



A REMARKABLE RETURN ON INVESTMENT IN FUNDAMENTAL RESEARCH

40 YEARS OF BASIC ENERGY SCIENCES AT THE DEPARTMENT OF ENERGY: A SUMMARY

Major technological, commercial, and national security innovations don't just happen. They typically have their roots in fundamental research breakthroughs over a period of decades and often require additional applied research. The major innovations described in this report are directly traceable to fundamental research supported by the Basic Energy Sciences (BES) office of DOE (and sometimes by other federal agencies as well) over the past 40 years. BES has also created and supported a national network of shared research facilities open to all scientists. These facilities have become a distinctive feature of the U.S. research effort and have greatly increased the productivity of university, federal, and industrial research efforts.

This report highlights key examples of innovations that matter, with impacts in national security, critical materials, clean energy technology, environmental stewardship, and high-performance computing. It documents BES contributions to U.S. industrial leadership in automotive, basic materials, energy, and pharmaceutical sectors. It also illustrates the importance of BES-supported research in catalyzing emerging high priority areas such as nanotechnology.



Innovations That Matter in...

CLEAN ENERGY

- > **LED lights** that are 15 times more efficient than traditional incandescent bulbs, last much longer, and will significantly lower U.S. lighting costs, based on research to understand how semiconductor materials absorb and emit light.
- > **Super-efficient solar cells** that can capture up to half of the energy in sunlight and that will power smart watches and the sensors that will enable smart homes and smart buildings, based on research on how to combine several different types of complex semiconductors.
- > **Improved batteries** for next-generation electric vehicles such as the GM Bolt that are safer and more powerful, based on research that discovered new battery materials with superior chemical properties.
- > **Smart windows** for offices and homes that tint themselves when needed to reduce solar glare and save on cooling costs, based on research into how a material's optical properties change.
- > **New automotive powerplants** that will use fuel cells to directly and efficiently convert fuels such as hydrogen into electric power *without combustion*, eliminating pollution and avoiding battery-recharge downtime, based on research into more efficient, less expensive catalyst materials.

MATERIALS UNDER EXTREME CONDITIONS

- > **Increased national security** from the ability to monitor U.S. stockpiled nuclear weapons or design new ones without test explosions, from research into the behaviors of metals under extreme conditions—in bomb explosions, in high temperature power plants, in car collisions. This research also led to new metal alloys and more precise control of metal processing techniques that enabled:
- > **Lighter, stronger alloys** in cars, trucks, and airplanes, including aluminum bodies in the Ford F-150 truck.
- > **More efficient coal-fired power plants** and other energy facilities, because of stronger steels that could safely operate at higher temperatures.

BIOLOGICAL SCIENCE AND BIOMEDICAL PRACTICE

- > **Rational drug design**, based on use of BES X-ray research facilities to determine the structure of complex biological molecules such as those that control how drugs attach to and affect human cells. This research also led to:
- > **Accelerated, more efficient drug development**, as pharma companies now use these X-ray facilities to screen more than 20,000 potential drug candidates a year, including new candidate opioid drugs that treat pain but are not addicting.



HIGH-PERFORMANCE COMPUTING

- > **Improved industrial catalysts and more efficient chemical production processes**, based on radically new software programs designed for high-speed supercomputers that have enabled modeling and predicting chemical processes. Similar research also led to:
- > **Novel magnetic materials**, from software that analyzes the properties of complex materials atom by atom, and
- > **Significant decreases in pollutant emissions from diesel engines**, as well as increased efficiency, from software that simulates the combustion of fuel in engines.

ENVIRONMENTAL STEWARDSHIP

- > **An automated process for removal and safe burial** of the most radioactive component of nuclear wastes left over from nuclear weapons production, enabling a faster and less expensive cleanup—based on research into molecules that selectively attach to a radioactive cesium atom. Similar research may soon enable:
- > **Recovery of critical national defense materials** from U.S. deposits of phosphate rock, lessening our dependence on China.

SUPERCONDUCTIVITY

- > **Superconducting microwave filters that prevent interference among mobile wireless signals**, now installed in more than 10,000 communication towers, based on decades of research into the unique properties of high temperature superconductors.
- > **Superconducting cables capable of carrying huge currents** that can be used to protect the electrical grid against sudden failure, based on research on how to “tune” the composition of high temperature superconducting materials to make them more practical for industrial applications. This research is also leading to:
- > **Smaller, lighter superconducting electrical generators** that will enable less expensive off-shore wind turbines.

THE EMERGING SCIENCE OF THE VERY SMALL

- > **Extremely bright, vivid TV screens** that incorporate tiny crystals which emit light of extremely pure colors, based on research done in collaboration with BES specialized research centers for study of the unique properties and behaviors of nanoscale materials. This research has also led to:
- > **Development of the world’s most powerful microscopes**, that can “see” things much smaller than are visible with light.
- > **Novel production processes** that utilize specialized nanoscale inks for 3-D printers and can create tiny batteries and electronic parts for mobile phones and wearable technology.

THE EMERGING TECHNOLOGY OF QUANTUM COMPUTING

- > **Candidate data processing devices** now being pursued by Google, IBM, Microsoft, and Intel as the core of quantum computers that, for problems such as breaking codes and searching massive data files, would be dramatically faster than today’s computers. These devices can be traced back to the BES-supported 1985 discovery of—and several decades of subsequent research on—materials that exhibit multiple quantum states.

NATIONAL FACILITIES NETWORK

- > **Development of shared research facilities with intense beams of X-rays and neutrons and specialized nanoscience facilities open to all researchers.** This system-level innovation now enables more than 16,000 researchers per year from universities, government laboratories, and industry to use these advanced research tools; helps train the future scientific workforce; and facilitates collaboration among visiting researchers and the scientific staff of the National Laboratories where they are located that enables rapid progress and maintains a U.S. competitive advantage.

