimed at developing predictive, systems-level understanding of the fundamental science associated with climate change and other energy-related environmental challenges.

The division advances the science necessary to further develop predictive climate and earth system models targeting resolution at the regional spatial scale and interannual to centennial time scales and to focus on areas of critical uncertainty including Arctic permafrost thaw and carbon release, in close coordination with the U.S. Global Change Research Program (USGCRP) and the international science community. The division supports two national scientific user facilities: the Atmospheric Radiation Measurements Climate Research Facility (ARM) and the Environmental Molecular Sciences Laboratory (EMSL). ARM provides unique, multi-instrumented capabilities for continuous, long-term observations needed to develop and test understanding of the central role of clouds and aerosols on the earth's climate. EMSL provides integrated experimental and computational resources needed to understand the physical, chemical, and biological processes that underlie DOE's energy and environmental mission.

The BER's priority research areas for SCGSR program include:

(a) Computational Biology and Bioinformatics

Major advances in DNA sequencing technology have vastly increased the volume and complexity of genomic data available to researchers and have far outpaced the ability to test and interpret genomic information. There is a projected need for biological researchers with advanced computational skills to access, analyze, organize, test and interpret large genomic datasets on high-performance computers and/or within cloud-based high performance computational systems. New approaches to systems biology research that emphasize the close coupling of genomic information with high-throughput experimentation and computational simulation form the basis for DOE's fundamental science in biology and the environment. Future research efforts in systems biology within BER's Genomic Science Program, the Joint Genome Institute, the Environmental Molecular Sciences Laboratory, and the Systems Biology Knowledgebase requires new expertise in computational biology and bioinformatics to advance a predictive understanding and design of biological processes in order to remain competitive in the global drive to develop renewable resources.

(b) Plant Breeding Science for Sustainable Bioenergy

Crops grown for bioenergy purposes will possess characteristics quite different from those required of plants grown for food. Characteristics such as a decreased or altered lignin composition, a longer juvenile period for increased biomass, and in some cases a perennial life style are beneficial traits for bioenergy feed stocks. Additionally, many of the more promising bioenergy feedstock species (e.g., switch grass, *Miscanthus*, *Populus*) are only beginning to be domesticated for agricultural purposes, presenting a compelling opportunity for large and significant improvements to be made in such crops. Current DOE research efforts in renewable feed stocks for bioenergy in the Bioenergy Research Centers and within the Genomic Science Program focus on the manipulation of metabolic pathways and carbon allocation in plant tissues to produce plant strains with enhanced biofuel production characteristics such as high biomass yields, modified cell walls, and optimized growth and development. Future DOE bioenergy research will require plant scientists trained in genetics and breeding to translate such metabolic studies to the field through the development of strategies to breed agronomically improved, dedicated bioenergy feed stocks for the production of biofuels and/or compounds useful for bio-based products.

(c) Environmental System Science

Current climate and ecosystem models ignore, or lack the complexity to adequately represent, subsurface processes (e.g., soil biogeochemistry, plant-soil interactions, reactive transport, microbial ecology, hydrology, etc.). The inadequate representation of these critically important ecosystem processes represents a major roadblock in our ability to predictively understand our changing environment. Improving our representation of the complex Earth system requires a new paradigm whereby climate modeling research is tightly coupled with empirical, process level ecosystem research. This coupled approach brings together process and modeling scientists to identify critical uncertainties in current generation climate models, and then co-design and implement studies that iteratively and directly refine and improve the representation of terrestrial ecosystem processes. DOE's Climate and Environmental Science programs have identified a critical need in the scientific workforce, namely increasing the number of doctoral-level ecologists and climate scientists trained in coupled modeling-experimental approaches with a strategic focus in subsurface ecological processes. Candidates would be required to engage and develop skills through research projects that integrate and couple empirical subsurface process research with climate modeling components. Developing a workforce with experience in innovative, coupled modeling-experimental approaches in subsurface ecology will enable DOE to make significant advances in the high resolution predictive understanding of the Earth system and to foster innovative research.

<u>EXCLUSIONS:</u> BER does not fund research in the following areas.

- Bioenergy from sewage processing, bioremediation of organics, phytoremediation, marine biology, and oceanography;
- Existing or newly proposed processes for commercial, industrial, residential, and municipal solid and liquid waste management, even if those processes hold potential to positively impact the carbon cycle, nitrogen cycle, etc.;
- Experimentation in support of industrial processes, including feedstock substitutions, emissions scrubbing, and other processes designed for greenhouse gas emissions;
- Policy and implementation studies related to climate change;
- General human behavioral research, even as it applies to such areas as biofuels acceptance and climate change; however, economic and risk research is very much on point and encouraged;
- Marine experimentation in support of climate research, including understanding of marine organisms and marine ecology even when it may impact carbon, nutrient, and other cycles and/or hold potential for marine carbon sequestration;
- Observations and experimentation on ocean currents, ocean heat transfer, and other physical ocean properties;

- Engineering of systems or instrumentation or deployment of innovative combinations of existing probes where basic research is not the main thrust;
- Technology development and testing for climate change mitigation or adaptation technology development;
- Air pollution measurements, control technology development or evaluation;
- Site-specific scientific studies of climate change where research may be focused on a particular community, localized resource, or region, but where more generalized extensions and interpretations of the research are not a central component;
- Medically related research; plant pests, biomass process engineering optimization, molecular dynamics simulations towards enzyme engineering; or DNA sequencing technology.

IV. Fusion Energy Sciences (FES)

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperature and density and to build the scientific foundation needed to develop a fusion energy source. This is accomplished by studying plasma and its interaction with its surroundings across wide ranges of temperature and density, developing advanced diagnostics to make detailed measurements of its properties and dynamics, and creating theoretical and computational models to resolve the essential physics principles. The National Research Council report *Plasma Science: Advancing Knowledge in the National Interest* has recognized that plasma science has a coherent intellectual framework unified by physical processes that are common to many subfields. Because of the wide range of plasma densities and temperatures encountered in fusion applications, it is valuable to support plasma science across many of its subfields in order to advance the fusion energy mission.

Program Website: http://science.energy.gov/fes/

The size and complexity of world-leading experiments in the field of plasma physics are rapidly expanding beyond the scale of the single university investigator. Prime examples of this are research in burning plasma science and high-energy-density plasmas. It is essential that the U.S. develop a workforce with the necessary skills and experience in *burning plasma science* to maintain U.S. leadership in fusion and to fully capitalize on the U.S. investment in ITER and its operation in the coming decade. This means enabling students to pursue grand challenge problems in burning plasma science by providing them access to parameter regimes only available at the highest pressures (thermal and magnetic) as well as state-of-the-art diagnostics, both of which are only available at FES's major magnetic confinement fusion science facilities. Student accessibility to these premier facilities is important for developing a workforce with the critical scientific and team-building skills necessary to achieve our mission and secure U.S. leadership in this emergent field of science in the coming decades.

The FES's priority research areas for SCGSR program include:

(a) Burning Plasma & Magnetic Fusion Energy Science

Research supported in this area will utilize major magnetic fusion research facilities to develop the physics knowledge needed to advance the FES energy mission. This priority area focuses on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. Among the fundamental problems addressed by this program are the macroscopic stability and dynamics of fusion plasmas; the understanding and controlling of the multi-scale, collisional, and turbulent physical mechanisms responsible for the loss of heat, momentum, and particles from the confining region; the interaction of externally launched radiofrequency waves designed to heat and drive current with the background plasma and surrounding structures; the nonlinear interaction between background plasma, various instabilities, and energetic particle populations, including how this impacts on the confinement of the alpha particles generated by the fusion reactions and the overall plasma performance; and the effect of multi-scale and multi-physics processes at the plasma edge on the plasma performance and on the interaction and interface of the hot plasma boundary with the material walls.

This priority area also supports the development of advanced diagnostic capabilities to enable close coupling of experiments and theory/computations for existing facilities, diagnostic systems relevant for the extreme conditions to be encountered in ITER, and sensors and actuators required for active control of plasma properties to optimize device operation and plasma performance.

(b) Discovery Plasma Science

Research supported in this priority area is directed toward addressing problems in fundamental plasma science that complement burning plasma science. Growth in new research areas, enabled by the development of new investigative techniques and tools, continues to present exciting opportunities for fundamental studies in basic plasma science. Topics being encouraged include magnetic field line reconnection, plasma turbulence, self-organized systems, dusty plasmas, and low-temperature plasmas. Discovery-driven scientific explorations of high-energy-density states of matter are also being supported in this priority area. Topical examples being emphasized include HED hydrodynamics, radiation-dominated dynamics and material properties, laser-plasma interactions, relativistic high-energy-density plasmas and intense beam physics, warm dense matter, and high-Z multiply ionized high-energy-density atomic physics.

V. High Energy Physics (HEP)

The mission of the High Energy Physics (HEP) program is to understand how our universe works at its most fundamental level. We do this by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time.

Program Website: http://science.energy.gov/hep

The HEP program focuses on three scientific frontiers:

- *The Energy Frontier,* where powerful accelerators are used to create new particles, reveal their interactions, and investigate fundamental forces;
- *The Intensity Frontier,* where intense particle beams and highly sensitive detectors are used to pursue alternate pathways to investigate fundamental forces and particle interactions by studying events that occur rarely in nature, and to provide precision measurements of these phenomena; and
- *The Cosmic Frontier,* where non-accelerator-based experiments observe the cosmos and detect cosmic particles, making measurements of natural phenomena that can provide information about the nature of dark matter, dark energy, and other fundamental properties of the Universe that impact our understanding of matter and energy.

Together, these three interrelated and complementary discovery frontiers offer the opportunity to answer some of the most basic questions about the world around us. Also integral to the mission of HEP are four cross-cutting research areas that enable new scientific opportunities by developing the necessary tools and methods for discoveries:

- *Theoretical High Energy Physics,* where the vision and mathematical framework for understanding and extending the knowledge of particles, forces, space-time, and the universe are developed;
- *Computational High Energy Physics,* where the framework of simulation and computational techniques are developed for advancing the HEP mission;
- *Accelerator Science and Technology Research and Development,* where the technologies and basic science needed to design, build, and operate the accelerator facilities essential for making new discoveries are developed; and
- *Particle Detector Research and Development,* where the technologies and basic science needed to design, build, and operate the detector facilities essential for making new discoveries are developed.

The scientific objectives and priorities for the field recommended by the High Energy Physics Advisory Panel are detailed in the long-range plan available at: http://science.energy.gov/~/media/hep/pdf/files/pdfs/p5_report_06022008.pdf

A thriving program in HEP theory and computation is essential for identifying new directions and opportunities for the field; moreover, the fields of experimental HEP and accelerator physics have always relied on inventing, developing, and adapting advanced technologies in order to enable this vision.

The HEP's priority research areas for SCGSR program include:

(a) Theoretical and Computational Research in High Energy Physics

This research area supports activities that range from detailed calculations of the predictions of the Standard Model to the extrapolation of current knowledge to a new level of understanding, and the identification of the means to experimentally verify such predictions. Topics studied in this research area include, but are not limited to: phenomenological and theoretical studies that support experimental HEP research at the Energy, Intensity and Cosmic Frontiers, both in understanding the data and in finding new directions for experimental exploration; development of analytical and numerical computational techniques for these studies; computational science and simulations that advance theoretical high energy physics or scientific discovery aligned with the HEP mission; and construction and exploration of theoretical frameworks for understanding fundamental particles and forces at the deepest level possible.

(b) Advanced Technology Research & Development in High Energy Physics

The advanced technology R&D research area develops the next generation of particle accelerators and detectors and related technologies for discovery science; and also for possible applications in industry, medicine and other fields. This research area supports world-leading research in the physics of particle beams and particle detection, particularly exploratory research aimed at developing new concepts.

Topics studied in the advanced accelerator technology R&D research area include, but are not limited to: accelerator and beam physics, including analytic and computational techniques for modeling particle beams and simulation of accelerator systems; novel acceleration concepts; the science of high gradients in accelerating cavities and structures; high-power radio frequency sources; high-brightness beam sources; and beam instrumentation. Also of interest are superconducting materials and conductor development; innovative magnet design and development of high-field superconducting magnets; as well as associated testing and cryogenic systems.

Topics studied in the advanced particle detector R&D research area include, but are not limited to: low- mass, high channel density charged particle tracking detectors; high resolution, fast-readout calorimeters and particle identification detectors; techniques for improving the radiation tolerance of particle detectors; and advanced electronics and data acquisition systems.

VI. Nuclear Physics (NP)

The mission of the Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter. The fundamental particles that compose nuclear matter—quarks and gluons—are relatively well understood, but exactly how they fit together and interact to create different types of matter in the universe is still largely unknown. It is one of the enduring mysteries of the universe: What, really, is matter? What are the units that matter is made of, and how do they fit together to give matter the properties we observe? To solve this mystery, the NP program supports experimental and theoretical research—along with the development and operation of particle accelerators and advanced technologies—to create, detect, and describe the different forms and complexities of nuclear matter that can exist, including those that are no longer commonly found in our universe.

Program Website: http://science.energy.gov/np

The three frontiers of the NP program are: Quantum Chromodynamics, Nuclei and Nuclear Astrophysics, and Fundamental Symmetries and Neutrinos. Specific questions within these frontiers are addressed by the research activities of subprograms supported by the Office of Nuclear Physics as described below.

In addition, the NP isotope subprogram produces and/or distributes stable and radioactive isotopes that are critical for the Nation and supports research into production techniques for such isotopes.

The NP program supports the development of the tools and capabilities that make fundamental research possible, including accelerator research and development for current and future nuclear physics facilities. It also supports applications of nuclear science and technology to help bridge the gap between basic nuclear physics research and applied science, and an initiative on advanced detector technology research and development.

The NP's priority research areas for SCGSR program include:

(a) Medium Energy Nuclear Physics

The Medium Energy subprogram of Nuclear Physics focuses primarily on questions having to do with the first frontier of Nuclear Physics, Quantum Chromodynamics (QCD), especially regarding the spectrum of excited mesons and baryons, and the behavior of quarks inside the nucleons (neutrons and protons). Specific questions that are being addressed include: What does QCD predict for the properties of excited mesons and baryons? What governs the transition of quarks and gluons into pions and nucleons? What is the role of gluons and gluon self- interactions in nucleons and nuclei? and What is the internal landscape of the nucleons?

In pursuing these topics the Medium Energy subprogram supports several experimental research programs, notably at the Thomas Jefferson National Accelerator Facility (TJNAF) and the Relativistic Heavy Ion Collider (RHIC). Two major goals of the Medium Energy research program at TJNAF are the discovery of “exotic mesons” which carry gluonic excitations, and the experimental study of the substructure of the nucleons.

(b) Heavy Ion Nuclear Physics

The Heavy Ion subprogram supports experimental research that investigates the frontier of Quantum Chromodynamics (QCD) by attempting to recreate and characterize new and predicted forms of matter and other new phenomena that might occur in extremely hot, dense nuclear matter and which have not existed since the Big Bang. This subprogram addresses what happens when nucleons “melt.” QCD predicts that nuclear matter can change its state in somewhat the same way that ordinary matter can change from solid to liquid to gas. The fundamental questions addressed include: What are the phases of strongly interacting matter, and what roles do they play in the cosmos? What governs the transition of quarks and gluons into pions and nucleons? What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime? Experimental research is carried out primarily using the U.S. Relativistic Heavy Ion Collider (RHIC) facility and the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN).

(c) Low Energy Nuclear Physics

The Low Energy subprogram aims primarily at answering the overarching questions associated with the second frontier identified by NSAC— Nuclei and Nuclear Astrophysics. These questions include: What is the nature of the nucleonic matter? What is the origin of simple patterns in complex nuclei? What is the nature of neutron stars and dense nuclear matter? What is the origin of the elements in the cosmos? What are the nuclear reactions that drive stars and stellar explosions? Major goals of this subprogram are to develop a comprehensive description of nuclei across the entire nuclear chart, to utilize rare isotope beams to reveal new nuclear phenomena and structures unlike those that are derived from studies using stable ion beams, and to measure the cross sections of nuclear reactions that power stars and spectacular stellar explosions and are responsible for the synthesis of the elements. The subprogram also investigates aspects of the third frontier of Fundamental Symmetries and Neutrinos. Questions addressed in this frontier include: What is the nature of the neutrinos, what are their masses, and how have they shaped the evolution of the universe? Why is there now more matter than antimatter in the universe? What are the unseen forces that were present at the dawn of the universe but disappeared from view as the universe evolved? The subprogram seeks to measure, or set a limit on, the neutrino mass and to determine if the neutrino is its own antiparticle. Experiments with cold neutrons also investigate the dominance of matter over antimatter in the universe, as well as other aspects of Fundamental Symmetries and Interactions.

(d) Nuclear Theory

The Nuclear Theory subprogram supports theoretical research at universities and DOE national laboratories with the goal of improving our fundamental understanding of nuclear physics, interpreting the results of experiments, and identifying and exploring important new areas of research. This subprogram addresses all of the field's scientific frontiers described in NSAC's long range plan, as well as the specific questions listed for the experimental subprograms above.

Theoretical research on QCD (the fundamental theory of quarks and gluons) addresses the questions of how the properties of the nuclei, hadrons, and nuclear matter observed experimentally arise from this theory, how the phenomena of quark confinement arises, and what phases of nuclear matter occur at high densities and temperatures. In Nuclei and Nuclear Astrophysics, theorists investigate a broad range of topics, including calculations of the

properties of stable and unstable nuclear species, the limits of nuclear stability, the various types of nuclear transitions and decays, how nuclei arise from the forces between nucleons, and how nuclei are formed in cataclysmic astronomical events such as supernovae. In Fundamental Symmetries and Neutrinos, nucleons and nuclei are used to test the Standard Model, which describes the interactions of elementary particles at the most fundamental level. Theoretical research in this area is concerned with determining how various aspects of the Standard Model can be explored through nuclear physics experiments, including the interactions of neutrinos, unusual nuclear transitions, rare decays, and high-precision studies of cold neutrons.

(e) Nuclear Data and Nuclear Theory Computing

This activity supports the National "Nuclear Data" effort, as well as several activities that facilitate the application of high performance computing to Nuclear Theory. The Nuclear Data program collects, evaluates, and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies through the National Nuclear Data Center (NNDC), which maintains open databases of scientific information gathered over the past 100+ years of nuclear physics research. "Nuclear Theory Computing" includes the NP component of the ASCR program Scientific Discovery through Advanced Computing (SciDAC). SciDAC promotes the use of supercomputers at national laboratories and universities to solve problems of current interest in the sciences. Recent topics in computational nuclear physics investigated under the SciDAC program include the theory of quarks and gluons on a lattice (LQCD), studies of a wide range of applications of models of nuclei and nuclear matter, and the development of theoretical techniques for incorporating lattice QCD results in more traditional many-body nuclear physics calculations.

(f) Accelerator Research and Development for Current and Future Nuclear Physics

The Nuclear Physics program supports a broad range of activities aimed at research and development related to the science, engineering, and technology of heavy-ion, electron, and proton accelerators and associated systems. Areas of interest include the R&D technologies of the Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC), with heavy ion and polarized proton beams; the development of a possible future electron-ion collider; linear accelerators such as the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF); and development of devices and/or methods that would be useful in the generation of intense rare isotope beams for the next generation rare isotope beam accelerator facility, the Facility for Rare Isotope Beams (FRIB). Also of interest is R&D in accelerator science and technology in support of next generation Nuclear Physics accelerator facilities.

(g) Isotope Development and Production for Research and Applications

The Isotope Development and Production for Research and Applications subprogram supports the production and development of production techniques of radioactive and stable isotopes that are in short supply. The program provides facilities and capabilities for the production and/or distribution of research and commercial stable and radioactive isotopes. The scientific and technical staff associated with general isotope research and production, and a supply of critical isotopes to address the needs of the Nation are also supported. Isotopes are made available by using the Department's unique facilities, the Brookhaven Linear Isotope Producer (BLIP) at BNL and the Isotope Production Facility (IPF) at LANL, of which the subprogram has stewardship responsibilities. The Program also coordinates and supports isotope production at a suite of university, national laboratory, and other federal accelerator and reactor facilities throughout the Nation to promote a reliable supply of isotopes domestically. Topics of interest are focused on the development of advanced, cost-effective and efficient technologies for producing, processing, recycling and distributing isotopes in short supply. This includes technologies for production of radioisotopes using reactor and accelerator facilities and new technologies for enriching stable isotopes. Of special interest are innovative approaches to model and predict behavior and yields of targets undergoing irradiation in order to minimize target failures during routine isotope production.

(h) Applications of Nuclear Science and Technology

The Nuclear Physics program supports a competitive program of targeted initiatives in Applications of Nuclear Science and Technology (ANS&T), the primary goal of which is to pursue forefront nuclear science research and development important to the NP mission, but which is also inherently relevant to applications. One of the goals of this initiative is to help bridge the gap between basic nuclear physics research and applied science. Areas of R&D responsive to this subprogram may include (but are not limited to) nuclear physics research relevant to the development of advanced fuel cycles for next generation nuclear power reactors; advanced cost- effective accelerator technology and particle detection techniques for medical diagnostics, treatment or improving human health; environmental and water resource management; food and agriculture; and research in developing neutron, gamma, and particle beam sources with applications in contraband material screening and nuclear forensics. Applications may be peer reviewed with participation from the applied sciences community. For this subprogram, the programmatic priorities will include an evaluation of the innovative nuclear science advances and their relevance to the application, the cost effectiveness and performance relative to existing technologies, and the impact of the expected science and technology transfer.

(i) Advanced Detector Technology Research and Development in Nuclear Physics

Future nuclear physics experiments will require new radiation detection material, measurement techniques and data acquisition architectures. Advances in these areas could allow the development of significantly high channel density, higher timing, position and/or energy resolution, particle identification, data bandwidth, high radiation tolerant devices, higher precision or extremely low noise per detection element. Many experiments will need two or more of these features at approximately the same or lower cost as present generation experiments. This program supports applications for innovative R&D efforts directed at achieving radically new advancements of detector technologies needed to perform or conceive future state-of-the-art nuclear physics experiments at NP's present, upgraded or planned accelerator facilities, or at non-accelerator research institutions supported by NP. The emphasis is on generic detector R&D concepts that are transformative, rather than incremental advancement of established ideas or fabrication techniques.

Interesting technologies include but are not limited to: new types of low-mass, high-channel-density radiation hard charged particle tracking detectors or calorimeters; particle identification detectors that have improved resolution, are lower in cost, or can be read out faster than currently available detectors; novel efficient gamma-ray, neutron and charged particle detectors; detector readout systems that eliminate wires or integrate wireless technologies; nanotechnology; novel materials such as composite polymers, ceramics and organics; non-planar 3-dimensional monolithic sensors or data processing circuitry; large scale self-calibrating detectors or novel detection methodologies.

<u>EXCLUSIONS:</u> NP does not support investigations into the development of nuclear reactors for purposes outside the scope of the NP subprograms described above.