Basic Energy Sciences Advisory Committee (BESAC)

Subcommittee on

Facing our Energy Challenges in a New Era of Science

Co-chairs:
George Crabtree, Argonne
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Solid State Sciences Committee
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BES Basic Research Needs Workshops

"Considering the urgency of the energy problem, the magnitude of the needed scientific breakthroughs, and the historic rate of scientific discovery, current efforts will likely be too little, too late. Accordingly, BESAC believes that a new national energy research program is essential and must be initiated with the intensity and commitment of the Manhattan Project, and sustained until this problem is solved."

BESAC Report, February 2003

The Basic Research Needs Workshops

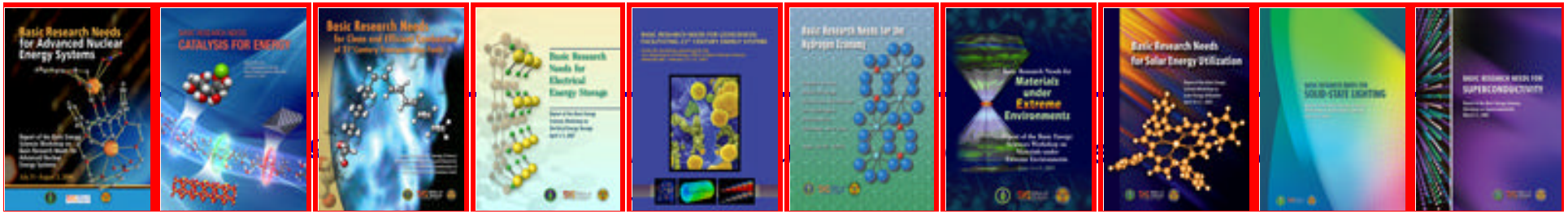
http://www.sc.doe.gov/bes/reports/list.html

Basic Research in Support of the DOE Missions

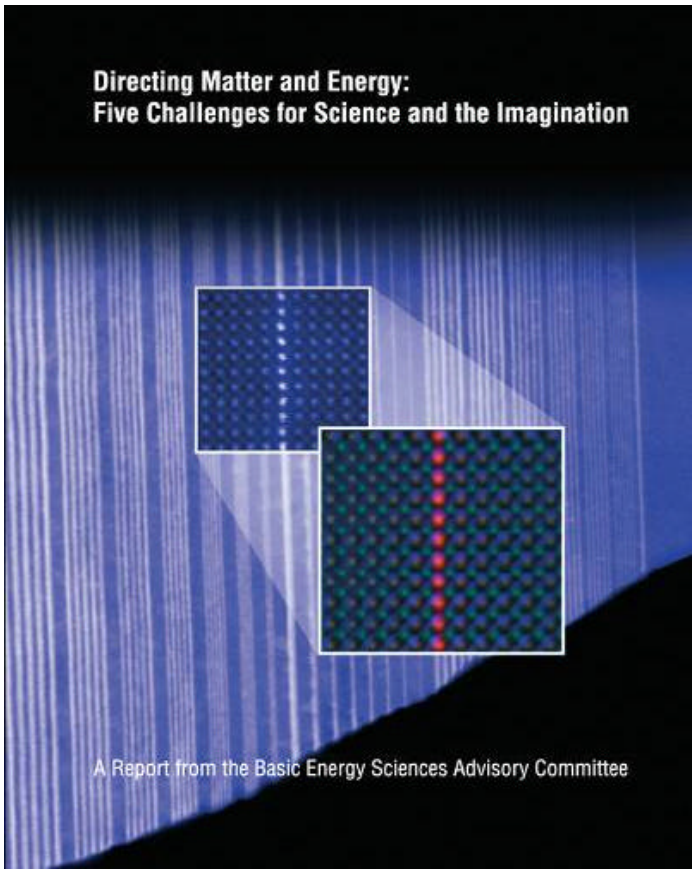
- **Basic Research Needs to Assure a Secure Energy Future**
  BESAC Workshop, October 21–25, 2002
  The foundation workshop that set the model for the focused workshops that follow
- **Basic Research Needs for the Hydrogen Economy**
  BES Workshop, May 13–15, 2003
- **Basic Research Needs for Solar Energy Utilization**
  BES Workshop, April 18–21, 2005
- **Basic Research Needs for Superconductivity**
  BES Workshop, May 8–10, 2006
- **Basic Research Needs for Solid-state Lighting**
  BES Workshop, May 22–24, 2006
- **Basic Research Needs for Advanced Nuclear Energy Systems**
  BES Workshop, July 31–August 3, 2006
- **Basic Research Needs for the Clean and Efficient Combustion of 21st Century Transportation Fuels**
  BES Workshop, October 30–November 1, 2006
- **Basic Research Needs for Electrical Energy Storage**
  BES Workshop, April 2007
- **Basic Research Needs for Geosciences: Scientific Challenges for Measurement, Monitoring, and Verification**
  BES Workshop, Spring 2007
- **Basic Research Needs for Materials Under Extreme Environments**

Materials Grand Challenges- From the BRN Workshops

- **New materials & functionalities discovery, design, development, and fabrication**, especially materials that perform well under extreme conditions
- **Science at the nanoscale, especially low-dimensional systems** that promise materials with new and novel properties
- **Methods to "control" photon, electron, ion, and phonon transport in materials** for next-generation energy technologies
- **Structure-function relationships** in both living and non-living systems
- **Designer catalysts**
- **Interfacial science and designer membranes**
- **Bio-materials and bio-interfaces**, especially at the nanoscale where soft matter and hard matter can be joined
- **New tools** for:
  - **Spatial characterization**, especially at the atomic and nanoscales and especially for in-situ studies
  - **Temporal characterization** for studying the time evolution of processes
  - **Theory and computation**
  - **Synthesis, crystal growth**



Grand Challenge Fundamental Science



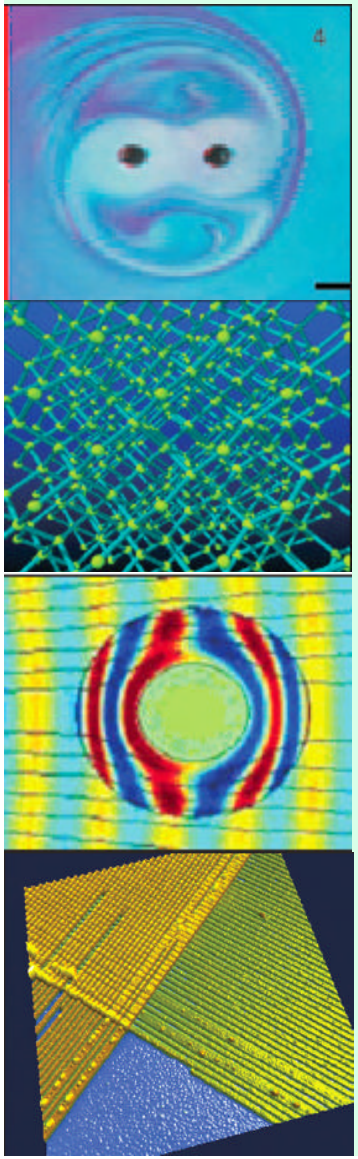
"In the 20th century, scientists continually improved their ability to observe and understand the interactions among atoms and molecules that determine material properties and processes. Now, scientists are positioned to begin directing those interactions and controlling the outcomes on a molecule-by-molecule and atom-by-atom basis, or even at the level of electrons."

http://www.sc.doe.gov/bes/reports/abstracts.html#GC

BESAC Grand Challenge Report
December 2007

Directing Matter and Energy: Five Challenges for Science and the Imagination

How does nature execute electronic and atomic design? How can we?



Control the quantum behavior of electrons in materials

Imagine: Direct manipulation of the charge, spin and dynamics of electrons to control and imitate the behavior of physical, chemical and biological systems, such as digital memory and logic using a single electron spin, the outcomes of chemical reactions and the strength of chemical bonds, and conversion of the Sun's energy into fuel through artificial photosynthesis.

Synthesize, atom by atom, new forms of matter with tailored properties

Imagine: Create and manipulate natural and synthetic systems that will enable catalysts that are 100% specific and produce no unwanted byproducts, or materials that operate at the theoretical limits of strength and fracture resistance, or that respond to their environment and repair themselves like those in living systems

Control emergent properties that arise from the complex correlations of atomic and electronic constituents

Imagine: Orchestrate the behavior of billions of electrons and atoms to create new phenomena, like superconductivity at room temperature, or new states of matter, like quantum spin liquids, or new functionality combining contradictory properties like super-strong yet highly flexible polymers, or optically transparent yet highly electrically conducting glasses, or membranes that separate CO_2 from atmospheric gases at high throughput.

Synthesize nanoscale objects with capabilities rivaling those of living things

Imagine: Master energy and information on the nanoscale, leading to the development of new metabolic and self-replicating pathways in living and non-living systems, self-repairing artificial photosynthetic machinery, precision measurement tools as in molecular rulers, and defect-tolerant electronic circuits

Control matter very far away from equilibrium

Imagine: Discover the general principles describing and controlling systems far from equilibrium, enabling efficient and robust biologically-inspired molecular machines, long-term storage of spent nuclear fuel through adaptive earth chemistry, and achieving environmental sustainability by understanding and utilizing the chemistry and fluid dynamics of the atmosphere.

http://www.sc.doe.gov/bes/reports/abstracts.html#GC

Workshop Charge: Energy Challenges in a New Era of Science

Following the completion of the 10 Basic Research Needs (BRNs) workshop reports by BES in the past five years and the recent Grand Challenges study under the auspices of BESAC, BESAC is now embarking on a study to tie together the aforementioned reports. This study has two primary goals: (1) to assimilate the scientific research directions that emerged from these workshop reports into a comprehensive set of science themes; and (2) to identify the new tools required to accomplish the science. Included in this should be the consideration of future light sources with technical characteristics that will address the science questions posed by these BESAC and BES studies.

Continued - ***Workshop Charge: Energy Challenges in a New Era of Science***

1. Summarize the range of scientific research directions that emerged from the 2002 BESAC report *Basic Research Needs for a Secure Energy Future*, the follow-on BES BRNs reports, and the BESAC report "*Directing Matter and Energy: Five Challenges for Science and the Imagination*". Identify key cross-cutting scientific themes that are common to these reports. In doing so, also make the connections between the themes that resulted from the "use-inspired" BRNs workshops and those that resulted from the consolidation of the fundamental challenges that face our disciplines.

2. Summarize the implementation strategies, and human resources that will be required to accomplish the science described in the aforementioned reports. These strategies may include new experimental and theoretical facilities, instruments and techniques. Consider possible new organizational structures that may be required to implement the strategies and supply the human resources.

3. Identify future light sources needs that will be required to help accomplish the scientific challenges described in these workshops. Specifically, consider the energy range (from vacuum UV to hard X-rays), coherence (both transversal and longitudinal), intensity (photon per pulse and photon per second), brightness (ultrahigh brightness with low electron emittance), and temporal structure (nano to atto seconds) for future light sources.