Basic Energy Science Investments in Electrical Energy Storage

IBM Almaden Institute
August 27, 2009

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Office of Basic Energy Sciences
Office of Science, U.S. Department of Energy
- Within 10 years save more oil than we currently import from the Middle East and Venezuela combined.

- Put 1 million plug-in hybrid cars – cars that can get up to 150 miles per gallon – on the road by 2015.

- Generate 10 percent of our electricity from renewable sources by 2012, and 25 percent by 2025.

- Implement an economy-wide, cap-and-trade program to reduce greenhouse gas emissions 80% by 2050.

http://www.whitehouse.gov/agenda/energy_and_environment/
DOE’s Priorities and Goals

Priority: Science and Discovery: Invest in science to achieve transformational discoveries
- Organize and focus on breakthrough science
- Develop and nurture science and engineering talent
- Coordinate DOE work across the department, across the government, and globally

Priority: Change the landscape of energy demand and supply
- Drive energy efficiency to decrease energy use in homes, industry and transportation
- Develop and deploy clean, safe, low carbon energy supplies
- Enhance DOE’s application areas through collaboration with its strengths in Science

Priority: Economic Prosperity: Create millions of green jobs and increase competitiveness
- Reduce energy demand
- Deploy cost-effective low-carbon clean energy technologies at scale
- Promote the development of an efficient, “smart” electricity transmission and distribution network
- Enable responsible domestic production of oil and natural gas
- Create a green workforce

Priority: National Security and Legacy: Maintain nuclear deterrent and prevent proliferation
- Strengthen non-proliferation and arms control activities
- Ensure that the U.S. weapons stockpile remains safe, secure, and reliable without nuclear testing
- Complete legacy environmental clean-up

Priority: Climate Change: Position U.S. to lead on climate change policy, technology, and science
- Provide science and technology inputs needed for global climate negotiations
- Develop and deploy technology solutions domestically and globally
- Advance climate science to better understand the human impact on the global environment
Current projections estimate that the energy needs of the world will more than double by the year 2050. This is coupled with increasing demands for “clean” energy—sources of energy that do not add to the already high levels of carbon dioxide and other pollutants in the environment. These enormous challenges cannot be fully met by existing technologies, and scientific breakthroughs will be required to provide reliable, economic solutions for our future energy security.

This seminal workshop report indentified the broad basic research directions that will help provide the major scientific discoveries necessary for major technological changes in the largest industries in the world—those responsible for energy production and use.

The findings of this 2003 report gave birth to 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 Department of Energy laboratories. These reports provide in-depth analyses on how the work of the scientific community can further our Nation’s most challenging energy missions.
Basic Research Needs to Assure a Secure Energy Future

- Hydrogen Economy
- Solar Energy Utilization
- Superconductivity
- Solid State Lighting
- Advanced Nuclear Energy Systems
- Clean and Efficient Combustion of 21st Century Transportation Fuels
- Geosciences: Facilitating 21st Century Energy Systems
- Electrical Energy Storage
- Catalysis for Energy Applications
- Materials under Extreme Environments
Control the quantum behavior of electrons in materials

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

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

Synthesize man-made nanoscale objects with capabilities rivaling those of living things

Control matter very far away from equilibrium
Basic and Applied Research Integration

**How Nature Works → Design and Control → Technologies for the 21st Century**

<table>
<thead>
<tr>
<th>Grand Challenges</th>
<th>Discovery and Use-Inspired Basic Research</th>
<th>Applied Research</th>
<th>Technology Maturation &amp; Deployment</th>
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<tbody>
<tr>
<td>Controlling materials processes at the level of quantum behavior of electrons</td>
<td>Basic research for fundamental new understanding on materials or systems that may revolutionize or transform today’s energy technologies</td>
<td>Basic research, often with the goal of addressing showstoppers on real-world applications in the energy technologies</td>
<td>Scale-up research</td>
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<td>Atom- and energy-efficient syntheses of new forms of matter with tailored properties</td>
<td>Development of new tools, techniques, and facilities, including those for the scattering sciences and for advanced modeling and computation</td>
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<td>At-scale demonstration</td>
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<td>Emergent properties from complex correlations of atomic and electronic constituents</td>
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<td>Cost reduction</td>
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<td>Man-made nanoscale objects with capabilities rivaling those of living things</td>
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<td>Prototyping</td>
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<td>Controlling matter very far away from equilibrium</td>
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<td>Manufacturing R&amp;D</td>
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**BESAC & BES Basic Research Needs Workshops**

**BESAC Grand Challenges Panel**

**DOE Technology Office/Industry Roadmaps**

**EFRC**
Basic Research Needs for Electrical Energy Storage
April 2-4, 2007

Chair: John Goodenough (UT-Austin)
Co-Chairs: Hector Abruna (Cornell)
          Michelle Buchanan (ORNL)

Breakout Session Panel and Leaders:
  Chemical Storage Science
    Stan Whittingham, SUNY-Binghamton
    Steven Visco, LBNL
  Capacitive Storage Science
    Bruce Dunn, UCLA
    Yury Gogotsi, Drexel
  Cross-Cutting
    Daniel Nocera, MIT
    Andy Gewirth, U Illinois

Plenary Session Speakers:
  Tien Duong (DOE-EERE) – Transportation Needs
  Imre Gyuk (DOE-OE) – Utility Needs
  Jean-Marie Tarascon (Univ. de Picardie Julies Verne) – Li-ion Technology, Present and Future
  John R. Miller (JME) – Electrochemical Capacitors
  Katsuhiko Naoi (Tokyo University of Ag &Tech) – Advances in Capacitors & Hybrid Devices in Japan

CHARGE: To identify basic research needs and opportunities underlying batteries, capacitors and related technologies, with a focus on new or emerging science challenges with potential for significant long-term impact on the efficient storage and release of electrical energy. Highlighted areas will include coupled ionic and charge transport, electrolyte physics, theory and modeling, and novel materials and approaches.
Priority Research Directions

- Novel Designs and Strategies for Chemical Energy Storage
- Solid-Electrolyte Interfaces and Interphases in Chemical Energy Storage
- Capacitive Energy Storage Materials by Design
- Electrolyte Interactions in Capacitive Energy Storage
- Multifunctional Materials for Pseudocapacitors and Hybrid Devices
- Rational Materials Design Through Theory and Modeling

Cross-Cutting Science for Electrical Energy Storage

- Advances in Characterization
- Nanostructured Materials
- Innovation in Electrolytes
- Theory, Modeling and Simulation
## From Science to Deployment: Electrical Energy Storage

<table>
<thead>
<tr>
<th>Discovery Research</th>
<th>Use-inspired Basic Research</th>
<th>Applied Research</th>
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<tr>
<td>- Retrosynthetic approaches to high performance new materials</td>
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<td>- Design of new materials capable of multi-electron storage per redox center</td>
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<td>- Understand design criteria for electrolytes that enable higher voltages</td>
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<td>- Tailoring nanoscale electrode architectures for optimal transport</td>
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<td>- Novel chemistries for scavenging impurities and self-healing</td>
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<td>- Generation of knowledge and computational and experimental tools to predict properties, performance evolution, and lifetime of materials</td>
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<td>- Understand and predict interfacial charge transfer and multi-body effects</td>
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<td>- Predict and control dynamics of phase transitions</td>
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<td>- Control of chemistry and its dynamics at electrified interfaces</td>
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<td>- Determining consequences of dimensionality</td>
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<td>- Physicochemical consequences of nano-dimensions</td>
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<td>- Fundamentals of solvation dynamics and ionic transport</td>
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<td>- Revolutionary tools for \textit{in situ} structural and dynamic studies over broad spatial / temporal regimes</td>
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<td>- Evaluate and benchmark novel chemical and material systems</td>
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<td>- Define advanced electrochemical systems through advanced electrolyte modeling, anode screening and development, and electrochemical testing and diagnostics</td>
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<td>- Assemble and performance test electrical energy storage devices with respect to power fade, overcharge, deep discharge, charge rate, abuse tolerance, safety, lifetime, cost, etc.</td>
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<td>- Demonstrate usage of energy storage systems in advanced vehicle applications with high power / energy density, long lifetime, appropriate charging time, deep discharge, reliability, safety and low cost.</td>
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<td>- Deployment of high capacity storage for centralized and distributed power sources for power quality and load leveling</td>
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<td>- Long shelf life storage devices for stand-by power</td>
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<td>- Long-lived, environmentally friendly, recyclable portable energy storage for portable and stationary energy storage</td>
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**Office of Science**  
BES

**Technology Offices**  
EERE and OE
Basic Research Needs for Electrical Energy Storage Workshop Report

Available on the web at:
http://www.sc.doe.gov/bes/reports/files/EES_rpt.pdf
EFRCs will pursue collaborative basic research that addresses both energy challenges and science grand challenges.

- Solar Energy Utilization
- Bio-Fuels
- Catalysis
- Energy Storage
- Geosciences for Waste and CO₂ Storage
- Advanced Nuclear Energy Systems
- Materials Under Extreme Environments
- Hydrogen
- Combustion
- Superconductivity
- Solid State Lighting

FY 2009 EFRCs Funding Status:

- Recovery Act (Stimulus Bill) $277M
- Omnibus Appropriations $100M

Total EFRCs = $777M over 5 years
46 centers awarded, representing 103 participating institutions in 36 states plus D.C.

Energy Frontier Research Center Locations (★ Leads; ● Participants)

By Topical Category:
- Energy Supply: 20
- Crosscutting Sciences: 14
- Energy Storage: 6
- Energy Efficiency: 6

By Lead Institution:
- Universities: 31
- DOE Labs: 12
- Industry/Nonprofit: 1
Michael Thackeray,  ANL
Center for Electrical Energy Storage: Tailored Interfaces

Grigori Soloveichik, General Electric Global Research
Center for Electrocatalysis, Transport Phenomena, and Materials (CETM) for Innovative Energy Storage

Héctor Abruña, Cornell Univ.
Nanostructured Interfaces for Energy Generation, Conversion, and Storage

Clare P. Grey, Stony Brook Univ.
Northeastern Chemical Energy Storage Center

Gary Rubloff, Univ. of Maryland
Science of Precision Multifunctional Nanostructures for Electrical Energy Storage

Ken Reifsnider, Univ. of South Carolina
Science Based Nano-Structure Design and Synthesis of Heterogeneous Functional Materials for Energy Systems
Energy Innovation Hub – Batteries and Energy Storage $34,020k

*Energy Innovation Hubs* are part of a set of Hubs that will be initiated by the Department in FY 2010. The set of Hubs aim at assembling multidisciplinary teams to address the basic science, technology, economic, and policy issues hindering the nation’s secure and sustainable energy future. Because the components and processes of energy systems are highly interdependent, innovative solutions to real-world energy challenges will require concerted efforts that couple the various elements of the technology chain and combine the talents of universities, national laboratories, and the private sector. Two Hubs are proposed in BES in FY 2010: Fuels from Sunlight and Batteries and Energy Storage.