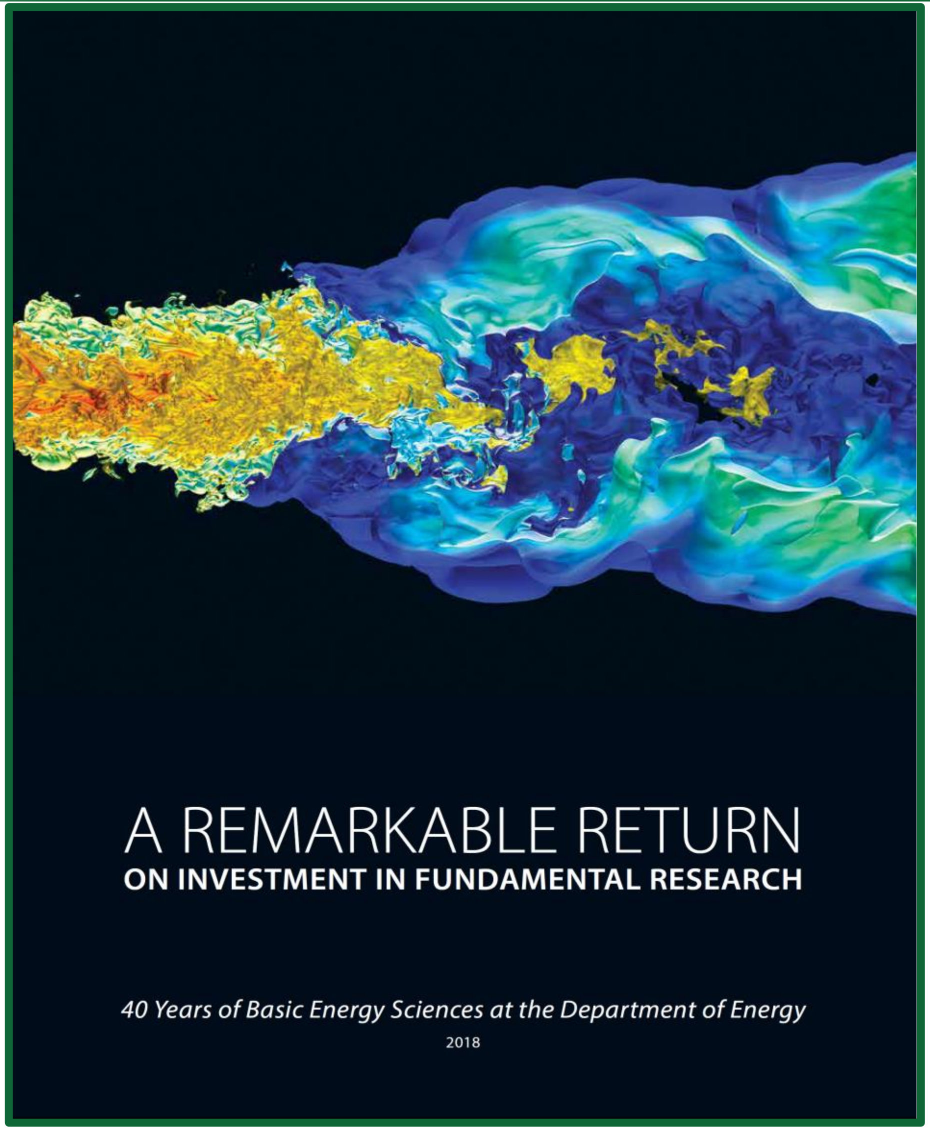
40 Years of Basic Energy Sciences at the Department of Energy



Agenda

Introduction (Marc Kastner)

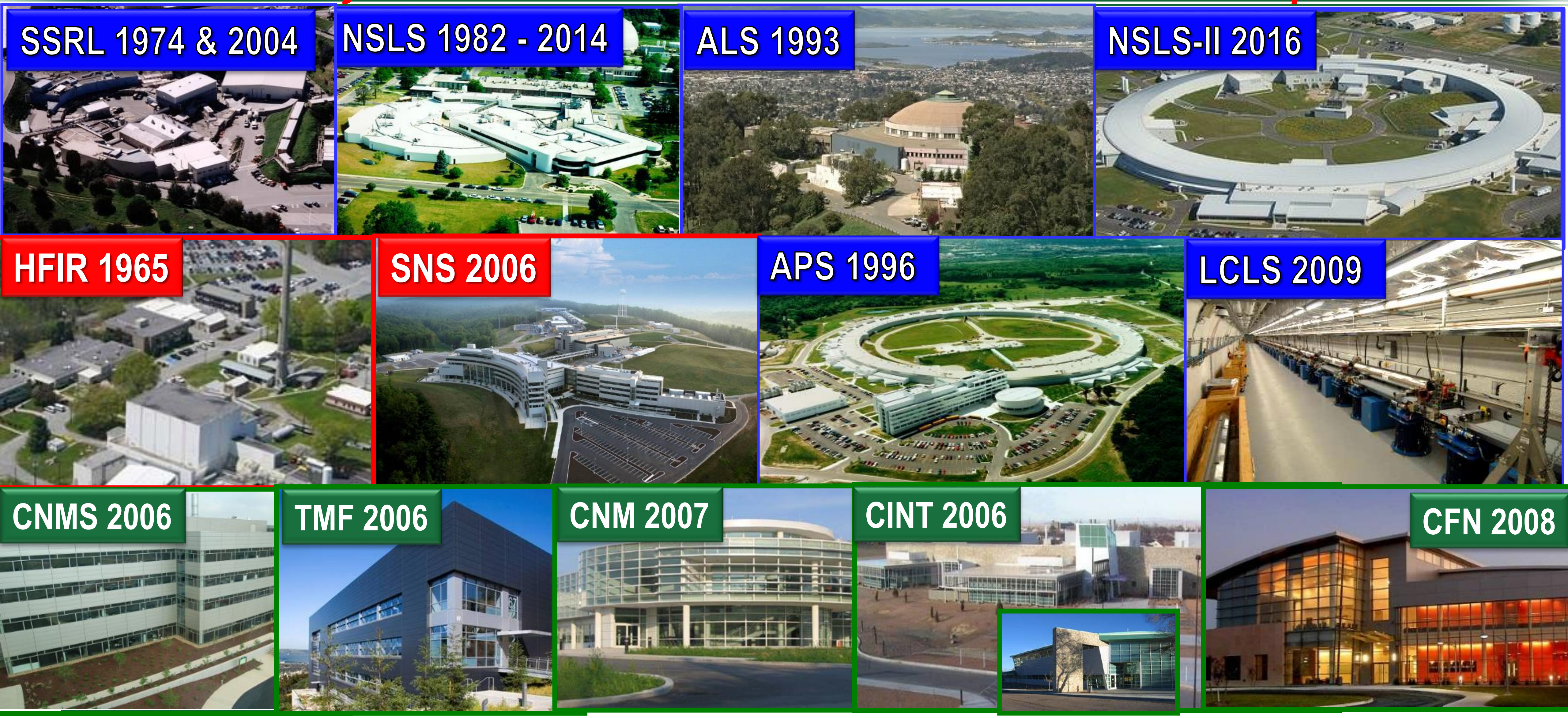
DOE Perspective (Steve Binkley)

Examples of Stories

- **Scientific Research Facilities (Marc Kastner)**
- **Nanoscience (Monica Olvera de la Cruz)**
- **Tough Stuff (John Sarrao)**
- **Superconductivity (George Crabtree)**
- **Quantum Computing (Marc Kastner)**

Shared Research Facilities:

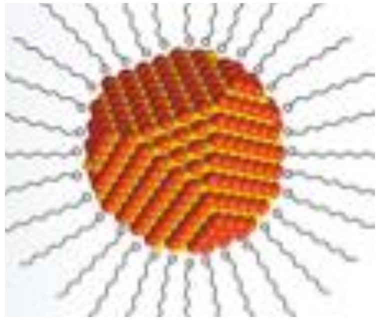
A Key Source of U.S. Scientific and Industrial Leadership

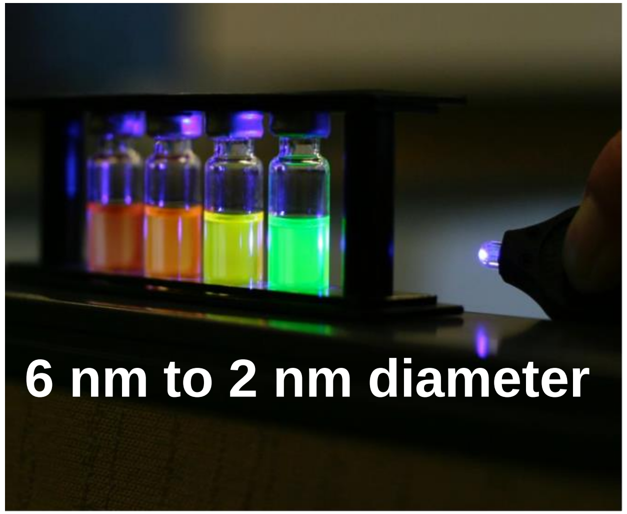


U.S. DEPARTMENT OF ENERGY | Office of Science

Dr. Marc Kastner
Science Philanthropy Alliance &
Massachusetts Institute of Technology

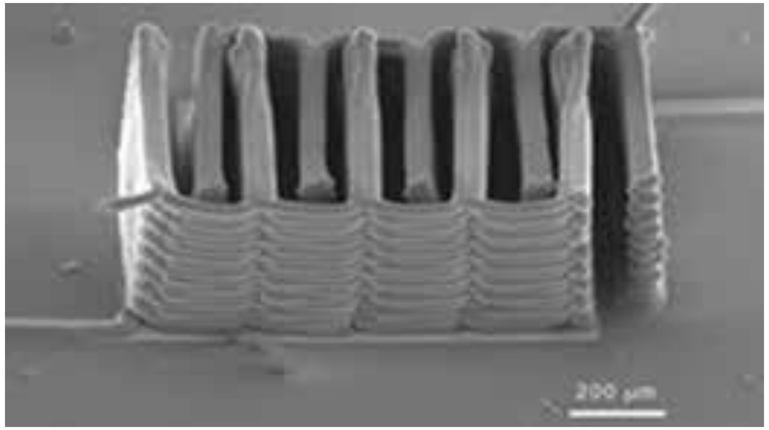
Nanoscience: How to Invent a Whole New Field

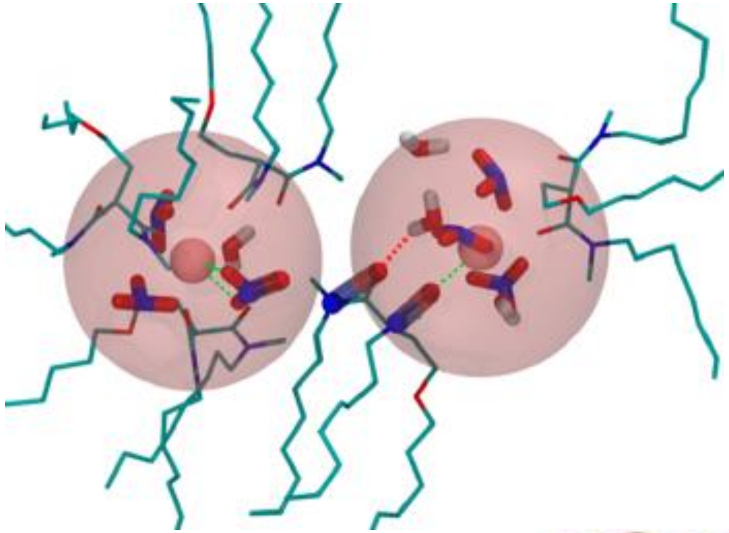


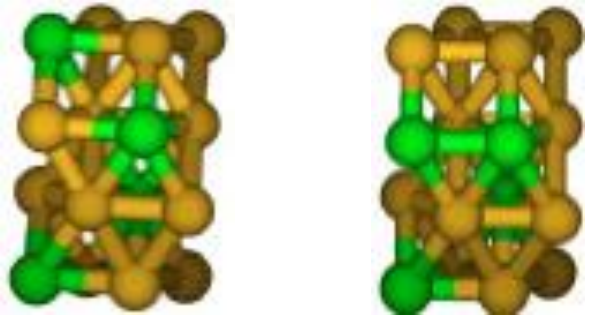


Dr. Monica Olvera de la Cruz
Northwestern University

Nanoscience: Energy & Environment

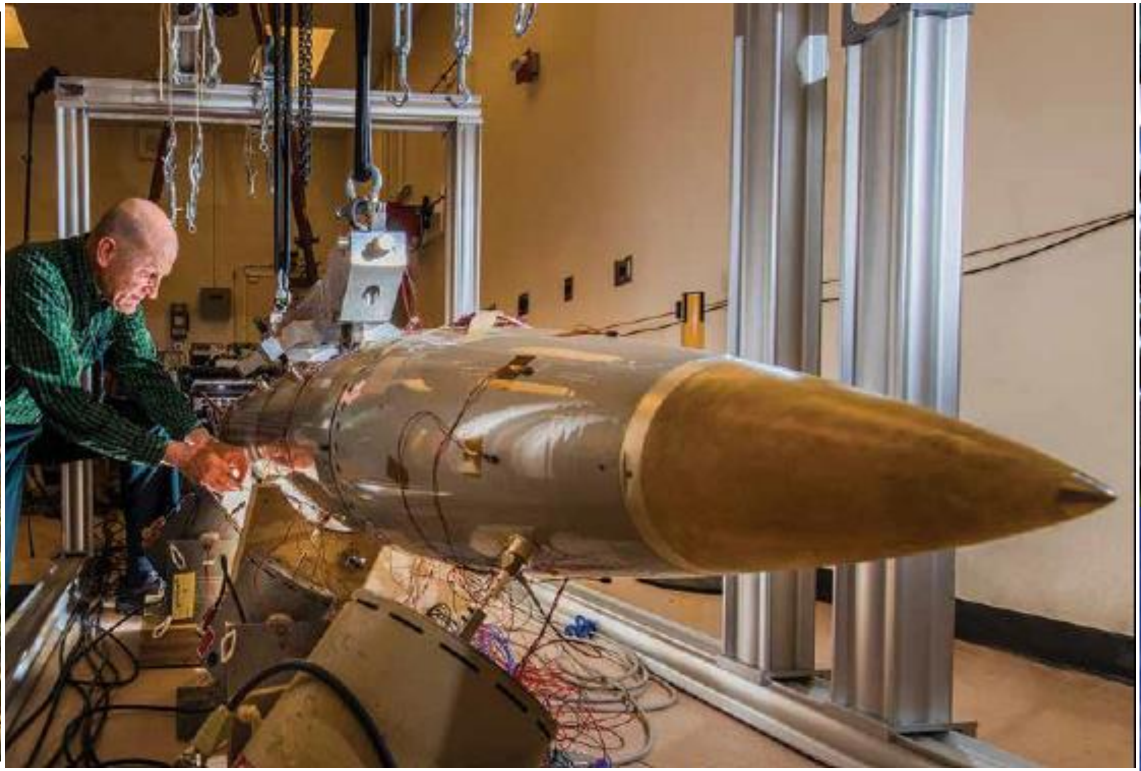






Solute Metal Noble Metal

Tough Stuff: Extreme Materials for Extreme Challenges

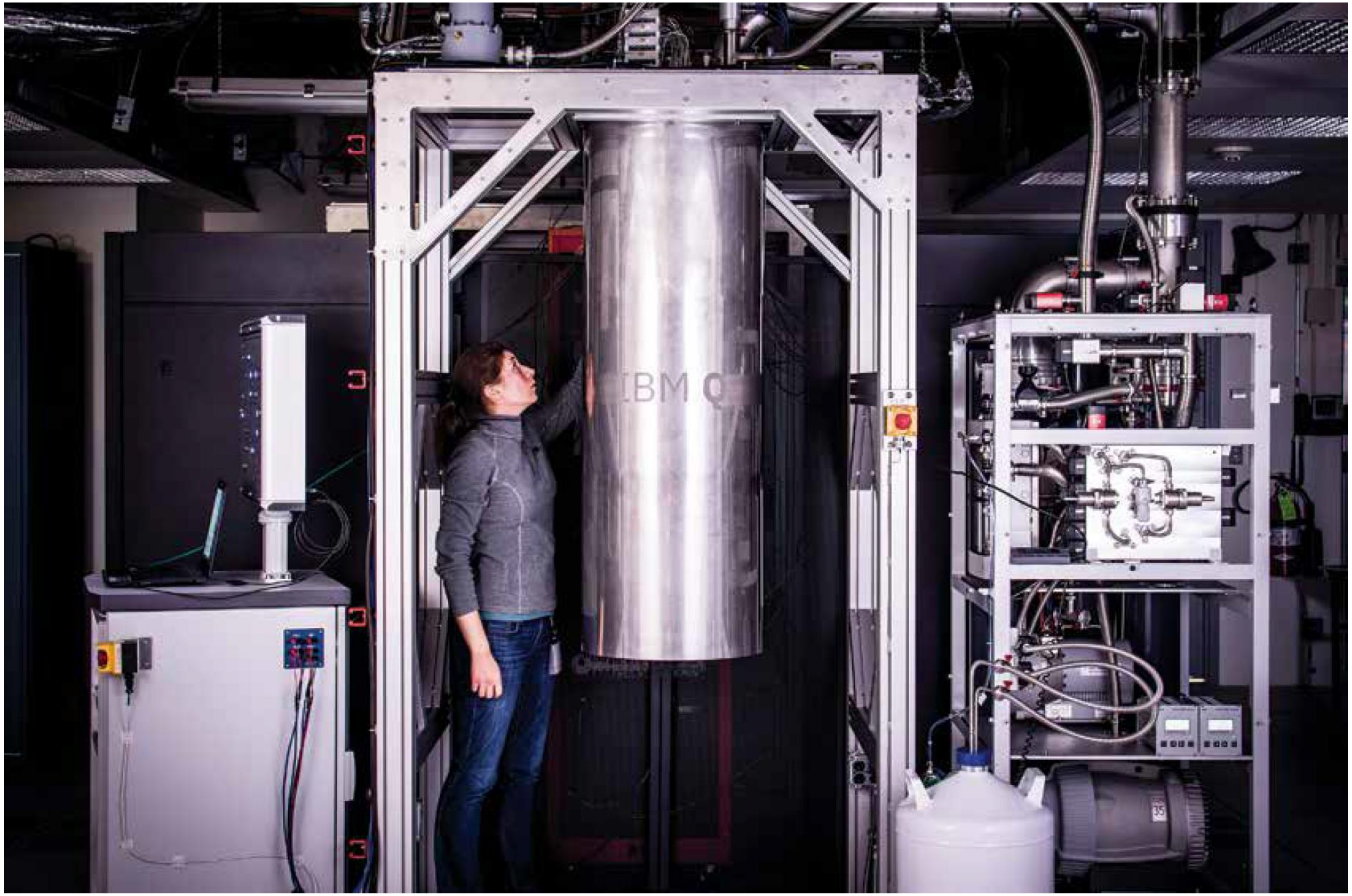


Dr. John Sarrao
Los Alamos National Laboratory

Making Superconductivity *Useful*

Dr. George Crabtree
Argonne National Laboratory &
University of Illinois, Chicago

Quantum Computing



Dr. Marc Kastner
Science Philanthropy Alliance & Massachusetts Institute of Technology

LEVERAGING
SEMICONDUCTOR SCIENCE
FOR CLEAN ENERGY TECHNOLOGIES

Keeping the lights on in the United States consumes 350 billion kilowatt hours of electricity annually. Most of that light still comes from incandescent bulbs, which haven't changed much since Thomas Edison invented them 140 years ago. But now a dramatically more efficient lighting technology is seeing rapid adoption: semiconductor devices known as light-emitting diodes (LEDs) use 85 percent less energy than incandescent bulbs, last 25 times as long, and have the potential to save U.S. consumers a huge portion of the electricity now used for lighting.

How we generate electricity is also changing. The costs of solar cells that convert light from the sun into electricity have come down dramatically over the past decade. As a result, solar power installations have grown rapidly, and in 2016 accounted for a significant share of all the new electrical

High-performance solar power plant in Alamosa, Colorado. It generates electricity with multi-layer solar cells, developed by the National Renewable Energy Laboratory, that absorb and utilize more of the sun's energy. *(Dennis Schroeder / National Renewable Energy Laboratory)*

TOUGH STUFF
EXTREME MATERIALS
for ***EXTREME CHALLENGES***

If you're going to make bombs, and you want them to perform predictably and reliably, then you want to know how the materials they are made of behave under extreme conditions. Metals such as steel or aluminum or plutonium are not uniform throughout: they have microstructure—various ways the metal grains are connected at the microscopic level. And it is the microstructure that determines their behavior—how they deform in an explosion or an automobile collision, how they fail at high temperatures. The microstructure, in turn, is influenced both by the composition of the material, by how it is processed or formed into useful parts, and by how the material ages.

A B61-12 gravity bomb, part of the U.S. nuclear weapons stockpile, undergoing tests. *(Sandia National Laboratories)*

Transforming
THE CHEMICAL INDUSTRY

There are huge reservoirs of oil in the deep waters of the Gulf of Mexico. Retrieving that oil safely presents very substantial challenges. Yet today a major oil company is poised to lower a string of pipe 7,000 feet down to the bottom of the Gulf to start pumping that oil, which comes out of the seabed at very high temperatures. The steel pipe is coated with a unique insulating layer, a type of plastic with remarkable properties: it can safely cope with oil at temperatures as high as 390°F while surrounded by water at temperatures close to freezing. The insulating plastic also protects the outside of the pipe from the corrosive effects of the seawater.

The special plastic or polymer is made from chains of organic (carbon-based) molecules that do not occur in nature. Rather they are synthesized by a powerful chemical process, which in addition to specialized plastics has also found application in the food industry, in the pharmaceutical industry, in agricultural chemicals, and even in novel biorefineries that transform natural products such as palm oil into chemicals and fuels. The result is a much more powerful toolkit for synthesizing new organic molecules, especially those known as *olefins* that contain double bonds between carbon atoms. This widespread industrial impact would not have occurred without long-term support for the underlying science from DOE's Basic Energy Sciences (BES) office and other federal agencies.

Drilling rig used for oil exploration and recovery. It lowers drill strings and specialized oil recovery pipe as much as 7 miles down to the seabed in the Gulf of Mexico. *(Credit: mikeuk / iStock)*

NANOSCIENCE
How to Invent a Whole New Field

In 1959, the famed physicist Richard Feynman gave a lecture that proved unusually prophetic. In it, he declared that there was "plenty of room at the bottom," meaning there were huge opportunities for new science and important new technologies by exploring and manipulating materials almost literally atom by atom. Today that "room at the bottom" is called nanoscience, and is an important part of research in physics, chemistry, materials science, and biology. Moreover, you can literally see the impact of this research on TV. The current generation of video screens made by Samsung, Sony, and others use a U.S.-developed nanotechnology called *quantum dots* to create very high-resolution images with increasingly precise, vivid colors.

But there wasn't a clear path leading from Feynman's vision to a well-developed area of science and to commercial technologies now embedded in a growing number of industrial, military, and consumer products. Rather it required a mix of discovery, strategically planned basic research, and both government- and industry-supported applied research. As the semiconductor industry pushed to make transistors and other electronic components ever smaller, for example, they eventually reached the nanoscale regime—smaller than 100 nanometers. At such scales, 1,000 times smaller than the width of a human hair, materials behave quite differently. The industry had to develop ways to understand and cope with these behaviors.

Quantum dots are tiny semiconductor crystals less than 100 atoms in width, yet this nanotechnology makes greens and reds pop on quantum dot displays (left) compared with conventional LCD displays (right). *(Nanosys, Inc.)*

CLEANING UP
NUCLEAR WASTES

Environmental management is a key DOE mission, in large part because five decades of nuclear weapons production and nuclear energy research have left behind huge quantities of radioactive waste. To make matters worse, large quantities have leaked from underground storage tanks into surrounding soils. DOE has already spent many billions of dollars in cleanup efforts and is expected to spend much more. Thanks to two decades of research supported by DOE's Basic Energy Sciences (BES) office, however, there is now an elegant new cleanup technology that will speed up the process and save over a billion dollars. Furthermore, science supported by BES has greatly improved the ability to assess the remaining risks and predict subsoil migration of leaked waste.

Double-shell tanks being built in 1978 at Savannah River, South Carolina, to store radioactive nuclear waste. *(U.S. DOE)*

HOW ONE SCIENTIST CAN MAKE A DIFFERENCE

Millie Dresselhaus died last year a much-honored legend. She was the first woman to become a tenured full professor at MIT and the first woman to win the National Medal of Science in engineering, among many other firsts. She was a pioneer in what is now called nanoscience, predicting the existence and fundamental properties of carbon nanotubes, studying their properties, and enabling the development of a field that has impact across the science spectrum, from high-strength materials to cancer biology. She also helped develop the science of thermoelectric energy conversion—bringing nanoscience approaches that enabled noiseless cooling systems for nuclear submarines, among other applications. Her stature and impact in the field of nanoscience was unmatched—from her scientific contributions to her leadership roles and her mentoring of young scientists. But none of those accomplishments were obvious from her beginnings.

Dr. Millie Dresselhaus early in her career as an engineering professor at the Massachusetts Institute of Technology. *(MIT)*

Transforming
BIOLOGICAL SCIENCE *and* BIOMEDICAL PRACTICE

In 2016, more than 53,000 people in the United States died from overdoses of opioid drugs. Many of these were illegal narcotics such as heroin and fentanyl. But the underlying cause of this epidemic is generally agreed to be widespread legal use (and perhaps over-prescribing) of opioid drugs such as oxycontin to control pain. People using such drugs develop a tolerance, meaning that they eventually need more of the drug to achieve the same effect and often turn to cheaper but more powerful illegal drugs such as fentanyl, which is 50 times more potent than heroin.

The epidemic of opiod overuse—both prescription medicines and illegal drugs—has become a national public health crisis. New understanding of how opioids and other drugs attach to and interact with cells may make possible medicines that stop pain but are neither addictive nor suppress breathing. *(karenfoleyphotography / Shutterstock)*

SHARED RESEARCH FACILITIES
A Key Source of U.S. Scientific and Industrial Leadership

In the aftermath of World War II, DOE and its predecessors built nuclear reactors used as research tools by nuclear engineers and high energy electron accelerators used by physicists to study the properties of sub-atomic particles. Before long, however, other scientists began to think of ways to use these facilities to study ordinary materials: tapping the neutrons produced in a reactor core or manipulating electron beams to create intense X-rays. Soon a few scientists gained permission to "borrow" access to these facilities and extract beams of neutrons or X-rays to interact with the materials they wanted to study. The results were spectacular. It rapidly became clear that such probes could provide insights into the detailed physical and electronic structure of materials that were not obtainable in any other way—including materials essential for national security as well as those used in all forms of energy production.

Electrons accelerated to almost the speed of light by a linear accelerator are then run through a gauntlet of magnets (shown here) that force the electrons to zigzag violently and give off extremely intense X-ray pulses that are used to study material properties and other phenomena. *(SLAC National Accelerator Laboratory)*

MAKING
SUPERCONDUCTIVITY ***USEFUL***

When you make a video call or watch NFL game highlights on your smart phone or other mobile device, the microwave signals between your phone and the mobile base station must transfer millions of bits of data while contending with the signals from thousands or tens of thousands of other users. A critical part of the technology that enables the base station to sort out each signal and keep your Apple Facetime call from interfering with someone else's Instagram post or Google query is a tiny superconducting microwave filter cooled to temperatures more than 300°F below freezing.

Superconducting microwave filters in cell phone towers enable high speed transmission of many signals without interference. *(Vlad Teodor / Shutterstock)*

The *HIGH-STAKES RACE* in
HIGH-PERFORMANCE COMPUTING

Bragging rights to the world's fastest computers have belonged to China for the past several years, with the U.S. seeming to slip behind. This matters, because so many areas of science and industry now depend on very fast computers. These include modeling combustion processes for improved engine design, predicting the properties of novel materials, and maintaining national security. Increasingly, academic and industrial scientists also depend on high-performance computing to help analyze masses of data from X-ray probes of complex molecules or other data-intensive areas of research including artificial intelligence.

The Department of Energy is now funding development of the next generation of U.S. supercomputers—so-called exascale computers because they will be able to perform a billion billion computations per second. These computers may enable the U.S. to regain the lead from China, but it turns out that raw computing speed is not the only thing that counts. Today's supercomputers attain their speeds by employing hundreds of thousands of separate processing units that work in parallel. And for the kinds of practical applications mentioned above, it is specialized software that enables effective use of these computers—software that must divide up a computational problem into many different parts, dole out those pieces to different processors, and reassemble the answers to give a useful result. And thanks in part to early support from the Basic Energy Sciences (BES) office of DOE, the U.S. leads in developing software for such massively parallel computers.

The Summit supercomputer nearing completion at Oak Ridge National Laboratory in Tennessee will have more than 36,000 separate processor units operating in parallel and is expected to process some 200 million billion operations per second. *(Oak Ridge National Laboratory)*