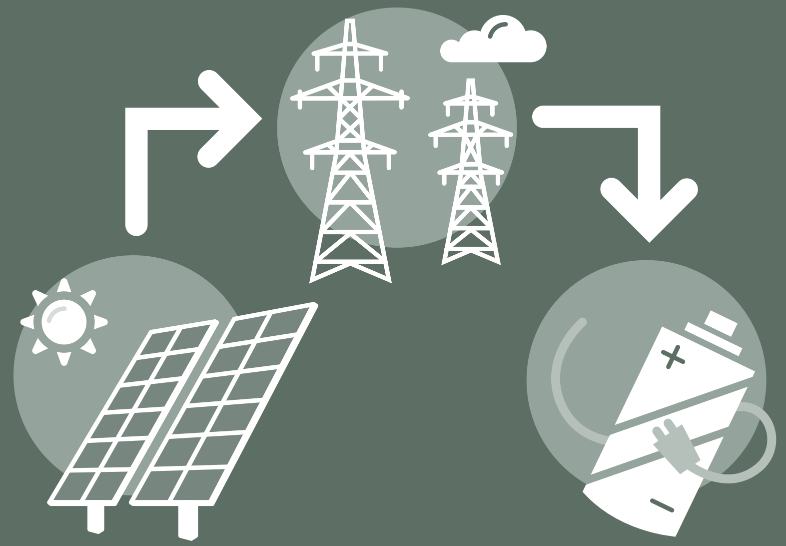
SIMES

Stanford Institute
for Materials
and Energy Sciences

Energy solutions through materials science

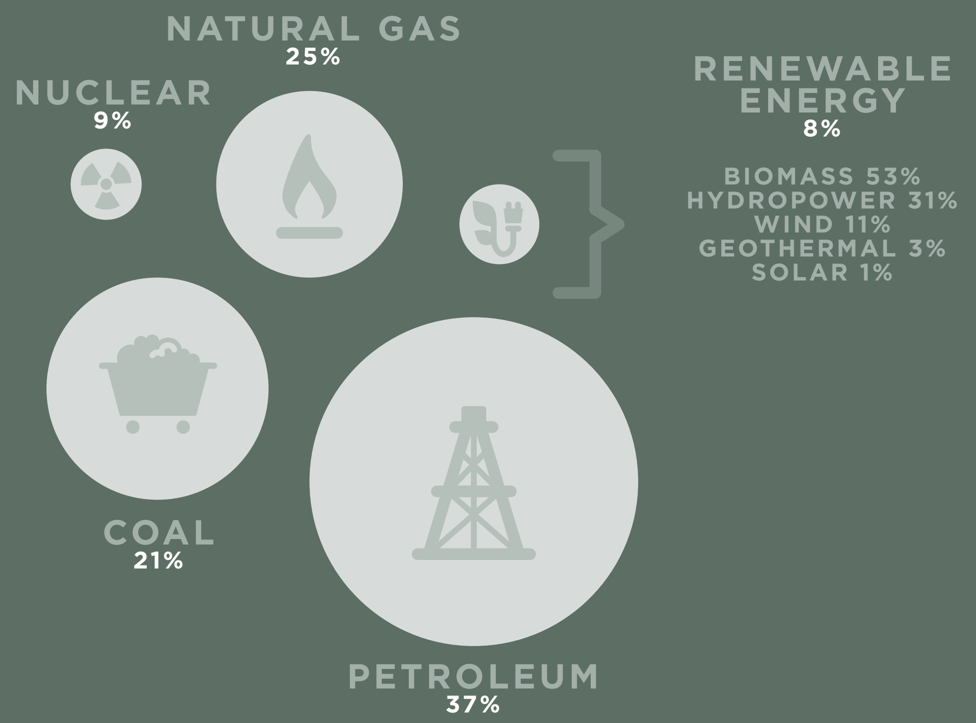
The Earth's night lights recorded by U.S. Department of Defense meteorological satellites.
Credit: NASA/GSFC/Craig Mayhew and Robert Simmon



We face an energy crisis

In the long term, we will solve this crisis by inventing new technologies. SIMES conducts the basic materials science research needed to discover technological solutions to today's problems of energy generation, storage, transmission and efficient use.

U.S. ENERGY CONSUMPTION BY SOURCE, 2009



Electricity generation

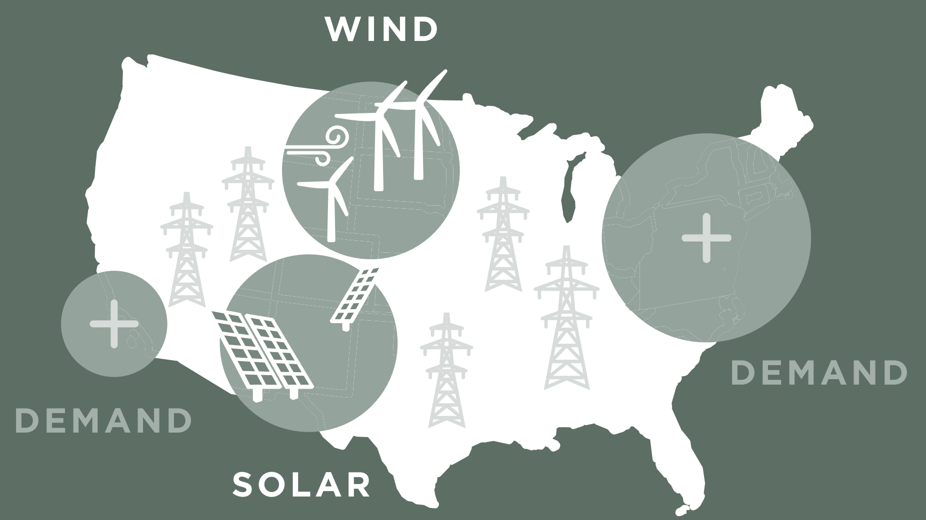
Currently, the cheapest way to generate energy is by burning coal. Solar energy, a truly renewable energy source, is not yet cost-competitive with coal power generation. SIMES is probing the basic science that will model and design the innovative materials needed to harness solar power. These new materials will make solar cheaper than coal while minimizing environmental and sustainability concerns.

The major cost of solar energy is construction of solar power plants.
Credit: Digital Vision

Steam and smoke billow from smokestacks of the coal-burning Navajo Generating Station outside Page, Arizona.
Credit: Ed Darack

Solar power produced in the Nevada desert needs to be transported to Los Angeles.
Credit: Jason Hawkes

Skyscrapers in downtown Los Angeles at night.
Credit: Allan Baxter



Energy transmission

Power cannot always be generated locally and efficiently. We envision a future in which energy can be transported from places of high production to places of high demand without a loss of electrical power. If room-temperature superconductivity can be discovered in the lab, we will be able to transport energy with no loss of power whatsoever.

CHEAPER SMALLER FARTHER

Energy storage

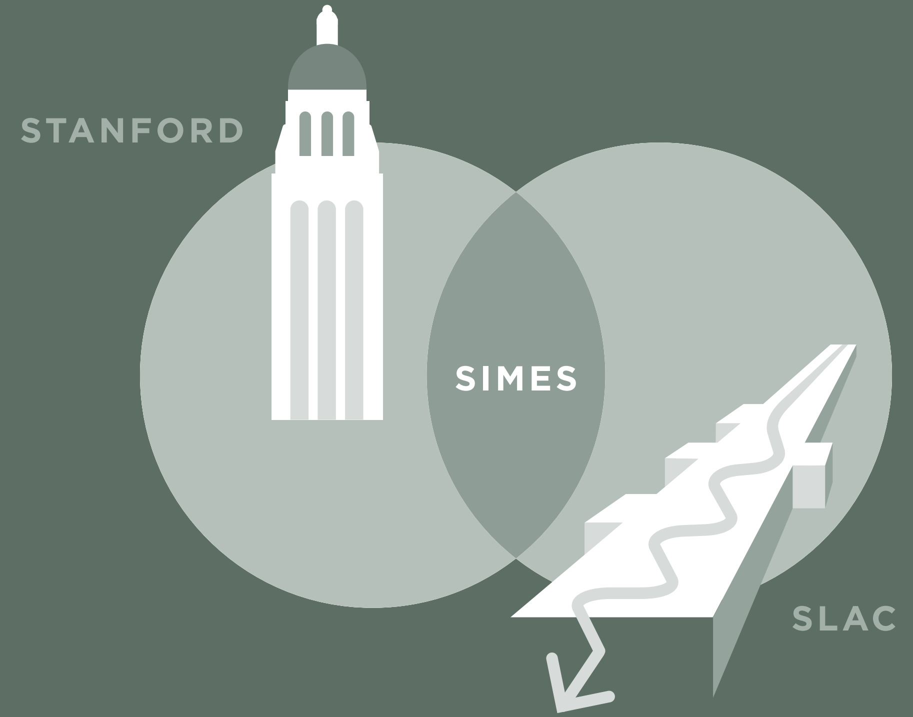
Once we collect energy in an efficient way, we still need to store it, often relying on batteries. Battery technology has lagged behind other technologies, with only slight improvements each year. Our science will lead to new materials that can double battery storage capacity, making batteries lighter, more efficient, and cheaper to use.

Electric car being charged.
Credit: Lucy Claxton

Driver stuck in Los Angeles freeway traffic.
Credit: Car Culture

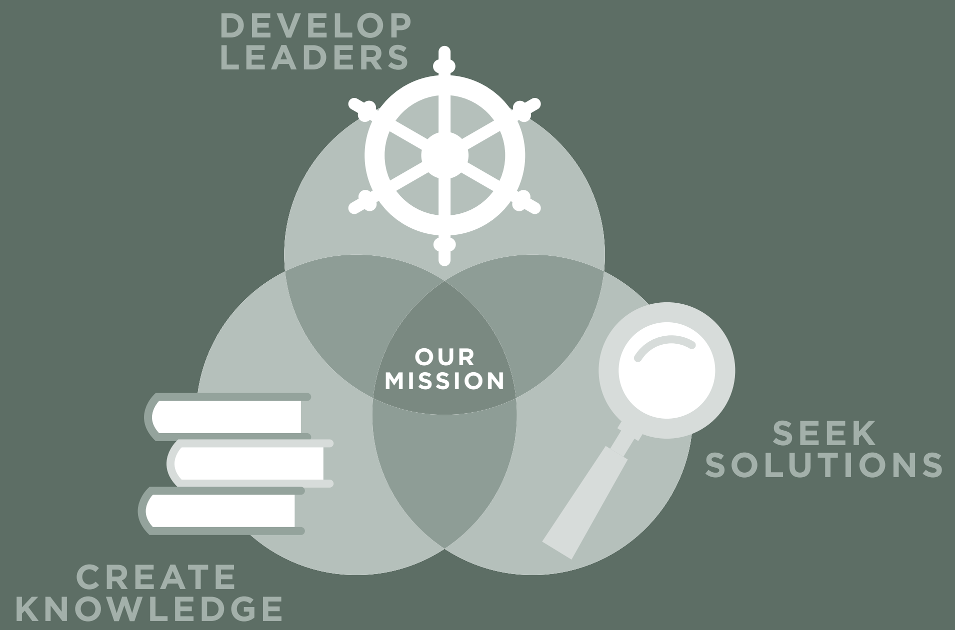
Stanford University is home to more than a dozen multi-disciplinary energy programs.
Credit: Stanford University

The klystron gallery of the 2-mile long linear accelerator at SLAC.
Credit: Peter Ginter



Stanford and SLAC

SIMES sits at the intersection of Stanford, a world-leading university, and SLAC National Accelerator Laboratory, a U.S. Department of Energy national laboratory. As a joint institute of Stanford and SLAC, SIMES brings a combination of intellectual resources and first-class experimental facilities to bear on the energy and security challenges facing our nation and the world.

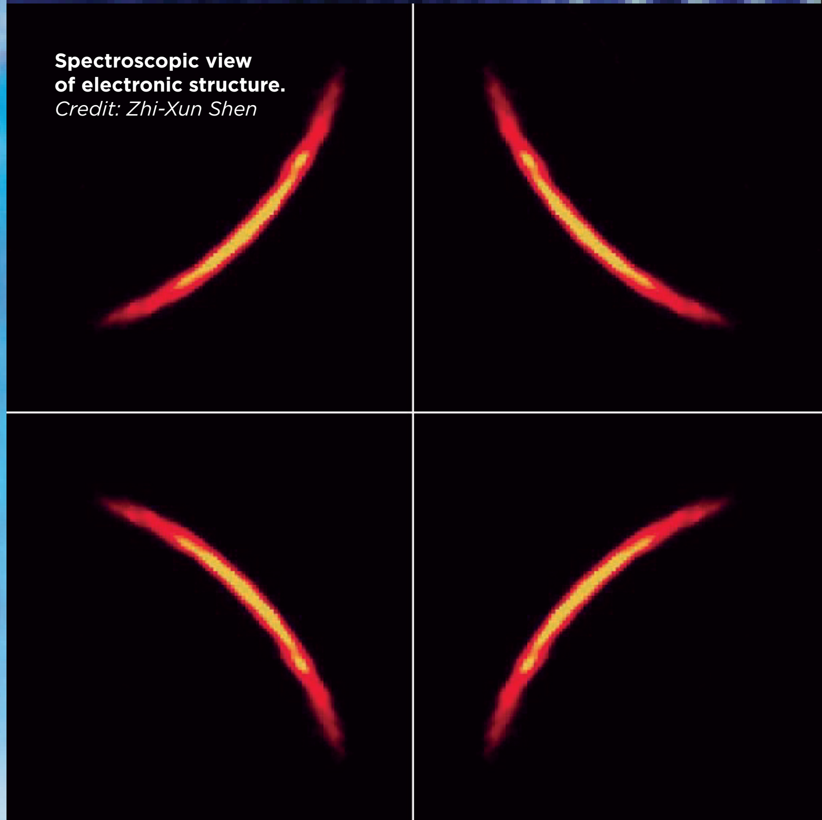


SIMES and solutions

SIMES is conducting groundbreaking research on a number of fundamental and applied energy problems using breakthroughs in physics, materials, chemistry, and ultrafast phenomena in novel ways. Our core mission is to address grand challenges in the science of energy-related materials, to create knowledge, to develop leaders, and to seek solutions.

A magnet levitating above a high-temperature superconductor.
Credit: Los Alamos National Laboratory

A nanoscale image of the surface of a high-temperature superconductor, revealing atomic superstructure.
Credit: Hari Manoharan



Spectroscopic view of electronic structure.
Credit: Zhi-Xun Shen

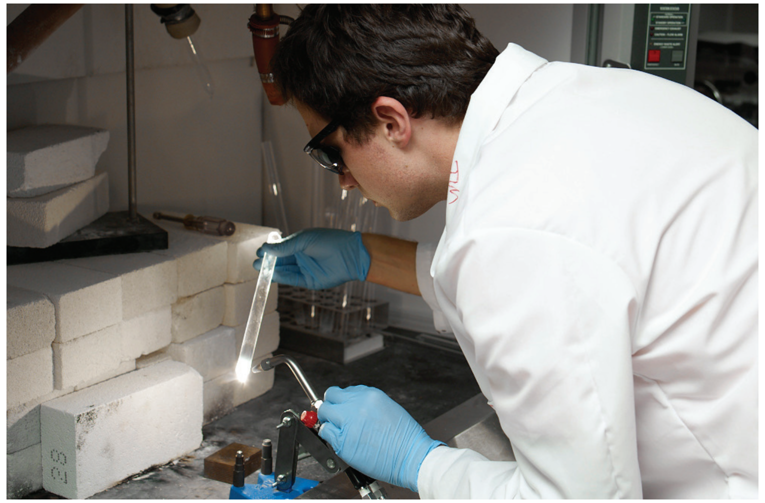
Our approach

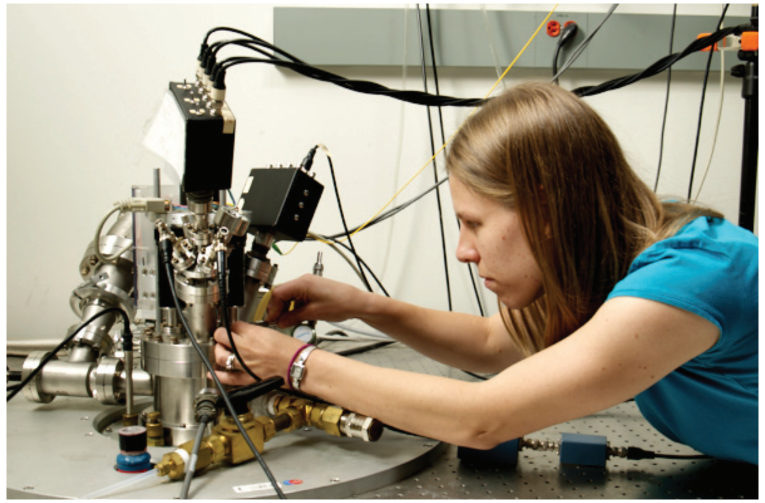
- Synthesize new materials, guided by scientific insights and theory or modeling.
- Characterize the materials in an effort to understand their properties and their behavior.
- Build and test devices made from the materials to exploit their novel properties.
- Use our discoveries to design a new generation of materials.

Key questions

1. Why do new types of electronic materials, based on the unusual properties of quantum physics, exhibit amazing properties beyond what is expected?
2. How can we design and synthesize materials, both physically and biologically inspired, that exhibit these transformative new quantum properties for energy applications?
3. What are the key pathways to turn energy from the sun's rays into electricity that can be stored and transported?
4. How can we measure, probe, and simulate the ultrafast processes that drive the new science and technologies we need for an energy revolution?

To answer our four key science questions, we divide our research program into four areas.





Q Why do new types of electronic materials, based on the unusual properties of quantum physics, exhibit amazing properties beyond what is expected?

Properties of Quantum Materials

Materials studied in the "quantum realm" or at the nanoscale exhibit unique properties not seen at the macro level. By understanding the structure of electrons in materials, we can deduce how new materials might work under different conditions. We measure and compute their properties—often using the intense X-ray beams available from SLAC's light-sources—to see whether our predictions are accurate and whether we can put our new materials to novel uses.

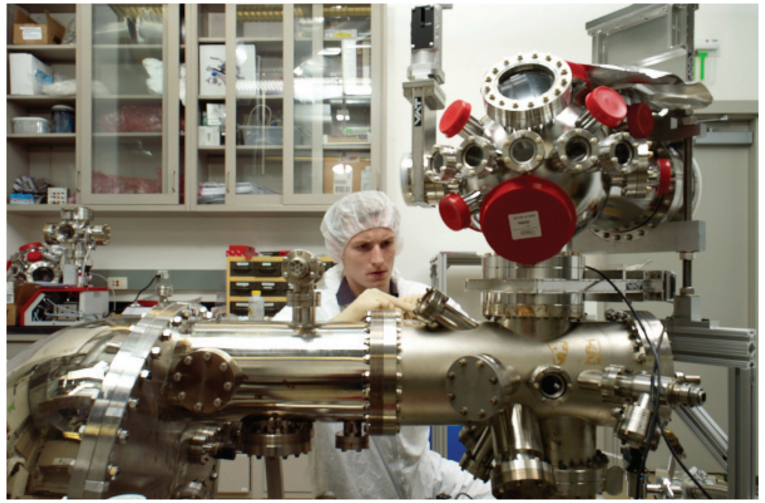
For example, we use a combination of characterization tools to understand the interplay between charge, spin and orbital degrees of freedom of new materials.

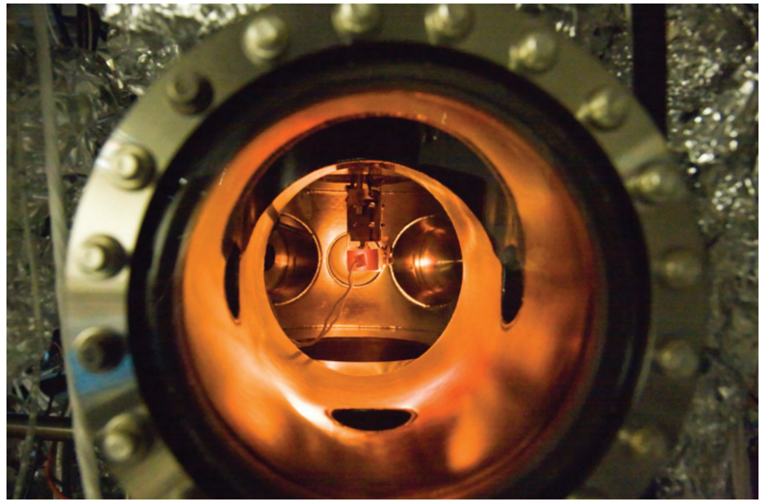
This research leads to a deeper understanding of the behavior of electrons in solids. Harnessing these effects has the potential to transform the next generation of electronic materials.

Programs

- Electronic and Magnetic Structure of Quantum Materials
- Correlated Materials—Synthesis and Physical Properties
- Spin Physics
- Atomic Engineering Oxide Heterostructures: Materials by Design
- Topological Insulators

LEFT: Sealing an evacuated quartz tube with a torch to grow samples in a vacuum and under high temperature.
RIGHT: Preparing the Magnetic Force Microscope (MFM) to investigate correlated materials.
Credit: Stanford University





Q How can we design and synthesize materials, both physically and biologically inspired, that exhibit these transformative new quantum properties for energy applications?

Organic and Bio-inspired Materials

Nature has already solved many engineering challenges. We look to nature's solutions to create new materials either inspired by, or actually using, biological and organic material.

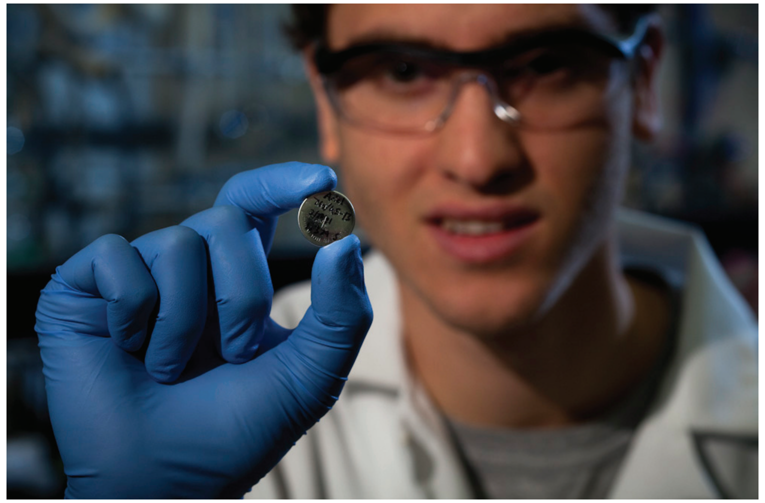
For example, diamondoids are tiny clusters of carbon atoms with the same structure as diamond and can be made easily and cheaply in the lab. Whether produced as a crystal, thin film, or nanowire, diamondoids may prove ideal for a number of applications, enabling scientists to control electron transport and energy flow at the nanoscale.

Other SIMES research explores how basic polymer and protein building blocks that exist in nature can be used as templates for creating hybrid materials. These materials can lead to fundamentally new designs in bio-inorganic devices for energy storage, catalysis, solar cells, and fuel cells.

Programs

- Clathrin Biotemplating
- Diamondoid Science and Applications

LEFT: Constructing vacuum components for use in an experimental chamber.
RIGHT: Glowing sample heater in an ultra-high vacuum chamber.
Credit: Stanford University



Q What are the key pathways to turn energy from the sun's rays into electricity that can be stored and transported?

Energy Conversion and Storage

Many of the processes that convert energy from one form to another occur at the interface between materials. By tailoring those interfaces, we can make energy conversion more effective and potentially create new devices for energy storage.

Solar cells work by converting the energy of light hitting their surface to electrical pulses in their interior. Modifying the surfaces of these cells—by adding advanced energy conversion dyes or nanoscale texturing, for instance—allows them to capture more light for conversion to electricity.

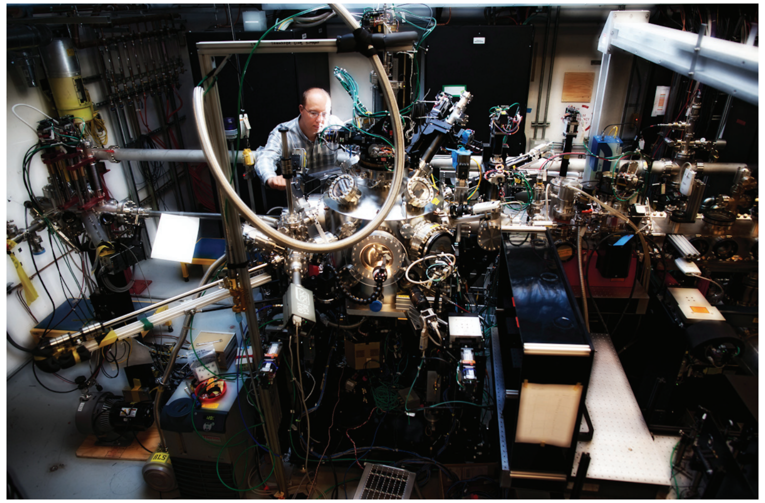
Once that electricity has been generated, it needs to be stored. Batteries have always relied on the physical separation of electrodes as their foundational structure. Higher density of energy storage might be available when we modify the internal materials and architecture of batteries. For example, we might use cheap, flexible nanowires instead of conventional bulk size particles as cathodes and anodes.

These are the kinds of questions we can now ask and approaches we can pursue as we search for better energy conversion and storage.

Programs

- Interfaces and Catalysis for Energy Conversion and Storage
- Designing Nanomaterials for Energy Storage
- Organic Photovoltaics
- Plasmonics for Energy Detection and Conversion
- Photon Enhanced Thermionic Emission

LEFT: **Students construct battery cells in the lab to test new materials for the next generation of energy storage.**
RIGHT: **Batteries undergo extensive performance testing. Many cells are tested in parallel to speed identification of the best chemistries and nanostructures.**
Credit: Bradley Plummer



Q How can we measure, probe, and simulate the ultrafast processes that drive the new science and technologies we need for an energy revolution?

Ultrafast Photonic and Electronic Processes

Electronic processes often happen at ultrafast speeds—too fast to observe with conventional tools. Now, with the advent of the Linac Coherent Light Source X-ray laser and by using other high-speed lasers, we can observe the dynamics of complex materials under operating conditions. We are especially interested in "emergence", the complex patterns, interactions, and systems that arise at the atomic level. By disentangling all the different phenomena that occur at these ultrafast speeds, we can build new materials that exploit the same phenomena in different ways.

Key processes for investigation are those that involve energy conversion, transport, and storage, such as how a light pulse is converted into an electrical signal. These fast processes pervade electronics and also control how well information can be stored in computer systems, for example. With an understanding of ultrafast photonic and electronic processes, we will be able to make faster and more efficient components for use in computers and other systems.

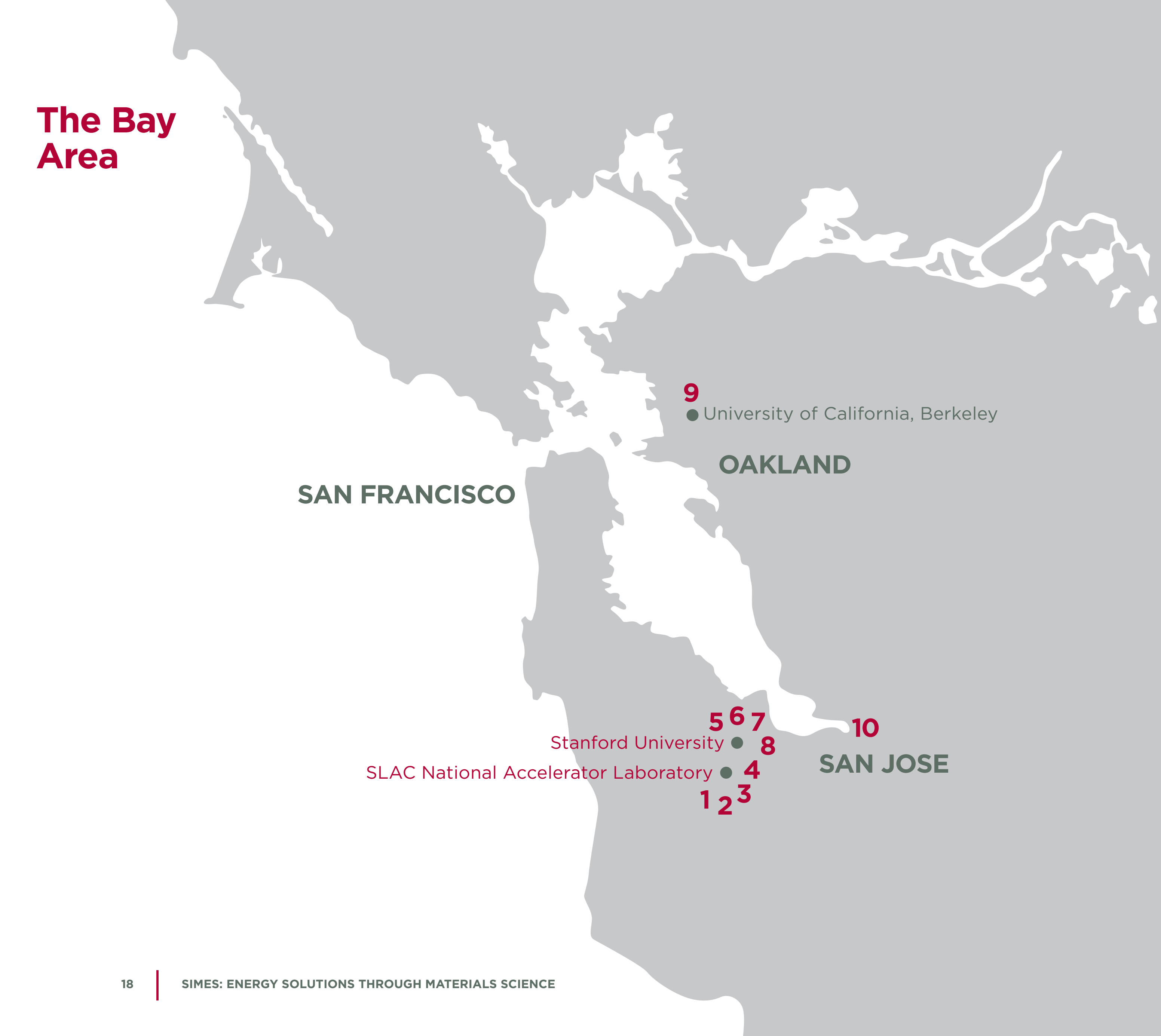
Programs

- Time Dynamics of Oxides and Related Materials
- Magnetization and Dynamics

LEFT: **The "undulator hall" at SLAC's Linac Coherent Light Source X-ray laser facility houses long arrays of special magnets used to generate powerful X-rays.**
RIGHT: **The Resonant Soft X-ray Scattering endstation at the Linac Coherent Light Source is used to look at how electrons move and behave in exotic materials such as high-temperature superconductors.**
Credit: Bradley Plummer

A cross-disciplinary institute such as SIMES requires the partnership of other institutions. To this end, SIMES has created research links with key partners at SLAC and Stanford, and in private industry.

The Bay Area



SLAC Campus

1 **THE LINAC COHERENT LIGHT SOURCE (LCLS)**
SLAC's ultrafast X-ray laser that can observe new quantum materials in action.

2 **THE STANFORD SYNCHROTRON RADIATION LIGHTSOURCE (SSRL)**
SLAC's X-ray facility that can determine the structure, and thereby function, of a wide range of new materials.

3 **THE CENTER FOR SUSTAINABLE ENERGY THROUGH CATALYSIS (SUNCAT)**
A new initiative that focuses on creating better catalysts for use in alternative energy industries.

4 **THE PULSE INSTITUTE FOR ULTRAFAST ENERGY SCIENCE**
A Stanford/SLAC institute providing world leadership in ultrafast and short wavelength science and technology, using LCLS as a primary tool.

Stanford University Campus

5 **THE GEBALLE LABORATORY FOR ADVANCED MATERIALS (GLAM)**
An independent Stanford laboratory that supports interdisciplinary education and research on advanced materials.

6 **THE PRECOURT INSTITUTE FOR ENERGY (PIE)**
A broad-ranging interdisciplinary Stanford program of research and education on environmentally and economically acceptable energy use and policy.

7 **THE WOODS INSTITUTE FOR THE ENVIRONMENT**
A Stanford institute that harnesses the expertise and imagination of leading academics and decision makers to create practical environmental solutions for people and the planet.

8 **THE CENTER ON NANOSTRUCTURING FOR EFFICIENT ENERGY CONVERSION**
A DOE Energy Frontier Research Center at Stanford that researches and characterizes materials at the nanoscale with the aim of advancing basic design principles for next generation batteries, capacitors, fuel cells, and solar cells.

Industry

9 **THE BAY AREA PHOTOVOLTAICS CONSORTIUM**
A Department of Energy SunShot initiative between Stanford, the University of California, Berkeley, and industry that addresses technical barriers to the solar power industry and how to reduce the cost of solar installations.

10 **KLA-TENCOR**
The world's leading supplier of process control and yield improvements for the semiconductor and related microelectronics industries.

SIMES' role at SLAC and Stanford

SIMES is the Materials Sciences Division of SLAC and forms a fundamental component of SLAC's program of energy science. SIMES relies on SLAC's world-class light sources, the SSRL and LCLS, to explore the properties and behaviors of its novel materials.

SIMES also lives within Stanford University, whose faculty, scientists, and visiting scholars provide the guidance and intellectual community needed to drive our vision and educate the next generation of scientific talent.

This union between a leading university and a national laboratory enables SIMES to form unique research partnerships and exchange technologies with other national and international universities, national laboratories, and private industry.

SIMES is still a young institute but we will expand, serving the DOE mission and Stanford's strategic plans through basic science research and development. We will:

- develop the new tools needed to push the frontiers of energy and materials sciences,
- expand our world-leading X-ray materials science program,
- solidify our leadership position in the study of novel quantum matter,
- become a center of excellence in materials discovery, design, and synthesis, and
- leverage Stanford's expertise in bio-inspired and organic materials.

With a strong and growing program, SIMES is taking a leadership role in the science of new materials, enabling a future of energy advances.

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Designed and produced by Sandbox Studio, Chicago

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