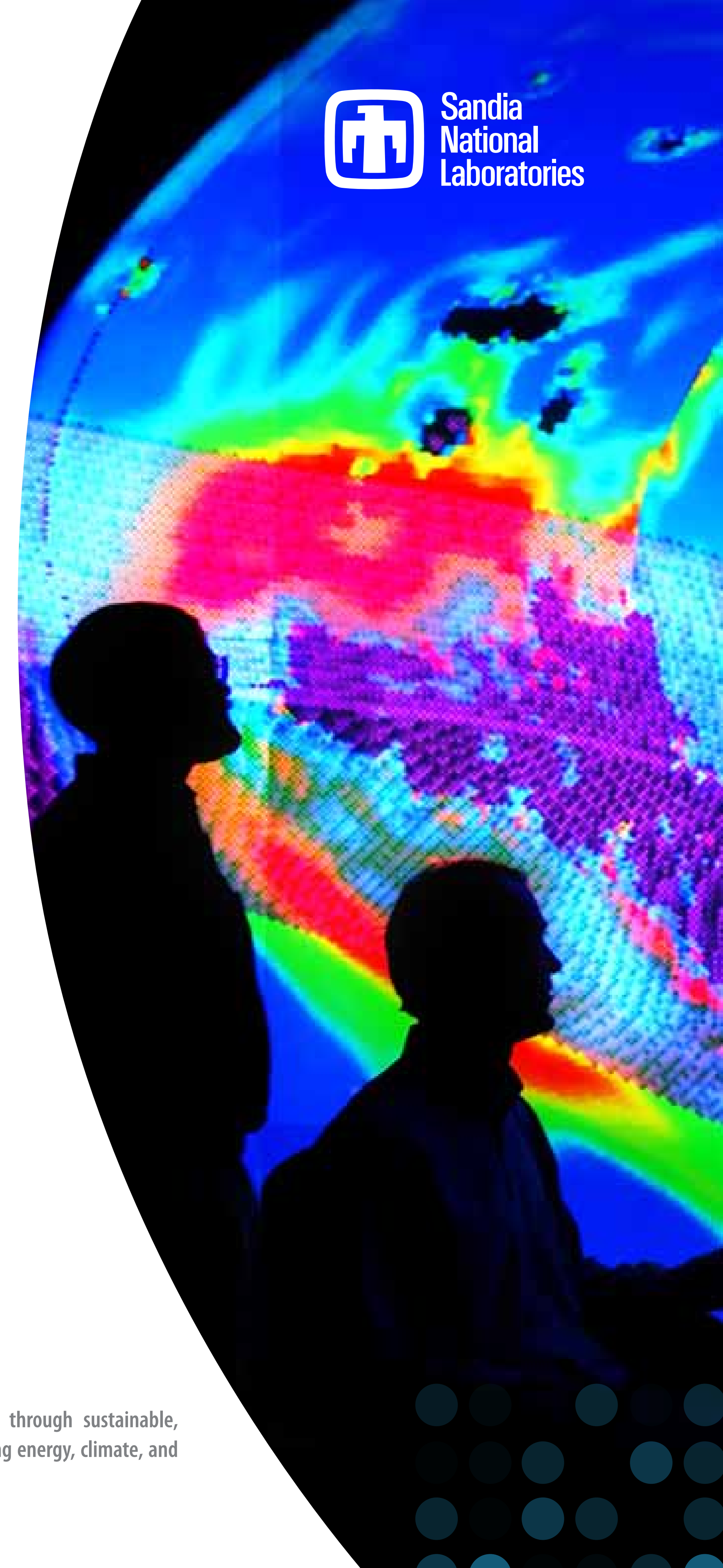

Sandia National Laboratories

Energy, Climate, & Infrastructure Security

FY11–14 STRATEGIC PLAN

Enhancing the nation's security and prosperity through sustainable, transformative approaches to the most challenging energy, climate, and infrastructure problems.

Message from the VP

Access to reliable, affordable, and sustainable sources of energy is essential for all modern economies. Since the late 1950s, we Americans have not been energy self-sufficient. Our addiction to foreign oil and fossil fuels puts our economy, our environment, and ultimately our national security at risk. Furthermore, there is a growing recognition of the requirement to balance our need for plentiful, low-cost energy, with an inherent responsibility to steward the natural environment. The U.S. does not face this challenge alone. As the world continues to become more connected, our collective futures are inextricably linked, and energy lies at the core of global interactions. Meeting our growing energy needs and how we manage the impacts on climate change will have profound ramifications on the global economy and ultimately on global geopolitical stability.

Sandia has a long history addressing the nation's energy challenges, beginning in the 1970s when our nation initiated its push towards energy independence. In 2010, Sandia combined programs in energy, climate, and infrastructure to create a new strategic management unit (SMU) that better leverages and integrates these three interrelated missions. Today, Sandia science and engineering expertise derived from our nuclear weapons heritage supports programs in solar and wind power for electricity generation, combustion science, nuclear repository design, and others. In FY10, our programs totaled approximately $300M and include national and international activities supported by three federal agencies and industry.

The Energy, Climate, and Infrastructure Security (ECIS) SMU leads and manages this mission area. Our heritage as a national security laboratory brings a unique perspective to addressing the new challenges and opportunities outlined by President Obama and the current administration. "Each of us has a part to play in a new future that will benefit all of us. As we recover from this recession, the transition to clean energy has the potential to grow our economy and create millions of jobs—but only if we accelerate that transition." (President Obama, June 15, 2010).

In this document you will see that we have developed a strategy that provides a roadmap for Sandia's research and development priorities: to accelerate development of reliable, affordable, and sustainable sources of energy; to be prepared for and understand potential consequences of climate change; and to ensure a safe, secure, and reliable energy delivery infrastructure. Combined together, these address the three main national challenges recently highlighted by the President's Council of Advisors on Science and Technology (PCAST), e.g., economic competitiveness, the environment, and energy security.

Looking toward the future, our success in serving the nation in the energy area continues to rely on our workforce. My vision for Sandia is to continue to build and sustain a diverse workforce composed of individuals who know that they are an important part of Sandia because they are valued, included, treated with respect and dignity, and are fully productive contributors to mission success.

Rick Stulen, Vice President
Energy, Climate, & Infrastructure Security SMU

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U.S. DEPARTMENT OF ENERGY

NNSA

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2011-4820 P. TRC.7.2011.

Executive Summary

Strategic Framework

The Energy, Climate, and Infrastructure Security (ECIS) Strategic Management Unit (SMU) Strategic Plan documents the long-range planning process to define its vision, objectives, goals, and portfolio of research to support Sandia's national security mission.

Our strategy is based on our role as a national security laboratory to address the nation's most daunting science and technology challenges within the national security context. Our plan is informed and guided by the five Sandia Laboratory objectives:

- Deliver with excellence on our commitments to the unique nuclear weapons mission
- Amplify our national security impact
- Lead the complex as a model 21st century government-owned contractor-operated laboratory
- Excel in the practice of engineering
- Commit to a learning, inclusive, and engaging environment for our people

Within this context, the objectives and goals developed by this SMU seek to both leverage and enhance key competencies associated with our nuclear weapons mission in order to amplify our contributions to broader national security in energy, climate, and infrastructure. The work of ECIS aims to further our engineering excellence with an emphasis on connecting deep science to engineering solutions. Finally, all of our work will be conducted in a manner that puts people first, assures the safety and health of employees and the public, protects the environment, and guards classified and other sensitive information.

The vision and set of enduring ECIS objectives described in this plan are congruent with foundational Sandia competencies built over decades. These competencies grew out of our historic mission in nuclear weapons and a synergistic environment in which capabilities and expertise from our complementary missions support and strengthen one another. Ultimately, our mission is to enhance the security of the nation. In this SMU, due to the nature of the mission, the private sector has a unique and important role that is reflected in our objectives, because it is there that most energy and infrastructure technologies and solutions are deployed. Our overarching objectives are driven by both our historical contributions as well as our fundamental role for the government as a national laboratory. These objectives are as follows:

- Anticipate and enable government policy and regulatory decisions
- Steward competencies to support inherently government functions and services
- Accelerate private sector deployment of solutions to meet U.S. policy objectives
- Support U.S. international engagement to solve national security challenges

As we developed our strategy and plan from these objectives, we faced the unique challenge that the nation does not currently have a well-articulated energy policy nor does the Department of Energy (DOE) have an enduring set of priorities and roadmaps that provide high-level integrated guidance. The DOE is now engaged in a Quadrennial Technology Review process, to which Sandia has contributed, to develop a framework that, in the future, we will be able to use for such guidance. While this is not yet available nor are clear governmental policies and priorities complete, there is general consensus at the national, regional, and state level on the most significant problems and challenges to our national security in this area. In our planning process, we reviewed these challenges and selected a set of seven national-level problems across the energy, climate, and infrastructure sectors that reflect our priorities and guiding framework. These are

- Reduce our dependence on foreign oil
- Increase deployment of low-carbon stationary power generation
- Understand risks and enable mitigation of climate change impacts

- Provide the foundation for a future global climate treaty
- Increase security and resiliency of the electrical grid and energy infrastructure
- Assure energy security for critical installations
- Strengthen the nation's science & technology (S&T) base in energy, climate, and infrastructure

From these challenges, we then created a set of five-year, outcome-focused goals that are consistent with our national laboratory role, our unique competencies, and our objectives. Each of these is described more fully in the following sections.

40 years of Sandia Contributions to the Nation's Energy Challenges

No modern nation is secure without an adequate supply of safe, assured, affordable, and environmentally sound forms of energy. Sandia's national security mission has driven the development of a broad range of programs in the energy area. These programs are built on the expertise and capabilities of Sandia's nuclear weapons legacy and continue to synergistically benefit from and strengthen this ongoing heritage.

The energy crisis of the 1970s was the catalyst of Sandia energy programs. For example, Sandia's strength in combustion science was directly stimulated by the oil crisis and has grown to a world-leading program. Results of this work have significantly improved internal combustion engine fuel efficiency through long-standing partnerships with automotive manufacturers. The Combustion Research Facility (CRF), a DOE Office of Science (SC) collaborative facility, was established in 1980 to bring together basic and applied research to improve the nation's ability to use and control combustion processes. A collaboration of CRF and modeling/simulation researchers with Cummins resulted in a 2007 diesel engine designed solely with computer modeling and analysis tools. Cummins achieved a 10%–15% reduction in development time and cost as they achieved a more robust design, improved mileage, and met all environmental and customer constraints.

During this same period, Sandia scientists and engineers established programs to support the Nuclear Regulatory Commission by providing independent technical expertise in nuclear reactor safety and reliability. Over 30 years of research into severe accident phenomenology has resulted in Sandia's MELCOR (Methods for Estimation of Leakages and Consequences of Releases) code which is now the preeminent tool to model severe accident progression in light water reactor power plants. It is being applied today as a key element of the U.S. support to Japan's Fukushima reactor crisis.

Sandia's programs in renewable energy were also initiated in the 1970s. Capabilities to model wind turbine blade configurations in a range of wind conditions and to predict their fatigue life were developed. Through partnering with universities and industry, Sandia has worked to advance the state of knowledge in the areas of materials, structurally efficient airfoil designs, active-flow aerodynamic control, and sensors. Sandia continues its applied research to improve wind turbine performance, reliability, and reducing the cost of energy and has participated in all aspects of wind-turbine blade design, manufacturing, large-scale testing, and system reliability.

Sandia has played a key role in developing solar technologies for commercial power-plant use. We have had responsibility for the materials-science work and computer codes that enable advanced designs. In the mid-1980s, Sandia partnered to build Solar One, the nation's largest solar power plant. To improve its efficiency, Sandia led an effort to develop molten salt energy-storage technology and proved it capable of operating smoothly through intermittent clouds and generating electricity long into the night. Many of the solar technologies developed at Sandia are being commercially deployed here and across the globe. Complementary work now going on at Sandia and elsewhere could also result in transportation fuels and chemicals from solar thermal technology.

Our concentrated solar power (CSP) research includes dish-Stirling engines—a parabolic-dish reflector with the externally heated Stirling engine. Sandia studied the basic thermodynamics to evaluate the prospects for commercialization. This research resulted in the system called the SunCatcher™—developed in partnership with Stirling Energy Systems (SES) of Phoenix, Arizona. It holds the world's record for solar-to-grid efficiency (31¼%) and has a full-year sunrise-to-sunset efficiency of ~25%—double that of other solar power systems. SES plans to deploy the systems at a utility scale in large fields in southern California.

One of the critical issues with "alternative" power generation is integrating that power into the local utility's network and, ultimately, into the national power grid. During the 1980s, Sandia initiated the Distributed Energy Technology Laboratory to integrate emerging energy technologies into new and existing electricity infrastructures. Sandia's research spans generation, storage, and load management at the component and systems levels and examines advanced materials, controls, and communications to achieve the Lab's vision of a reliable, low-carbon electric infrastructure.

These past successes and future accomplishments rely on our strong foundational science programs. In early 2009, *Science Watch®* published the results of its survey of scientific literature in the energy journals listed in the Science Citation Index. They identified Sandia as the most-cited institution in this research category, with 4,147 citations to its 395 papers published between 1998 and 2008. In the 21st century, Sandia has expanded its energy programs and partnerships to include climate research (because power generation and energy use are primary contributors to climate instability) and energy infrastructure security (because, as we integrate renewable energy power into the national power grid, we must initiate fundamental improvements). As it has since its founding, Sandia is working to provide the foundational science and engineering to underlie the nation's security. The Energy, Climate, and Infrastructure strategic management unit is working toward this goal with regard to our energy future.

National Energy Challenges

Since the late 1950s, we Americans have not been energy self-sufficient. Our addiction to foreign oil and fossil fuels puts our economy, our environment, and ultimately our national security at risk. Furthermore, there is a growing recognition of the requirement to balance our need for plentiful, low-cost energy, with an inherent responsibility to steward the natural environment. With the growth of complexity of our energy supply has come the complexity of our infrastructure and the importance of its resilience and security. The U.S. does not face this challenge alone. As the world continues to become more connected, our collective futures are inextricably linked, and energy and its infrastructure lie at the core of global interactions. Meeting our growing energy needs and how we manage the impacts on climate change will have profound ramifications on the global economy and ultimately on global geopolitical stability. Achieving a sustainable future requires solutions to some difficult national-scale problems. Using our unique competencies and objectives as a guide, we have selected the following national challenges as the framework for determining our goals and milestones.

Reduce our dependence on foreign oil

Transportation by automobiles and trucks accounts for about two thirds of U.S. oil use.[1] In 2009, 60% of the oil consumed was imported and 40% of that comes from unstable states.[2] A certain and significant part of any path toward reducing oil use is to develop more fuel efficient power conversion systems for vehicles. Current DOE program targets are to improve light-duty engine fuel efficiency by 50% and heavy-duty engine fuel efficiency by ~25% over the dominant engines on the road in each respective vehicle class. Such engine fuel-efficiency improvements alone would reduce domestic petroleum consumption by as much as four billion barrels per day. DOE is pursuing advanced biofuel research that will use sustainable biomass (e.g., lignocellulose and algae) that does not compete with food production to generate fuels that are "drop-in" replacements for today's gasoline, diesel, and jet engines. Sandia is a key partner of the DOE-funded Joint BioEnergy Institute (www.jbei.org), a facility that is developing new conversion technologies that will enable the commercialization and deployment of these advanced biofuels that are capable of displacing a significant portion of the ~200 billion gallons of petroleum consumed by the nation's transportation sector annually.

Increase deployment of low carbon stationary power generation

The clean energy sector is undergoing tremendous growth with investments increasing at a 50% annual rate since 2004 and topped $100B in 2007.[3] Policy is playing a central role in this development. Renewable portfolio standards, laws requiring electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date, have been adopted by over 30 states and many countries. For electrical utilities to meet these standards on a large scale, they must build new generating capacity that uses wind, solar, biomass, geothermal, or hydropower.

Understand risks and enable mitigation of climate change impacts

Hazards stemming from greenhouse gas (GHG) emissions are fundamentally different from those of previously identified acid-rain-producing pollutants. Once we curtailed those emissions, natural atmospheric processes neutralized the pollutants relatively quickly and the environment began to recover. Carbon dioxide's effects are more subtle and slower acting, requiring 1,000 years to break the molecule down. Climate instability could create geopolitical disruptions, changing the global balance of power. A sound understanding of the potential socio-economic changes driven by climate is essential. Sandia's extensive competencies in systems analysis and uncertainty quantification couples with our foundational research capabilities to allow us to provide policy makers with usable (properly formulated and properly communicated) information that assists them in understanding these risks.

Provide the foundation for a future global climate treaty

We must develop a deeper understanding of climatic processes and develop the sensors and computational modeling tools that can accurately monitor and account for GHG emissions on a global scale, which will provide the scientific foundation that will make such a treaty both possible and meaningful should the U.S. desire to enter into one. Detecting, attributing, and quantifying man-made emissions must occur in the presence of natural sources and must be credible to contribute to verifying international treaties. These data provide the foundation for computer simulations that capture sources and sinks and model transport in the atmosphere, land, and oceans; carbon-cycle activity; and differentiate natural and anthropogenic emissions.

Increase security and resiliency of the electrical grid and energy infrastructure

Reliably delivering energy to its end-use points is vital to our national security and economic prosperity. The Galvin Electricity Initiative tells us that each day roughly 500,000 Americans spend at least 2 hours without electricity in their homes and offices. Such outages cost our economy $150B each year.[4] To compete globally, the U.S. must redesign its electric grid infrastructure to be resilient enough to swiftly compensate for interruptions and flexible/intelligent enough to incorporate the planned renewable energy sources (with their inherent variability in power generation). A failure in the power grid affects other critical infrastructure such as hospitals, fire and rescue, and military and police agencies. Interruptions put these security and safety institutions in jeopardy—an intentional disruption could have even greater consequences.

Assure energy security for critical installations

To function as they are intended, our military's installations, tactical operations, and training all require secure, uninterrupted access to energy. The Department of Defense (DoD) is the largest single consumer of energy in the U.S. In 2006, the DoD spent over $3.5B for energy to power fixed installations. For the U.S. military, reliable, secure power is an essential element of our national security.

Strengthen the nation's S&T base in energy, climate, and infrastructure

To overcome looming issues in energy generation, infrastructure security, and climatic effects, the nation requires science-based technological advances—not only in applied areas to refine and improve existing technologies, but in foundational science that will underlie the next generation of transformative technologies that will address the roots of these energy-infrastructure-climate challenges. It is clear that how we address and eventually meet these needs will have a broad impact on our standard of living and the national economy. Effective solutions will require scientific breakthroughs and truly revolutionary developments.

The Energy, Climate, & Infrastructure Security Strategic Management Unit

Vision

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

Objectives

Anticipate and Enable Policy and Regulatory Decisions

Anticipate and enable sound government policy and regulatory decisions by providing timely and objective technology assessments and systems analyses.

Accelerate Solutions

Accelerate U.S. industries' innovation, development, and successful deployment of

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1. U.S. Energy Information Administration, "Annual Energy Review 2009," Figure 2.0: Primary Energy Flow by Source and Sector, 2009, http://www.eia.doe.gov/.
2. U.S. Energy Information Administration, "Annual Energy Review 2009," http://www.eia.doe.gov/emeu/aer/pdf/perspectives_2009.pdf, p. xix.
3. Kanter, James, "Investments in Clean Energy Topped $100 Billion for First Time in 2007," International Herald Tribune (reprinted in The New York Times), January 3, 2008, http://dealbook.nytimes.com/2008/01/03/clean-energyinvestments-break-100-million-barrier/.
4. The Galvin Electricity Initiative, "The Electric Power System Is Unreliable," http://galvinpower.org/casetransformation/power-system-unreliable, accessed on 25-Mar-2011.

solutions to the nation's most challenging energy, climate, and infrastructure problems to meet U.S. policy objectives.

Steward Competencies

Create and steward enduring science, systems, and security competencies to support inherently government functions and services and anticipate national security challenges.

Support International Engagement

Support U.S. leadership in global energy, climate, and infrastructure challenges through strategic international engagement.

Guiding Principles

Our strategy has been guided by two central concepts:

- Industry plays the leading role in providing and adopting new energy and climate technologies.
- Policy and regulatory decisions at all levels of government drive the implementation of any new approaches to our nation's energy, climate, and infrastructure security.

ECIS Program Structure

The ECIS SMU has four principal program areas each led by a director: Energy Security, Climate Security, Infrastructure Security, and Enabling Capabilities. Each program area has a set of five-year goals, aligned with the SMU objectives and national challenges that drive our internal investments to accelerate development of reliable, affordable, and sustainable sources of energy; be prepared for and understand potential consequences of climate change; and ensure a safe, secure, and reliable energy delivery infrastructure. Program development resources are directly tied and tracked to the SMU program area goals. Our SMU goals are not intended to be fully comprehensive for the entire set of SMU activities but instead form the principal roadmap for priority investments. They align with federal program priorities, our current activities and competencies, and our focus for future impact.

Energy Security Program Area

Energy Security research at Sandia seeks to address key challenges facing our nation and the world. We work with the energy industry to improve current solutions and develop the next generation of technologies to extract or produce energy. The ECIS SMU spearheads research into energy alternatives that will help the nation reduce its dependence on fossil fuels and to combat the effects of climate change. Sandia's long history with geothermal, solar, and wind energy research has seen a vast increase in effort and intensity over the past 15 years and has also been supplemented in recent years with efforts in biologically based fuels: biomass from nonfood plant sources and algae—both of which can be grown on land unsuitable for farming. Sandia also maintains research into energy efficiency, one of the surest ways to reduce consumption, in the form of materials research to develop efficient lighting and power electronics and into combustion science to increase the fuel efficiency of vehicle engines.

ENERGY SECURITY GOALS:

1. **Develop advanced solar energy technologies and systems that will enable a domestic solar industry to deliver electricity at less than 10¢/kWh.**

A key requirement for the acceptance of new energy technologies is bringing their cost to parity with existing technologies. DOE Solar Energy Technology Program has key targets and funded research activities to accelerate the development of photovoltaic (PV) technology capable of producing electricity at grid parity, ~10¢/kWh. Sandia supports this goal through innovative research and development (R&D), technology development, performance testing and reliability, and market transformation (deployment). Developing advanced solar technologies and systems that will deliver electricity at less than 10¢/kWh will provide the U.S. industry with a competitive advantage worldwide. PV systems that meet the 10¢/kWh goal would increase the viability and deployment of solar systems throughout the nation.

2. **Demonstrate, in a working prototype, 12.5% sunlight to syngas (or other intermediate) and analysis for a system design to achieve >6% end-to-end sunlight to fuel and a roadmap to >10% lifecycle sunlight to fuel.**

The nation faces a difficult transition to a nonpetroleum-fuel-based transportation sector. In the interim, strategic investments must identify ways that clean energy solutions can provide a significant contribution, mitigate climate change risks, and coexist with petroleum-based fuels. To address the nation's vulnerabilities with regard to energy security and from petroleum-based fuels, innovative approaches can ensure a diversified energy and fuel supply. Given today's transportation energy infrastructure and the effectiveness of our current suite of liquid fuels, replacement solutions will be both difficult and take time to develop. Sandia has leveraged existing capabilities and resources to begin to answer some of the fundamental questions and approaches to this dilemma. Initial results have shown great promise and the viability of producing clean fuels from the sun and domestic resources at high efficiency and affordable costs, but investments and partnerships will be critical to fully realize the opportunity. Our multi-institutional Sunshine to Petrol team is working to develop/demonstrate 12.5% sunlight-to-syngas energy conversion and analysis for a system design to achieve >6% end-to-end sunlight to fuel and a roadmap to >10% lifecycle sunlight-to-fuel. The team has built a prototype thermochemical engine which has been tested at Sandia's National Solar Thermal Test Facility (NSTTF).

3. **Develop reactor design and support systems to demonstrate the application of small, modular reactors (SMRs) to fulfill DoD mission goals for energy security.**

To address energy security while simultaneously enhancing mission assurance at domestic facilities, the DoD will accelerate innovative energy and conservation technologies from laboratories to military end users. The surety microgrid concept is to place power-generating facilities and energy storage within the military installation. SMRs have considerable DoD appeal—primarily for their matched power output and the possibility of location within DoD bases for grid independence and security. SMRs have DOE interest for their commercial appeal primarily for their expected lower capital costs to first power, their size and modular scalability, and their benefits of carbon-free energy production. Sandia capabilities present an opportunity to provide the systems analysis necessary for the demonstration of nuclear power as an effective solution at the right price for mutual DOE and DoD energy security goals. Sandia's assessments of military energy security, activities in DoD logistic support, SMR design and construction, and reactor safety assessment position us to facilitate the DOE demonstration of an SMR at a DoD base.

4. **Complete a deep borehole disposal system demonstration project with industry that will transform nuclear waste management.**

The U.S. nuclear industry has produced about 62,500 metric tons of spent nuclear fuel. Congress assigned responsibility to the DOE to site, construct, operate, and close a repository for the disposal of spent nuclear fuel and high-level radioactive waste. With the closing of the Yucca Mountain site, the nation is exploring the options for the safe disposal of this high-level radioactive waste. Due to an emphasis on mined repositories and concern regarding retrievability, deep borehole disposal (DBHD) is a concept that has been discussed for many years, but never pursued despite several advantages. A full-scale demonstration of a DBHD system will secure U.S. leadership in repository sciences; close the fuel cycle with permanent, secure waste disposal; address political/regional equity concerns over hosting a single repository; provide factual data to support analysis of cost savings; and create a permanent disposal method that is highly proliferation resistant.

5. **Provide for the science-based design tools necessary for industry to reduce carbon dioxide and petroleum footprint of the transportation fleet by 25%.**

Transportation by automobiles and trucks accounts for about two-thirds of our oil use[1] and one-fourth of our GHG emissions. The American Clean Energy and Security Act of 2009 describes goals for clean energy, energy efficiency, reducing GHG emissions, and creating clean energy jobs. A certain and significant part of any path toward reducing both oil use, and concurrently, GHGs is to develop more fuel-efficient power conversion systems for vehicles and accelerate the introduction of low-net-carbon fuels. The potential impact of fuel-efficiency improvements on reducing oil use and GHG emissions is enormous. As a nation, we urgently need to provide faster innovation, development, and introduction of high-efficiency, clean power sources for vehicles. Such investments are needed to grow jobs and bolster U.S. leadership in transportation. Because no single technology is the panacea for the future, it is incumbent to work on each advanced technology with the expectation that the market will determine the mix of engines powering our vehicles by mid-century. The Transportation Energy element of Energy Security is working on future ultra-efficient internal combustion engines using liquid fuels (either petroleum- or biomass-based), advanced battery materials and technologies including testing of battery packs, and the technologies to support the successful introduction of fuel cell vehicles into the market.

Climate Security Program Area

Our nation's fundamental security requires not only military capability and infrastructure, but also stability and predictability in a host of other areas ranging from energy supply, communications, and financial markets to the nation's preparedness for natural disasters and long-term changes in our environment, such as shifts in climate. Abundant scientific data point to Earth's present-day warming, and the nation must be prepared to deal with specific consequences of an evolving climate. The impacts may range from international instability, to the need for additional electricity for heating and cooling, to more frequent extreme weather events. Sandia has formulated a Climate Security program to understand and help address the impacts of climate change on the nation. Developing scientifically sound, reliable, and economically reasonable mitigation technologies is central to our strategy for adapting to climate change.

CLIMATE SECURITY GOALS:

1. **Assess U.S. prosperity and security impact risks by modeling climate and human response at the regional level with quantified uncertainty.**

Climate instability could create geopolitical disruptions over the next 40 years, changing the global balance of power. Potential socio-economic changes driven by changes in climate must be understood in order to mitigate climate-change impacts on the nation, and, in fact, in the international arena. Every year that we wait increases the potential severity of the disruptions and decreases our ability to act effectively. On the other hand, acting imprudently or without the proper scientific foundation could exacerbate global climate instability or cause socio-economic suffering without significantly mitigating the situation. Largely, these issues have not been addressed in a systematic way; we must understand them now in order to implement the least disruptive mitigation policies possible. This ECIS program-area activity seeks to assess the risks to U.S. prosperity and security by modeling climate and human response at the regional level with quantified uncertainty.

2. **Design data-gathering and analysis systems to enable the U.S. to sign a global climate treaty.**

The 2009 Copenhagen Summit tried to forge a global treaty to govern GHG emissions at the international level. One of the reasons this summit failed to achieve the hoped-for results was the lack of an accredited system for monitoring and measuring GHG emissions. Also lacking was a means for reliably distinguishing between natural and man-made GHG emissions. Without the ability to track, accurately measure, and reliably determine the source of GHG emissions, no country was or will be willing to agree to the obligations an international treaty would impose.

An operational and scientifically robust GHG information system (GHGIS) would combine ground-based and space-based observations, carbon-cycle modeling, GHG inventories, meta-analysis, and an extensive data integration and distribution system, to provide information about sources, sinks, and fluxes of GHGs at policy-relevant temporal and spatial scales. The ECIS monitoring and sensing program is working to develop data gathering and analysis systems and sensing technologies that will work in concert with a GHGIS partnership to implement a GHG emission information system that will be both transparent and credible enough to serve as the basis for an international treaty.

3. **Develop a credible technical path for achieving DOE's 2015 goal of an industrial-scale demonstration of carbon capture and sequestration (10 MT/yr).**

Energy use and energy generation are at the heart of the GHG emissions problem. One of the solutions being discussed to reduce GHG emissions from fossil-fuel energy generation is CO_2 capture and storage (CCS)—a group of technologies for capturing the CO_2 emitted from power plants and industrial sites; compressing this CO_2; and transporting it to suitable permanent storage sites, such as deep underground. CCS is in an early phase of development, with several key questions remaining unanswered, including about its costs, timing, and relative attractiveness vs other carbon-lowering opportunities.

Sandia's capabilities in geosciences, the CRF, material science, advanced simulation, probabilistic risk assessment, and dynamic simulation, while developed for other purposes such as underground repositories, the nuclear weapons program, and automobile efficiency research, can be applied to this CCS problem facing the nation and the world. Our partnership efforts will be working toward completing a multi-scale, multi-physics CO_2 sequestration geophysical model and leveraging our unique capabilities into a sustainable R&D program with federal agencies, universities, and industry partners to enable an industrial-scale CCS demonstration.

4. **Joint Venture for Safe and Secure Offshore Petroleum R&D—an industry-government partnership to advance R&D and emergency response for offshore oil & gas exploration and production.**

Petroleum is the source of 95% of the nation's transportation-sector fuels, and natural gas fuels more than 21% of the nation's electricity generating plants. While much of the petroleum that we consume is imported, a significant fraction is withdrawn from domestic sites like the Gulf of Mexico. The offshore oil & gas industry is faced with technical challenges that hamper its safety and reliability such as cost-effective advances in technology that enhance safety, security, and reliability and an understanding of full-system risk and reliability for the offshore environment. ECIS can leverage its capabilities in high-reliability system engineering, drilling, geosciences, material science, advanced simulation, probabilistic risk assessment, and dynamic simulation to assist the industry in surmounting these challenges. In addition, our 60 years of systems-engineering expertise can assist the industry establish emergency-response mechanisms including authorities, roles, and communication systems that will help restore/increase public confidence in the offshore petroleum enterprise.

5. **Deploy technology solutions that make government and private sector success in water safety, security, and sustainability, both domestically and globally.**

Nationally, water is a critical part of our economy through the connection to energy production and to our economic prosperity and security. Globally, the world is challenged by water issues that add stress to populations in many regions of the world—that stress could lead to socio-political instability. Our goal in the ECIS water activity is to deploy technology solutions that make possible government and private-sector success in water safety, security, and sustainability, both domestically and globally. To address these national security issues, Sandia's program focuses on

- water-treatment technology development to improve water quality and quantity and
- systems analysis and modeling to improve understanding and comprehension of diverse sets of information and aid water decision makers.

We apply these technological solutions to water security issues and energy and water problems to advance the state of the art and impact issues that face the nation today concerning future water supplies and adaptation to climate change.

Infrastructure Security Program Area

America's critical infrastructures provide the foundation for the nation's economic vitality, national security, and way of life. They frame citizens' daily lives and support one of the world's highest living standards. The systems, facilities, and functions that comprise these infrastructures are sophisticated, complex, and highly interdependent. They are comprised of physical, human, and cyber assets and have evolved over time to be economical and efficient systems. The increasing interconnections and complexity of these systems, subject to natural hazards and coupled with the new malicious threat environment, have created the need for a focus on interdependencies and the consequences they propagate. A key objective of the Infrastructure Security Program Area is to support the preparedness and protection of our nation and society by providing analyses of the technical, economic, and national security implications of the loss or disruption of these critical infrastructures, and assist in the understanding and technology development of infrastructure protection and infrastructure disruption mitigation, response, and recovery options.

INFRASTRUCTURE SECURITY GOALS:

1. **Establish and grow critical cyber security capabilities within the Department of Homeland Security with Sandia as the enduring advanced development partner.**

As the U.S. benefits from technological advances, we increase our dependence on interconnected devices and systems, which creates vulnerabilities that might be exploited by adversaries ranging from criminal organizations through nation states. The complexity of these interconnected systems and the rate of technological change cries out for a national-lab-level approach to mitigate the risks to our government systems and our critical computer infrastructures. Sandia's goal is to develop game-changing cybersecurity capabilities to support the Department of Homeland Security's (DHS's) mission of securing the nation's ".gov" domain and to defend critical infrastructures (e.g., the electric grid and other energy infrastructure) from cyber-based vulnerabilities. Our partnership's goal is to build/use a threat model in order to guide development, acquisition, and operation of a protective system whose complexity and scale will be unprecedented; it must scale over a wide range of network sizes, data sensitivities, communications capacities, geographical distributions, and operational authorities.

2. **Increase resilience of U.S. critical infrastructure systems by providing government, regulatory, and industry stakeholders with increased understanding of interdependencies and risk.**

America depends on its infrastructure—not only for its economic prosperity but for the survival of its urban population. Disruptions can come from many causes—natural, accidental, and some that are malicious. America has endured these disruptions before and will again. Critical infrastructure, infrastructure whose disruption will put many lives at risk, is not only under threat of direct interruption but also from disruption via the interruption of another element of the infrastructure on which it depends. The nation must understand these interdependencies; we must understand if some systems are more at risk than others and why. Understanding the linked, interdependent nature of the nation's critical infrastructure in order to enhance preparedness, protection, response, recovery, and mitigation is a hard problem. It is through high-performance computing (HPC) modeling and analysis at the National Infrastructure Simulation and Analysis Center (NISAC) that Sandia can quantify and qualify the interactions of political, health, social, economic, and technical systems. By studying these infrastructure systems and their effects on each other in simulation, we can advise policy makers and industry stakeholders on how to mitigate disruption effects and build resiliency into the national system.

3. **Reduce the risk of energy supply disruptions from globally strategic sources to the U.S. and to key overseas installations.**

The U.S. economy and national infrastructure depends heavily on our imports of oil and gas resources. The economic consequences of oil price shocks depend on how strong the economies of key countries are at the time of a supply interruption and how long an interruption lasts. Because energy drives the U.S. economy and transportation keeps it rolling, our national security and economic prosperity demand that we address the security needs of the top tier oil-supplying countries (more than one million barrels of petroleum per day). Global Critical Energy Infrastructure Protection (G-CEIP) is a U.S. interagency program that seeks to ensure the supply of energy to the U.S. by securing critical energy and infrastructure sites across the world. Sandia brings more than 30 years of experience with projects that utilize "denial" strategies, born out of our nuclear weapon protection experience, to the G-CEIP program.

4. **Design and demonstrate 30% renewable energy penetration into the energy surety microgrid within five years.**

The present electricity grid is based on a foundation created more than 100 years ago. The infrastructure is geographically fixed, power sources are centralized and dispatchable (completely controllable), the loads are largely predictable, and the control of power flow at the load is essentially an open-loop—making it vulnerable to terrorist attacks, natural disasters, infrastructure failures, and other disruptive events. Further, this grid model limits renewables and other distributed energy sources from being economically and reliably integrated into the grid because it has been optimized over decades for large, centralized power-generation sources. The energy surety microgrid is a Sandia-developed grid architecture that moves away from unidirectional power and limited information flow and, rather, adopts closed-loop controls and an agent-based architecture with integrated communication networks. By advancing these technologies, we are enabling reliable, resilient, secure, and cost-effective microgrids and interconnected microgrids that will make up the smart grid of the future.

5. **Develop and use energy security systems analysis/assessment tools and a sustainable implementation business model to meet DoD/DOE/DHS defined energy security objectives.**

The nation's security is compromised by the fact that a large majority of the energy we consume comes from foreign sources. Our security is placed in jeopardy by foreign competition for the energy resources and international instabilities and conflicts. DoD Energy Assurance seeks to develop and apply tools to conduct complete vulnerability assessments of critical missions at military installations. The tools allow us to understand the interdependencies within an installation and to identify gaps in energy reliability, availability, and security. We will explore the utility and benefit of energy management against a physical and cyber threat and consider the use of alternative energy sources/supply with the goal of making the installation independent from external supply. The nation has complex interdependencies and a heavy reliance on private industry. The tool will also assist in the development of conceptual designs that will provide decision makers a risk vs cost basis for selecting the optimal solution for a given design basis threat.

Enabling Capabilities Program Area

Enabling Capabilities is unique among ECIS' program areas. The other three areas each focus on one research area to bring Sandia's research and engineering capabilities to bear on a problem and help the areas in pursuit of their goals. Enabling Capabilities is home to four activities that are designed to cut across the other three ECIS areas.

Discovery Science and Engineering scientists and engineers pursue fundamental research that has applications in multiple program areas. Enabling Capabilities' interwoven connections throughout the ECIS SMU project teams allow this discovery science to easily find multiple applications.

The Regulatory and Policy activity interfaces between the ECIS program areas/SMU management and national regulatory and policy bodies. This activity can either work with the policy/regulatory authority to understand how new technologies can meet energy/climate/infrastructure needs with some modification to the policy/regulatory structure or work with ECIS research staff to modify the technology so that it can still provide a workable solution with the modifications necessary to fit the existing regulatory/policy structure.

The Systems Analysis activity looks "from the top" at project-team results and "weaves" them into coherent systems. Where two research areas may seem to be isolated, this activity—through a complex, adaptive, system-of-systems approach—seeks to forge meeting points between research efforts throughout the nation's energy/climate/infrastructure research enterprise.

ARPA-E (Advanced Research Projects Agency–Energy) was created to be a catalyst for transformation and to do so with fierce urgency. ARPA-E's goal is to identify and support the pioneers of the future. The ECIS ARPA-E activity is tasked with working with ECIS scientists and engineers to form partnerships with industry, academia, and entrepreneurs to develop research proposals that will win grant awards from ARPA-E.

ENABLING CAPABILITIES SECURITY GOALS:

1. **Deepen fundamental science and engineering competencies in key strategic areas to enable ECIS mission objectives and goals.**

Focused, applied research and analysis can only bring us so far in addressing the serious, looming challenges in the areas of energy, climate, and infrastructure security. Many of these challenges cannot be solved with improvements to current technologies or extrapolations from them—they require an understanding of the foundational characteristics of materials, energy, and their interactions. The Enabling Capabilities program area supports this foundational research at facilities throughout Sandia, which gives Sandia extensive, in some cases unique, state-of-the-art laboratory facilities for understanding combustion science; material growth; fabricating microsystems; semiconductor processing; and characterizing structural, electronic, and optical materials. In addition to special lab facilities and equipment, we have cultivated substantial personnel expertise, in parallel, over decades, in a broad range of physical science, chemistry, materials science, and engineering disciplines. It is through the use of these facilities by our collection of unique scientific and engineering capabilities that we can understand and develop the foundational scientific principles of novel materials and processes into the technology of tomorrow that can surmount the challenges that we face in energy, climate, and infrastructure protection that can secure and sustain our nation.

2. **Nurture discovery science for fundamental breakthroughs in interfacial science, quantum phenomena, materials physics, bioscience, gas-phase chemistry, nanomaterials systems and architecture, and math algorithms.**

In order to develop solutions to the energy, climate, and infrastructure challenges, Sandia's existing facilities and capabilities provide a good start, but not the complete answer. We need to develop new facilities, new capabilities, and expand or establish partnerships with other research institutions (national labs, universities, industry). Sandia must establish these laboratory centers because the research they will undertake is so novel that no facilities currently exist to pursue them to their potential. In our new research efforts, Sandia would seek out collaborative partnerships with other institutions in order to better leverage all available capabilities. A shining example of this collaborative spirit is the Center for Integrated Nanotechnologies (CINT), which we co-host with LANL. Sandia will continue to nurture and grow this relationship and expand CINT's impact on Sandia's mission areas and our partnerships with industry. With new exascale machines like Red Storm open to the broader scientific community through open-source codes, Sandia can expand the role and impact of HPC into a wider range of DOE/Sandia mission areas (energy, climate, infrastructure assurance) that positions Sandia in a leadership role for the DOE complex in exascale planning and execution.

3. **Determine capability needs for SMU and support capability development through targeted Laboratory-Directed Research & Development (LDRD) projects.**

Coupling S&T is critical to the success of our SMU and a differentiating expertise that we bring to the nation. The ECIS LDRD investment area (IA) seeds and initiates transformative approaches that provide real solutions to our key national challenges as articulated by the President. The ECIS LDRD IA focuses on ideas that would be considered too risky for the direct-funded program funding areas to develop and create products and capabilities to incubate solutions for future program needs. Future LDRD awards will address priorities to the IA where gaps exist in the current research/investment portfolio.

4. **Accelerate industry development of transformational energy technologies through ARPA-E.**

The nation that successfully grows its economy with more efficient energy use, a clean domestic energy supply, and a smart energy infrastructure will lead the 21st century global economy. ARPA-E was created within DOE to catalyze such a transformation, and to do so with fierce urgency. ARPA-E has created a portfolio of innovative, high-risk R&D projects targeted to address the nation's technological gaps and leapfrog over current approaches in the energy sector. Sandia can further accelerate innovation by engaging current and future ARPA-E innovators that otherwise might not benefit from our intellectual resources and relevant capabilities. Sandia's facilities, the innovative spirit ignited within the Laboratories by the initial ARPA-E solicitations, and an ability to work in precompetitive or proprietary modes will enable Sandia to deliver critically needed innovation for our nation's energy security.

ECIS SMU Key Facilities

Many of Sandia's unique research facilities are available for use by industry, universities, academia, other laboratories, state and local governments, and the scientific community in general. User and collaborative facilities are a unique set of scientific research capabilities and resources whose primary function is to satisfy DOE programmatic needs, while also being accessible to outside users.

The **National Solar Thermal Test Facility (NSTTF)**, a DOE Office of Energy Efficiency and Renewable Energy (EERE) sponsored facility, provides energy researchers with experimental engineering data for the design, construction, and operation of unique components and systems in proposed solar thermal electrical plants.

The **Joint BioEnergy Institute (JBEI)** is a DOE SC

-sponsored San Francisco Bay Area scientific partnership with a mission to advance the development of the next generation of biofuels—liquid fuels derived from the solar energy stored in lignocellulosic (nonfood) plant biomass.

The **Combustion Research Facility (CRF)** is an internationally recognized DOE SC-sponsored collaborative research facility aimed at improving our nation's ability to use and control combustion processes.

Sandia's **Battery Abuse Testing Laboratory (BATLab)** is a DOE EERE-sponsored facility at the forefront of testing the limits of what batteries can safely handle and provides critical data for ensuring the safety and reliability of the next generation of batteries.

The **National Infrastructure Simulation and Analysis Center (NISAC)** is a DHS-sponsored modeling, simulation, and analysis program that provides strategic, multidisciplinary analyses of critical infrastructure and key resource interdependencies and the consequences of disruptions at national, regional, and local levels.

The **Photovoltaic Systems Evaluation Laboratory (PSEL)** is a multiuser, multi-sponsor facility that supports research in PV cells, modules, and arrays—allowing detailed, comprehensive analysis in PV systems design, optimization, and characterization in real-world scenarios. PSEL conducts research on behalf of the DOE, DoD, and other customers, often in collaboration with industry/academic partners.

The **National Supervisory Control and Data Acquisition (SCADA)** Test Bed is a DOE Office of Electricity Delivery and Energy Reliability-sponsored resource that combines state-of-the-art operational system testing facilities with research, development, and training to discover and address critical security vulnerabilities and threats to the energy sector.

The **Center for Integrated Nanotechnologies (CINT)** is a DOE SC-sponsored user facility that supports researchers working to determine the scientific principles that govern the design, performance, and integration of nanoscale materials. CINT's emphasis is on exploring the path from scientific discovery to the integration of nanostructures into the micro and macro worlds.

The **Distributed Energy Technologies Laboratory (DETL)** is a DOE EERE-sponsored facility that supports research with industry/academic partners to integrate emerging energy technologies into new and existing electricity infrastructures to achieve a reliable, low-carbon electric infrastructure.

ECIS SMU Leadership of Federal Energy Research Efforts

Concentrated Solar Power

The DOE EERE's Solar Energy Technologies Program Concentrated Solar Power (CSP) subprogram works to lower costs and advance technology to the point that CSP is competitive in the intermediate power market by 2015–2017 and in the baseload power market by 2020–2022. Sandia and the National Renewable Energy Laboratory manage the R&D support for the U.S. CSP industry with critical research to meet cost, reliability, performance, and manufacturability challenges.

Energy Frontier Research Center for Solid-State Lighting Science

Solid-state lighting (SSL) is an emerging technology with the potential to reduce that energy consumption by a factor of 3–6 times. Despite a decade's enormous progress, however, SSL remains a factor of 5–10 times away from this potential. Sandia's Solid-State Lighting Science a DOE SC Energy Frontier Research Center will accelerate advances in this fundamental science by exploring energy conversion in tailored photonic structures.

Energy Storage Systems

The Sandia managed DOE Energy Storage Systems program studies integrated electrical storage systems and power sources: materials, engineering, and testing (including power electronics and controls), especially as storage technologies relate to electric utilities, renewables, and grid security.

Global Critical Energy Infrastructure Protection

Critical energy infrastructure comprises the production, storage, refining, processing, and distribution of fossil fuels that traverse remote, mostly uninhabited areas and cover great distances, which makes monitoring difficult. Sandia is applying its well-developed capability and recognized leadership in critical infrastructure protection, cybersecurity, and energy systems solutions to enhance national security by helping energy supplier nations secure their critical energy infrastructure.

National Infrastructure Simulation and Analysis Center

Physical, human, and cyber assets make up key resources and critical infrastructures. NISAC's infrastructure modeling and analysis, decision support tools, and knowledge management support our nation's preparedness by providing analyses of the technical, economic, and national security implications of the loss or disruption of critical infrastructure; NISAC activities assist in understanding infrastructure protection, mitigation, response, and recovery options.

Ocean Energy

The DOE's Water Power Program supports the development of advanced water power devices that capture energy from waves, tides, ocean currents, rivers, streams, and ocean thermal gradients. Sandia, through a partnership with several national laboratories and academic institutions, leads two of the four topic areas awarded under a $9M grant and will provide technical support in a third topic area.

Smart Power Infrastructure Demonstration for Energy Reliability and Security Joint Capabilities Technology Demonstration

The SPIDERS JCTD—a combined agency (DOE, DoD, DHS) demonstration effort for energy security at military installations—combines several DOE efforts: smart grid, cyber security, energy efficiency, renewable energy, and energy storage via demonstration and early deployment. Sandia is the lead systems engineering lab (among five overall DOE labs), and is providing the Deputy Technical Manager for the project.

Strategic Petroleum Reserve

Sandia is the technical leader for geology, geomechanics, and computational modeling issues related to the Strategic Petroleum Reserve (the largest stockpile of government-owned emergency crude oil in the world), which stores crude oil in solution-mined salt domes as a national response option should a disruption in commercial oil supplies threaten the U.S. economy and as a national defense fuel reserve.

Our History

Sandia & the Nation's Energy Challenges

Sandia was born as a nuclear weapons (NW) engineering laboratory, a place with deep strengths in science and engineering to support complex systems solutions.

Long-standing competencies in areas such as materials at extreme conditions, large-scale test, engineering design simulation, systems reliability, and risk assessment proved to be invaluable to broader national security challenges beginning in the 1960s. It is Sandia's national security mission that brought energy science and engineering into the labs. Just as no nation can ensure its security without a means to defend itself, no nation can survive without an adequate supply of safe, assured, affordable, and environmentally sound forms of energy.

The energy crisis of the 1970s spawned significant and continuing Sandia energy programs. These programs benefitted from enduring support by Sandia's technical base in areas that were relevant to the nation's energy challenges, while also strengthening on our core NW expertise.

Nuclear Energy

In the 1970s and 1980s, Sandia scientists and engineers supported the Nuclear Regulatory Commission (NRC) by providing independent technical expertise in nuclear reactor safety and reliability. In the 1990s and 2000s, the

NRC and Department of Energy (DOE) Offices of Nuclear Energy and Naval Reactors continued to expand our core capabilities especially in the area of probabilistic risk assessment, computer simulation, and environmental testing.

Over 30 years of research into severe accident phenomenology, spurred by the Three Mile Island accident of 1979, has led to the development of the modern risk informed regulatory framework in place today. Sandia has played a principal role in many of the regulatory research efforts. For example, MELCOR (Methods for Estimation of Leakages and Consequences of Releases) was developed in 1989 as a fully integrated, engineering level code to model severe accident progression in light water reactor power plants. MELCOR is being applied today as a key element of the U.S. support to the Fukushima reactor crisis in Japan.

Renewable Energy

Wind energy programs at Sandia began in the early 1970s, leveraging our world-leading expertise in systems analysis and integration from our NW programs. Our initial activities were aimed at modernizing the eggbeater-shaped vertical-axis wind turbine (VAWT) invented by G.J.M. Darrieus in the 1920s. Complex computer codes were developed to accurately simulate the performance of a variety of blade configurations in a wide range of wind conditions and to predict their fatigue life. Advanced materials were applied to improve reliability. In return, the wind analyses activities stimulated advances in mathematical modeling that later found benefit in the NW program, bringing this synergistic relationship full circle.

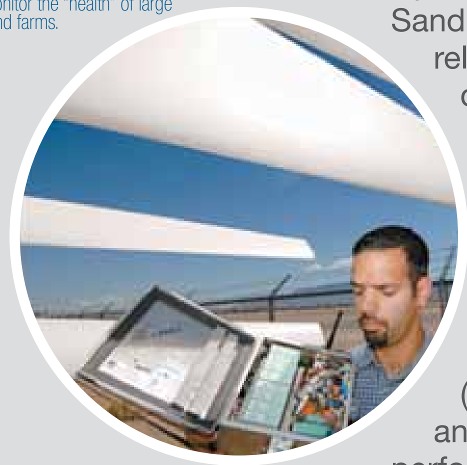
The VAWT concept showed early promise, but cannot be scaled up like modern designs.

From these early beginnings, Sandia has continued to make major contributions to the state-of-the-art in wind turbine technology. Our scientists have continued to conduct applied research to improve wind turbine performance, reliability, and reduce the cost of energy. Sandia has participated in all aspects of wind-turbine blade design, manufacturing, large-scale testing, and system reliability. By partnering with universities and industry, Sandia has worked to advance the state of knowledge in the areas of materials, structurally efficient airfoil designs, active-flow aerodynamic control, and sensors.

Researchers at Sandia are currently investigating integrated blade designs where airfoil choice, blade platform, materials, manufacturing process,

Sandia researchers prepare a mock-up of a spent nuclear fuel rod bundle for testing.

and embedded controls are all considered in a system perspective. By collaborating with operators, developers, and manufacturers, Sandia evaluates known reliability problems and develops tools and methods to anticipate and investigate future reliability issues. From these collaborations, Sandia developed the Accurate Time-Linked data Acquisition System (ATLAS II) to monitor and record total system performance. The system provides data to help researchers and operators understand how turbine blade designs perform in real-world conditions, facilitating improvements on blade designs and our design codes.



The ATLAS II technology can monitor the "health" of large wind farms.

Sandia's efforts in solar energy research began in 1972 in similar fashion to the area of wind energy. Existing expertise in systems analysis and engineering along with our long-standing experience in large scale testing were applied to improving concentrated solar technologies. Ever since that time, Sandia has played a key role in developing concentrated solar technologies for commercial power-plant use—technologies that involve collecting and focusing solar energy onto a receiver for conversion to other forms of energy. In each case, the goal is to heat a fluid (water, gas, or molten salt) and use that energy for driving a turbine/generator and/or for space-heating or other industrial purposes. Sandia has established baseline data on the performance of both traditional and innovative line concentrators (parabolic troughs), point concentrators (parabolic dishes), and heliostats for concentrating sunlight on tower-based receivers. We have also had responsibility for the materials-science work and computer codes that make these advanced designs possible.

In the mid-1980s, Sandia assisted in the engineering development of the nation's largest electricity-producing solar plant at that time, Solar One, near Barstow, California, which operated successfully from 1982 to 1986. To improve efficiency, Sandia led an effort to develop molten salt technology for energy storage. This enabled a recommissioned Solar Two in 1996. This facility produced steam to drive a turbine/generator that produced enough electricity for 5000 homes. The system was operated into 1999 and proved itself capable of operating smoothly through intermittent clouds and continued generating electricity long into the night.

Our competency in concentrated solar power (CSP) then expanded to the area of dish-Stirling engines. This concept links a parabolic dish reflector with the externally heated Stirling engine. Sandia began by studying the basic thermodynamics to evaluate the prospects for commercialization. For distributed receiver systems, then-current system analyses were a combination of simple models and detailed questions about the day-to-day performance of components. The models were refined as components arrived for testing.

In central receiver technology, Sandia developed more-complete mathematical models of plants based on operating experience at Sandia's Central Receiver Test Facility (Solar Tower, established in the late 70s) and at Solar One. These models simulate operation of a plant and determine its power output under varying conditions, allowing utilities to predict outcomes using different subsystem components. It also helps researchers direct efforts at improving key design areas to meet overall system goals.

Sandia's Solar Tower, parabolic trough, and dish-Stirling facilities were combined in the late 1970s into the National Solar Thermal Test Facility (NSTTF). Operated by Sandia for the DOE, the NSTTF is the only test facility of this type in the U.S. NSTTF's primary goal is to provide fully instrumented test facilities that furnish researchers with experimental engineering data for the design, construction, and operation of unique components and systems in proposed solar thermal electrical plants planned for large-scale power generation. In addition the facility can provide: high heat flux and temperatures for materials testing or aerodynamic heating simulation; large fields of optics for astronomical observations or satellite calibrations; a solar furnace; and a rotating platform for parabolic trough evaluation.

Many aspects of the solar technology developed at Sandia more than thirty years ago are being commercially deployed. The Andasol generating station, located in central southern Spain, is a parabolic-trough style plant that employs molten-salt storage—enabling it to provide full generating power 7.5 hours after the sun has set.[1] Andasol 1 went online in March 2009. Andasol 2 has started the commissioning phase, and Andasol 3 is currently under construction.[1] Our technologies will also be integrated into the Ivanpah Solar Electric Generating System, located in the Mojave Desert. Ivanpah is planned to have a capacity of 392 MW, making it the world's largest solar thermal power project currently under construction.[2] Final approval was gained in October 2010. The first phase of the Ivanpah facility is scheduled to be finished in 2013.[2] Complementary work now going on at Sandia and elsewhere could also result in transportable fuels and chemicals from solar thermal technology.

Another progeny of Sandia's decades-long solar energy research program is the parabolic dish/ Stirling engine system called the SunCatcher™. Stirling Energy Systems (SES) of Phoenix, Arizona, developed this system in partnership with Sandia. The SunCatcher system holds the world's record for solar-to-grid efficiency (31¼%) and has a full year sunrise-to-sunset efficiency of ~25%—double that of other solar power systems.

Top right: A parabolic trough concentrator with a black chrome receiver.

Bottom right: The Sandia solar tower has been a mainstay solar research facility for nearly 30 years.

Equally revolutionary is the SES-Sandia partnership's effort to design the system with economy of manufacture and deployment. This latest design eliminated 6000 lbs from the structure and dramatically simplified the assembly processes—reducing materials and labor costs, while simultaneously increasing system performance. The mirror modules are stamped from sheet metal, using the same manufacturing processes as car body parts, reducing costs and leveraging the existing automotive supply chain. SES and Sandia have also performed development and testing that has led to significant performance improvements and operating cost reductions. SES plans to deploy the systems at a utility scale in large fields, in order to optimize costs throughout the deployment chain.

An early version of the dish-Stirling concept used many small cast parabolic mirrors.

The high system efficiency coupled with the advantages of mass production position the SunCatcher to have a significant impact on our nation's energy future. The partnership with Sandia has allowed SES to leverage the accumulated knowledge and research capabilities of Sandia's CSP program. Sandia has benefitted tremendously through access to operating systems, for development of optical tools, controls algorithms, and other activities supporting many solar projects.

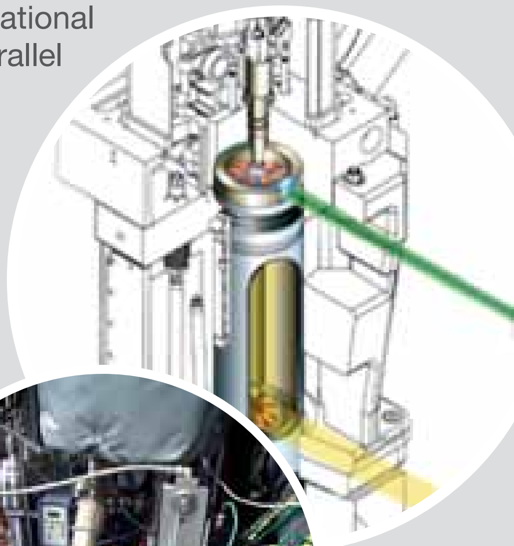
Electric Grid Infrastructure

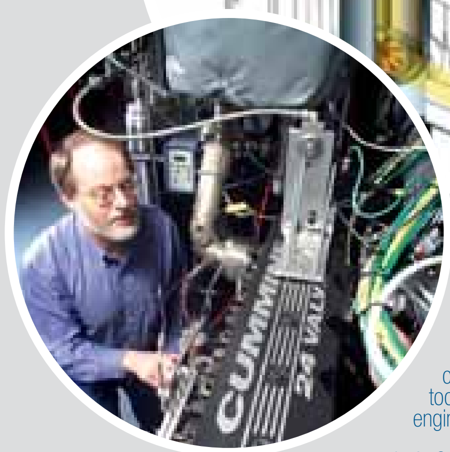
One of the critical issues with "alternative" power generation is integrating that power into the local utility's network and, ultimately, into the national power grid. During the 1980s, Sandia initiated the Distributed Energy Technology Laboratory (DETL) to integrate emerging energy technologies into new and existing electricity infrastructures. Sandia's research spans generation, storage, and load management at the component and systems levels and examines advanced materials, controls, and communications to achieve the Lab's vision of a reliable, low-carbon electric infrastructure.

Combustion Science

Sandia has a long history of working with industry to move our science and technology (S&T) into the marketplace. Our research into the science of combustion, for example, has had a significant impact on internal combustion engine fuel efficiency only through longstanding partnerships with automotive manufacturers. In 1980, Sandia established the Combustion Research Facility (CRF), a DOE Office of Science (SC) collaborative research facility, to bring together our basic and applied research aimed at improving our nation's ability to use and control combustion processes. The CRF conducts research in tandem with university and industry. Visiting researchers have access to the CRF's state-of-the-art facilities and expert staff, and bring with them experience and knowledge that enhances and brings new approaches to CRF projects. A glowing example of our partnership efforts is a collaboration of CRF and modeling and simulation researchers with Cummins on their newest diesel engine—marketed in 2007 solely with computer modeling and analysis tools, which replaced the traditional build-and-test approach. Cummins achieved a 10%–15% reduction in development time and cost as they achieved a more robust design, improved mileage, and met all environmental and customer constraints.

The CRF's engine combustion research program led the development of the S&T foundation for diesel combustion. The research effort spanned more than 15 years and was largely funded by DOE. Sandia provided much of the detailed understanding of the physical and chemical processes that drive the very complex diesel combustion process. Other key contributors included Los Alamos National Laboratory (LANL, numerical framework for engine combustion models), Lawrence Livermore National Laboratory (LLNL, chemical kinetic models for combustion and emissions processes), and the universities of Wisconsin and Michigan (helped develop and validate many of the submodels for diesel combustion)—to name a few key collaborators. This understanding of diesel combustion was developed through the application of laser diagnostics in the CRF's optical engine facilities. The information was essential for developing the computational tools used by industry. CRF researchers are expanding the S&T foundation to include new, clean combustion strategies for high-efficiency engines utilizing future fuels, and developing the next generation of computational tools utilizing massively parallel machines.





Right: The "optical" cylinder, a new tool for diesel engine design.

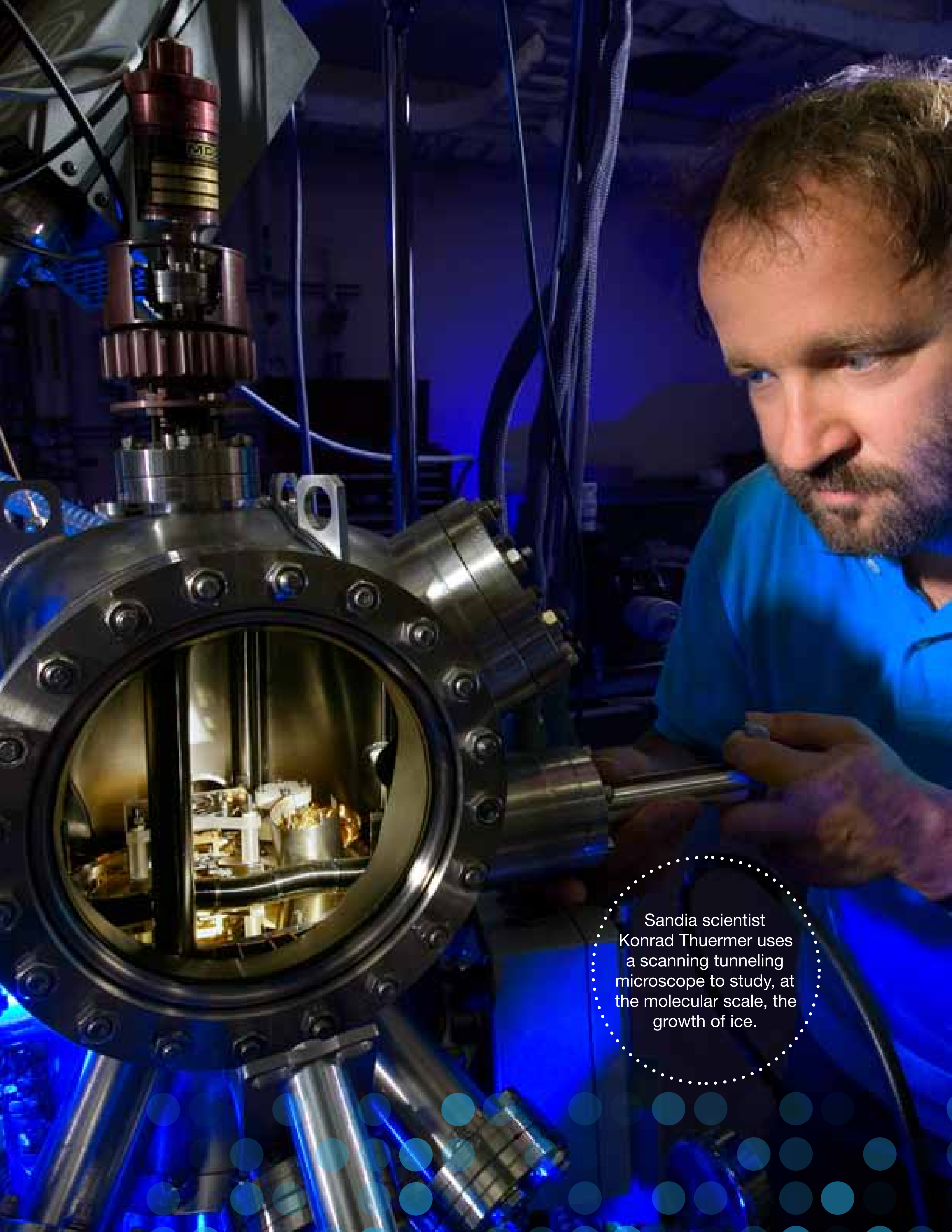
Left: Cummins Engine

Basic Science Research

These past successes and future accomplishments rely on our strong foundational science programs. Sandia maintains its reputation in energy research through foundational research in important energy areas. Recently, *Science Watch*® published the results of its survey of scientific literature in the energy journals listed in the Science Citation Index. The 94 journals of the "Energy & Fuels" category published ~100,000 papers between 1998 and 2008. From that body of research, *Science Watch* identified Sandia National Laboratories as the most-cited institution in this research category, with 4,147 citations to its 395 papers.

In late 2009, Sandia announced its initial development of glitter-sized photovoltaic (PV) cells that could revolutionize solar energy collection. The millimeter-length crystalline silicon micro-PV cells will be cheaper and have greater efficiencies than current PV collectors. Micro-PV cells require relatively little material to form well-controlled, highly efficient devices. Micro-PV cell fabrication uses common micro-electronic and micro-electromechanical systems (MEMS) techniques that leverage Sandia's NW competency at the Microsystems Engineering Science and Applications (MESA) facility. From 14–20 μm thick, micro-PV cells are 10 times thinner than conventional cells, yet perform at about the same efficiency. Micro-PV benefits include improved performance, reduced costs, higher efficiencies, and new applications.

In the 21st century, Sandia has expanded its energy programs and partnerships to include climate research (because power generation and energy use are primary contributors to climate instability) and energy infrastructure security (because, as renewable energy power is integrated into the grid, the national power grid must initiate some fundamental improvements). These programs, in addition to our energy research, continue Sandia's tradition of exceptional service in the national interest. As it has since its founding, Sandia is working to provide the foundational science and engineering to underlie the nation's security. The Energy, Climate, and Infrastructure strategic management unit is working toward this goal with regard to our energy future.



Sandia scientist Konrad Thuermer uses a scanning tunneling microscope to study, at the molecular scale, the growth of ice.

Strategic Framework

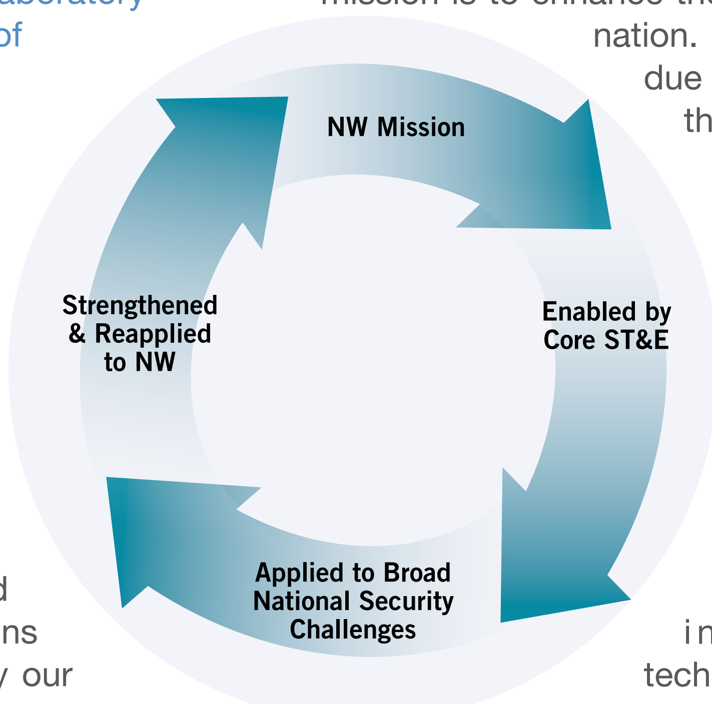
The Energy, Climate, and Infrastructure Security (ECIS) Strategic Management Unit (SMU) Strategic Plan documents the long-range planning process to define its vision, objectives, goals, and portfolio of research to support Sandia's national security mission.

Our strategy is based on our role as a national security laboratory to address the nation's most daunting science and technology challenges within the national security context. Our plan is informed and guided by the five Sandia Laboratory objectives:

- Deliver with excellence on our commitments to the unique nuclear weapons mission
- Amplify our national security impact
- Lead the complex as a model 21st century government-owned contractor-operated laboratory
- Excel in the practice of engineering
- Commit to a learning, inclusive, and engaging environment for our people

Within this context, the objectives and goals developed by this SMU seek to both leverage and enhance key competencies associated with our nuclear weapons mission in order to amplify our contributions to broader national security in energy, climate, and infrastructure. The work of ECIS aims to further our engineering excellence with an emphasis on connecting deep science to engineering solutions. Finally, all of our work will be conducted in a manner that puts people first, assures the safety and health of employees and the public, protects the environment, and guards classified and other sensitive information.

The vision and set of enduring ECIS objectives described in this plan are congruent with foundational Sandia competencies built over decades. These competencies grew out of our historic mission in nuclear weapons and a synergistic environment in which capabilities and expertise from our complementary missions support and strengthen one another. Ultimately, our mission is to enhance the security of the nation. In this SMU, due to the nature of the mission, the private sector has a unique and important role that is reflected in our objectives, because it is there that most energy and infrastructure technologies and



solutions are deployed. Our overarching objectives are driven by both our historical contributions as well as our fundamental role for the government as a national laboratory.

These objectives are as follows:

- Anticipate and enable government policy and regulatory decisions
- Steward competencies to support inherently government functions and services
- Accelerate private sector deployment of solutions to meet U.S. policy objectives
- Support U.S. international engagement to solve national security challenges

As we developed our strategy and plan from these objectives, we faced the unique challenge that the nation does not currently have a well-articulated energy policy nor does the DOE have an enduring set of priorities and roadmaps that provide high-level integrated guidance. The DOE is now engaged in a Quadrennial Technology Review (QTR) process, to which Sandia has contributed, to develop a framework that, in the future, we will be able to use for such guidance. While this is not yet available nor are clear governmental policies and priorities complete, there is general consensus at the national, regional, and state level on the most significant problems and challenges to our national security in this area. In our planning process, we reviewed these challenges and selected a set of seven national-level problems across the energy, climate, and infrastructure sectors that reflect our priorities and guiding framework. These are

- Reduce our dependence on foreign oil
- Increase deployment of low-carbon stationary power generation
- Understand risks and enable mitigation of climate change impacts
- Provide the foundation for a future global climate treaty
- Increase security and resiliency of the electrical grid and energy infrastructure
- Assure energy security for critical installations
- Strengthen the nation's S&T base in energy, climate, and infrastructure

From these challenges, we then created a set of five-year, outcome-focused goals that are consistent with our national laboratory role, our unique competencies, and our objectives. Each of these is described more fully in the following sections.

National Priorities and Challenges

Our Vision
To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

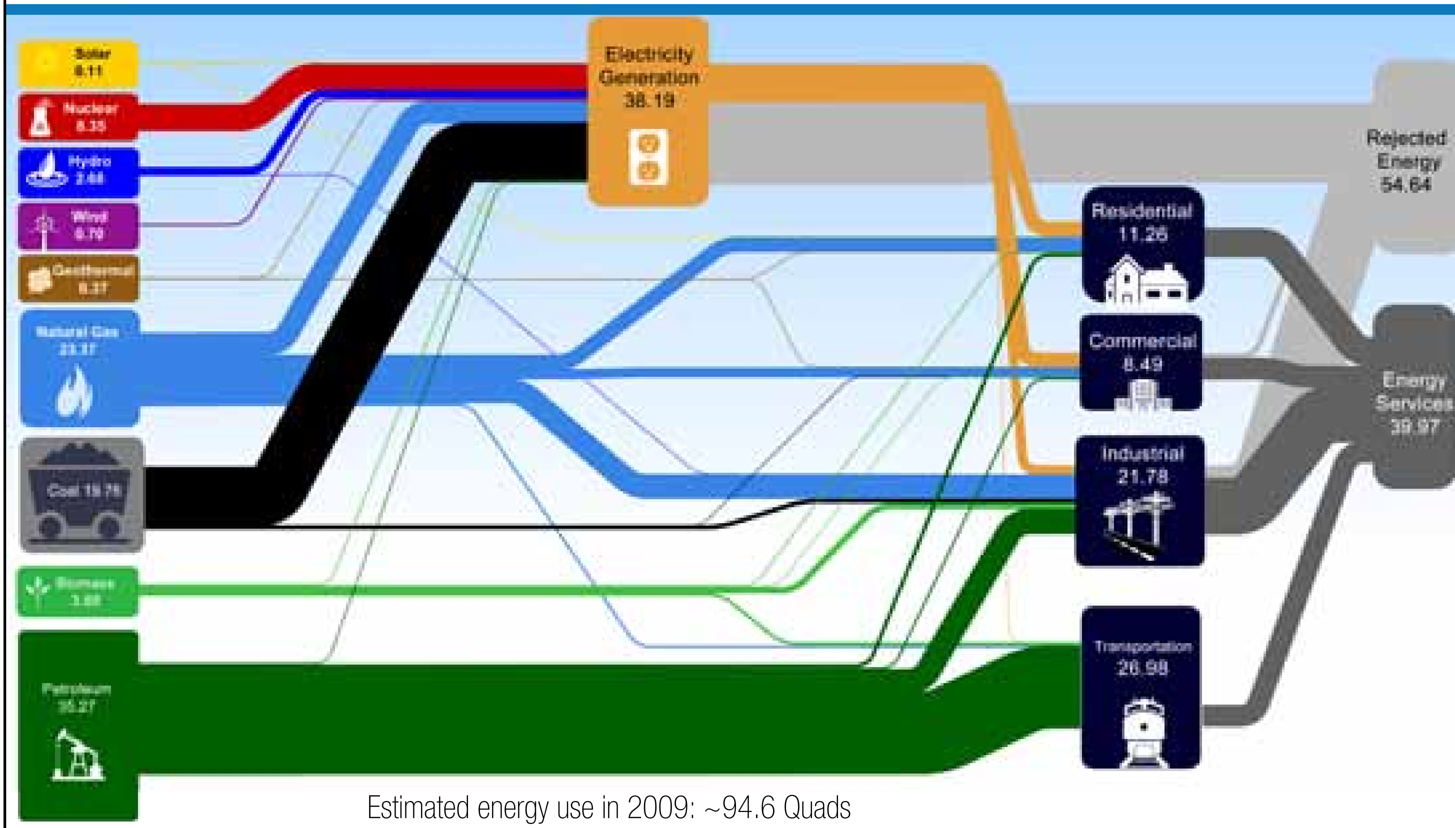
Access to reliable, affordable, and sustainable sources of energy is essential for all modern economies. The global demand for electricity will increase from 18.8 petawatt-hours (PWh) in the year 2007 to 32.5 PWh by the year 2035.[3]

This is driven to a great extent by the growing population in developing countries (note that 1.5 billion people, 22% of world population, presently do not have access to electricity). Meeting this need will have a profound impact on energy production/consumption patterns, on the environment, on the global economy, and ultimately on the global political atmosphere.

The future security of our nation will rely on our ability to address the energy, climate, and infrastructure challenges facing the U.S. and the world. The U.S. share of world consumption is presently around 20%. How we use this energy is shown in the upper figure on the opposite page. A parallel flow chart for our carbon dioxide (CO_2) emissions is shown in the lower figure on that page. Electricity generation and transportation are the two largest energy use sectors and, not surprisingly, they also are the largest contributors to U.S. CO_2 emissions. Together, they comprise around 70% of our consumption and CO_2 emissions. Innovative approaches in these two sectors would have tremendous impact to our national security.

It is interesting to note that the U.S. was energy self-sufficient until the late 1950s, when energy

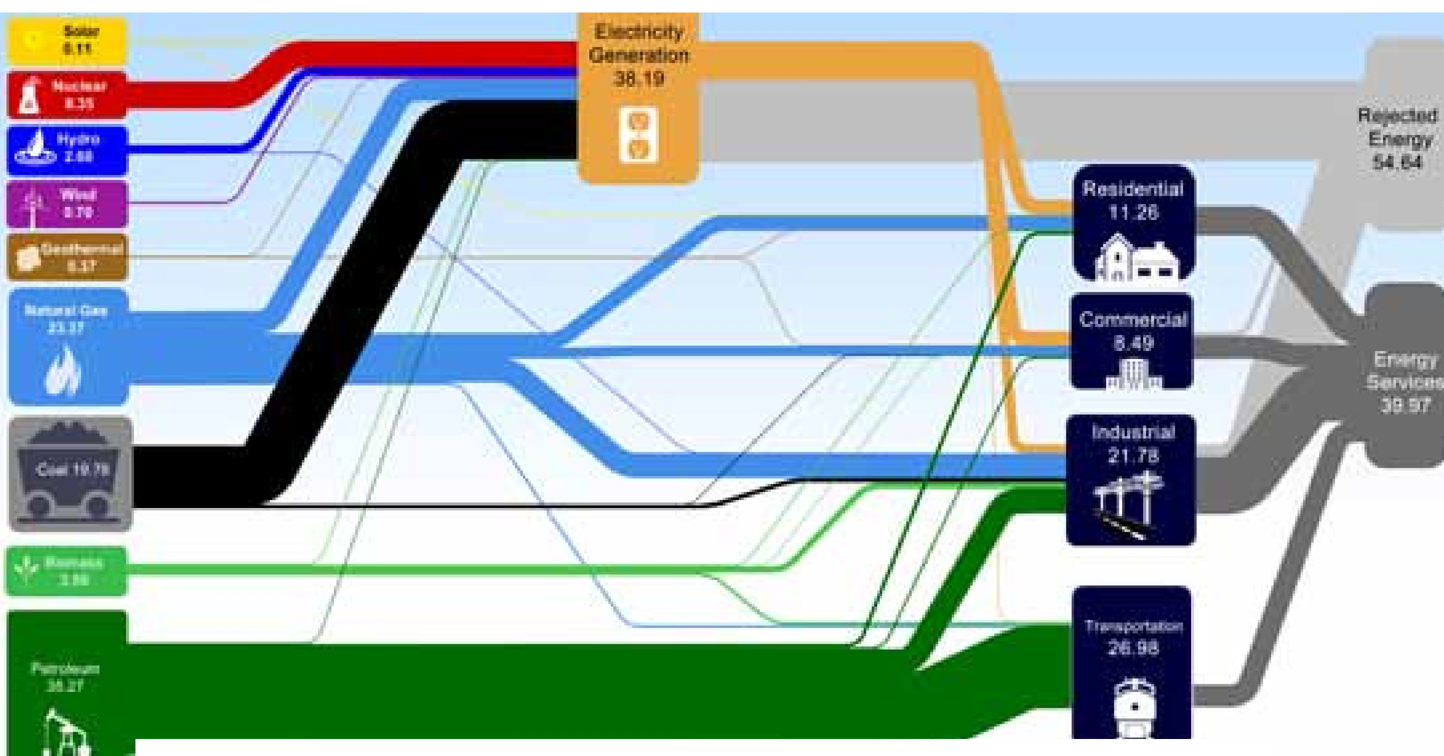
U.S. Energy Flows by Sector



Estimated energy use in 2009: ~94.6 Quads

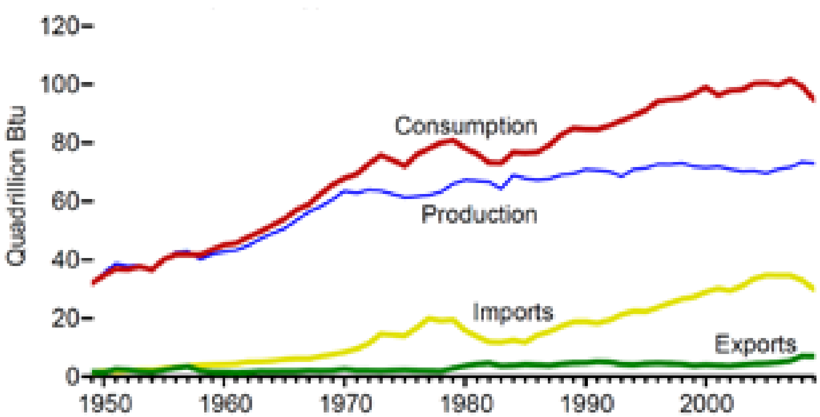
Source: Lawrence Livermore National Laboratory and the Department of Energy, LLNL 201. Data is based on DOE/EIA-0384(2009), August 2010.

CO_2 Flows by Sector



Estimated U.S. Carbon Dioxide Emissions in 2007: ~5991 Million Metric Tons

Energy Overview



The U.S. was energy self sufficient through the late 1950s. The divergence between red and blue lines, indicates the extent to which we have become dependent on foreign oil (and to a lesser extent, since the late 80s, natural gas).

Source: U.S. Energy Information Administration, "Annual Energy Review 2009," http://www.eia.doe.gov/emeu/aer/pdf/perspectives_2009.pdf, p. xix.

consumption began to outpace domestic production. In 2009, 60% of the oil consumed was imported and 40% of that comes from unstable states. **Reducing our dependence on foreign oil** is of primary importance to our national security.

In working toward that goal, developing clean energy sources is a key strategy. This economic sector is undergoing tremendous growth with investments increasing at a 50% annual rate since 2004 and topped $100B in 2007.[4] Policy is playing a central role in this development. Renewable portfolio standards (RPSs), requiring electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date, have been adopted by over 30 states and many countries. For electrical utilities to meet these standards on a large scale, **increased use of low-carbon power generation** is needed.

Reliably delivering energy to its end-use points is vital to our national security and economic prosperity. We must **increase the security and resilience of our electrical grid and energy infrastructure**—make it resilient enough to compensate for interruptions and flexible/intelligent enough to incorporate the planned renewable energy sources (with their inherent variability in power generation). The national power grid is based on technology developed in the 19th and early 20th centuries, and much of it was built in the years surrounding World War II. This aging grid is susceptible to damage and outages from storms, accidents, and human error. The fragility of this system was unfortunately demonstrated in 2003 by the blackout that struck the Northeast. While this was an unusually widespread event, the Galvin Electricity Initiative tells us that each day roughly 500,000 Americans spend at least 2 hours without electricity in their homes and offices. Such outages cost our economy $150B each year.[5]

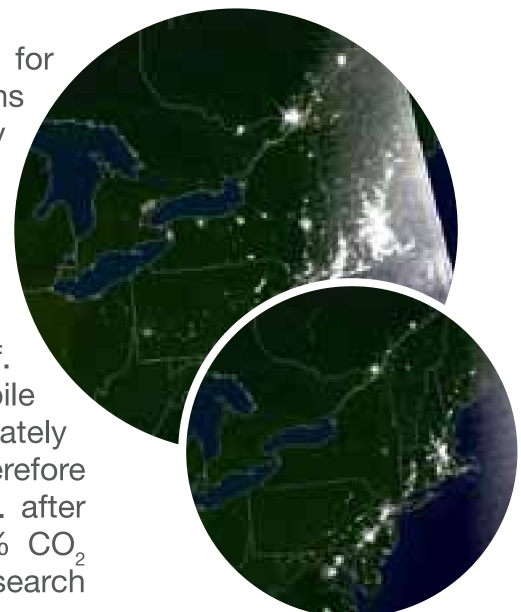
Economic prosperity is not all that is at stake. A failure in the power grid affects other critical infrastructure such as hospitals, fire and rescue, and military and police agencies. Interruptions put these security and safety institutions in jeopardy—an intentional disruption could have even greater consequences. To forestall such a situation, we must secure information access to our energy infrastructure.

For the U.S. military, reliable, secure power is also essential. To function as they are intended, our military installations, tactical operations, and training all require secure and uninterrupted access to energy. According to the Defense Science Board Task Force on Department of Defense (DoD) Energy Strategy, the DoD is the largest single consumer of energy in the U.S. In 2006, the DoD spent over $3.5B for energy to power fixed installations. An essential element of our national security is **assuring energy security for critical installations**.

Intimately coupled to the increasing need for energy are the threats posed to our environment by emissions of greenhouse gases (GHGs) leading to climate instability. This hazard is fundamentally different from previously identified acid-rain-producing pollutants. Natural atmospheric processes neutralized these pollutants relatively quickly and the environment began to recover. Carbon dioxide's effects are more subtle and slower acting, requiring 1,000 years to break the molecule down. The chart shown on the next page indicates the levels of these emissions since the beginning of industrialization and their rapid increase since the 1950s. Sandia's extensive competencies in systems analysis and uncertainty quantification couples with our foundational research capabilities to allow us to provide policy makers with usable (properly formulated and properly communicated) information that assists them in **understanding risks and enabling mitigation of climate change impacts.**

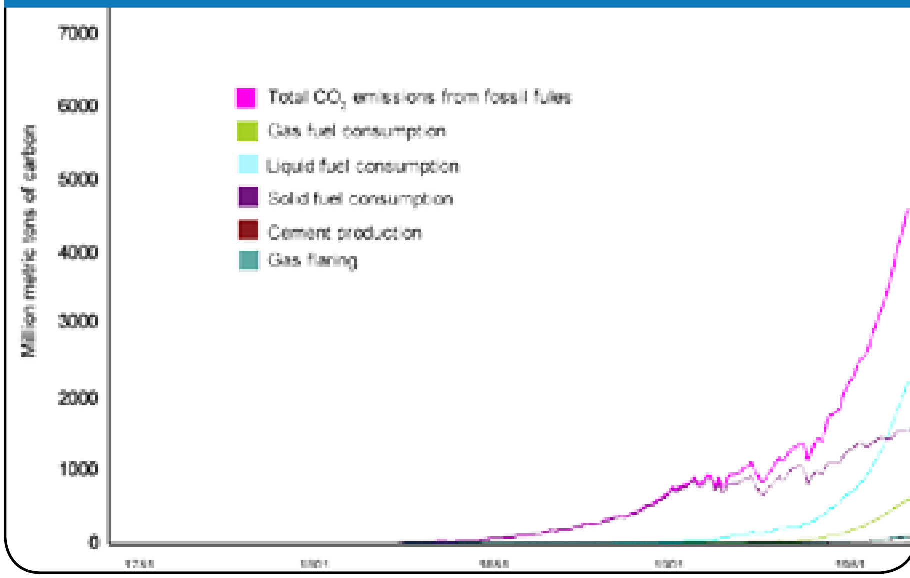
Aggressive national goals for reducing GHG emissions by 17% by 2020 and by 83% by 2050[6] will require major improvements in all aspects of our energy use. Achieving an 80% reduction of CO_2 by 2050 may seem a long way off. However, the U.S. automobile fleet turns over approximately every 20 years—therefore every car sold in the U.S. after 2030 must meet the 80% CO_2 reduction. Foundational research will be needed to develop new mitigation approaches and technologies to address the global GHG inventory—thus advancing credible carbon management strategies.

For the foreseeable future, fossil fuels will be an essential energy source for modern societies. New technologies will be a significant factor in credibly and economically managing fossil fuel energy production's effects on the environment and the climate we experience. Climate instability could also



NOAA satellite images of the Northeast and lower Canada before (top) and during (bottom) the 2003 outage.

Global carbon emissions from human activities (1750–2004)



Source: Marland, G., T.A. Boden, and R.J. Andres, "Global, Regional, and National CO_2 Emissions," in *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

create geopolitical disruptions, changing the global balance of power. A sound understanding of the potential socio-economic changes driven by climate is an essential **foundation to enable a global climate treaty.** We must develop a deeper understanding of climatic processes, which will provide the scientific foundation that will make such a treaty both possible and meaningful should the U.S. desire to enter into one. And, should climate instability effects become more pronounced, access to safe, secure, and sustainable sources of fresh water will become more difficult, and may shift. Under these circumstances, we must work to assure water safety, security, and sustainability.

To overcome these looming issues in energy generation, infrastructure security, and climatic effects, the nation requires science-based technological advances—not only in applied areas to refine and improve existing technologies, but in foundational science that will underlie the next generation of transformative technologies that will address the roots of these energy/infrastructure/climate challenges. It is clear that how we address and eventually meet these needs will have a broad impact on our standard of living and the national economy. Effective solutions will require scientific breakthroughs and truly revolutionary developments. We must facilitate these developments by **strengthening the nation's S&T base to accelerate innovation for energy and climate security.**

Our future security is not assured without a strong national economy. The energy enterprise constitutes 8.8% of the U.S. gross domestic product and approximately 9% globally. The growing green economy provides a tremendous opportunity for economic growth and leadership. This is now recognized internationally and the competition is fierce—particularly from China. Meeting targets on GHG emissions and improving energy security will require hundreds of billions of dollars of investment in renewable technologies, and this opens up the attractive prospect of an explosive growth in jobs in these new industries at a time when more traditional jobs are disappearing. The unanswered question for the developed world is where those jobs will be.

While countries such as the U.S., the UK, Germany, and Japan have all worked hard to be centers of green technological development, parts of the rapidly industrializing world have also seen the opportunity. Western governments are acutely aware of the need to build up their green industries quickly, or face being outdone by the rapid growth in China and India.

The ECIS SMU here at Sandia stands ready to play its part in supporting the nation in implementing the President's ambitious agenda to invest in clean energy, reduce our dependence on foreign oil, address the global climate crisis, and create millions of new jobs. A secure energy future will rely on industry. Central to our strategy will be to expand and deepen our partnerships with U.S. industry to accelerate the development of new energy and climate technologies.

In the ECIS SMU, our vision is building upon our 40 years of energy research programs and strengthening the coupling to our foundational systems engineering in the support of stockpile stewardship to **enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.**

Sandia researchers hold up samples of their recently developed glitter-sized PV cells.

Our **Vision**

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

Guiding **Principles**

Our strategy has been guided by two central concepts:

- Industry plays the leading role in providing and adopting new energy and climate technologies.
- Policy and regulatory decisions at all levels of government drive the implementation of any new approaches to our nation's energy, climate, and infrastructure security.

National **Energy Challenges**

- Reduce our dependence on foreign oil
- Increase use of low-carbon power generation
- Understand risks and enable mitigation of climate change impacts
- Provide the foundation for a global climate treaty
- Increase security and resiliency of the electrical grid and energy infrastructure
- Assure energy security for critical installations
- Strengthen the nation's S&T base in energy, climate, and infrastructure

10 Year **Objectives**

Anticipate & Enable Policy & Regulatory Decisions

Anticipate and enable sound government policy and regulatory decisions by providing timely and objective technology assessments and systems analyses.

Accelerate Solutions

Accelerate U.S. industries' innovation, development, and successful deployment of solutions to the nation's most challenging energy, climate, and infrastructure problems to meet U.S. policy objectives.

Steward Competencies

Create and steward enduring science, systems, and security competencies to support inherently government functions and services and anticipate national security challenges.

Support International Engagement

Support U.S. leadership in global energy, climate, and infrastructure challenges through strategic international engagement.

Energy, Climate, & Infrastructure Security

Program Areas & Goals

ECIS has four principal program areas each led by a director: Energy Security, Climate Security, Infrastructure Security, and Enabling Capabilities. Each program area has a set of five-year goals, aligned with the SMU objectives and national challenges that drive our internal investments. Program development resources are directly tied and

Energy Security

To accelerate the development of transformative energy solutions that will enhance the nation's security and economic prosperity.

The Energy Program Area consists of research programs in renewable energy systems; nuclear energy systems; energy for transportation; and energy efficiency.

Climate Security

To understand and prepare the nation for the national security implications of climate change.

The Climate Program Area is home to research programs for sensing and monitoring; modeling and analysis; carbon capture, sequestration, and water management; and water systems.

tracked to these goals. Our program area goals are not intended to be fully comprehensive for the entire set of SMU activities but instead form the principal roadmap for priority investments. They align with federal program priorities, our current activities and competencies, and our focus for future impact.

Infrastructure Security

To secure the nation's critical infrastructure against natural or malicious disruption.

Enabling Capabilities

Provides a differentiating science understanding that supports the SMU and Sandia's mission technologies now and into the future.

The Infrastructure Program Area hosts Sandia's expertise and capabilities in cybersecurity; electricity transmission, distribution, and energy infrastructure; modeling and analysis; and energy assurance.

The Enabling Capabilities Program Area is home to the discovery science and engineering (basic research); systems analysis; regulatory and policy support activities; and Advanced Research Projects Agency-Energy (ARPA-E) efforts that support the other program areas in their efforts.

Energy Security

The Energy Security program area works to accelerate the development of transformative energy solutions that will enhance the nation's security and economic prosperity.

Energy security research at Sandia seeks to address key challenges facing our nation and the world. We work with the energy industry to improve current solutions and develop the next generation of technologies to extract or produce energy.

The ECIS SMU spearheads research into energy alternatives that will help the nation reduce its dependence on fossil fuels and to combat the effects of climate change. Sandia's long history with geothermal, solar, and wind energy research has seen a vast increase in effort and intensity over the past 15 years and has also been supplemented in recent years with efforts in biologically based fuels: biomass from nonfood plant sources and algae—both of which can be grown on land unsuitable for farming.

Sandia researchers are pushing back the boundaries of the energy frontier with revolutionary projects like Sunshine to Petrol, which converts CO_2 and water into synthetic fuels, thus strengthening our energy security by providing new alternative fuel sources.

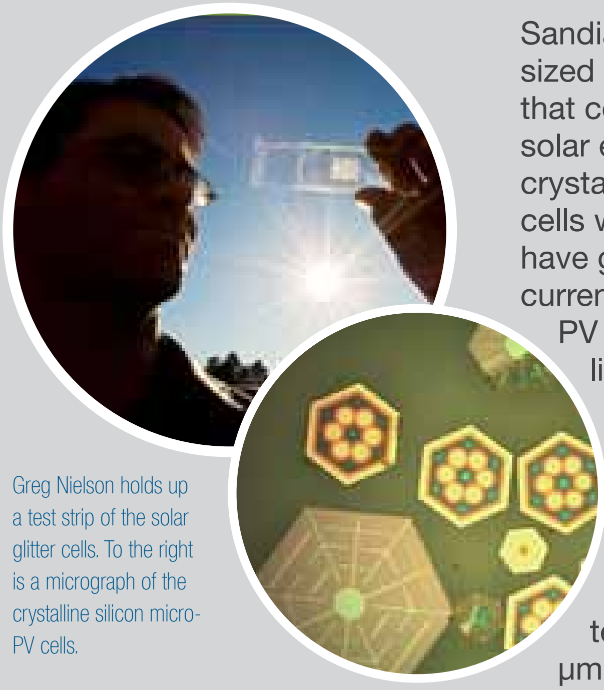
Approximately 28% of the energy our nation uses transports people and goods from one place to another. Nearly all of this energy is derived from petroleum: gasoline for cars and light trucks; diesel fuel for heavy trucks, busses, locomotives, and construction vehicles; and jet fuel for airplanes. Personal vehicles, mostly cars and light trucks, consume 60% of the total energy used for transportation. Together, gasoline and diesel fuel make up 84% of all the energy used in transportation.

Sandia's Energy for Transportation activity studies reacting flow fluid dynamics, combustion chemistry, engine combustion, thermal/fluid mechanics and heat and mass transfer, and hydrogen & combustion technologies to develop a science-based, first-principles understanding of combustion's properties and behavior in order to help industry:

1. improve current engine technologies to be more efficient,
2. reduce or eliminate a variety of harmful engine emissions, and
3. develop the next generation of engines that can efficiently use new fuel formulations and low-carbon alternative fuels that will help us reduce our impact on the environment.

Geologists and geophysicists in the ECIS SMU work with the strategic petroleum reserve (SPR) program to identify and characterize underground caverns to be used to store the nation's reserve crude oil. Our researchers also work to

Solar Glitter



Greg Nielson holds up a test strip of the solar glitter cells. To the right is a micrograph of the crystalline silicon micro-PV cells.

Sandia developed tiny glitter-sized photovoltaic (PV) cells that could revolutionize solar energy collection. The crystalline silicon micro-PV cells will likely be cheaper and have greater efficiencies than current PV collectors. Micro-PV cells require relatively little material to form well-controlled, highly efficient devices. Cell fabrication uses common microelectronic and micro-electromechanical systems (MEMS) techniques. From 14–20 µm thick, they are 10 times thinner than conventional cells, yet perform at about the same efficiency.

Micro-PV benefits include improved performance, reduced costs, higher efficiencies, and new applications. Units could wrap around unusual shapes for solar power integrated into buildings, tents, and maybe even clothing. Rooftop micro-PV modules could have intelligent controls, inverters, and even storage built into the chip—simplifying the grid-integration process. The tiny cells could turn a person into a solar battery charger—military personnel in the field or backcountry hikers could recharge batteries for phones, cameras, and other electronics as they walk or rest.

improve the processes in the nuclear power and waste disposal industries while also perfecting new concepts like the small modular reactor (SMR) that will contribute to the next generation of nuclear power generation.

Energy Security Goals

1 **Develop advanced solar energy technologies and systems that will enable a domestic solar industry to deliver electricity at less than 10¢/kWh.**

A key requirement to the acceptance of new energy technologies is bringing the cost to parity with existing technologies. For example, once wind-generated electricity became competitive with prevailing prices (~11 cents/kilowatt-hour in 2008), wind turbine deployment in the U.S. skyrocketed to the point that the U.S. became the leading nation for wind-generated electricity in 2007[7] with 36,300 MW of generating capacity installed by June 2010[8].

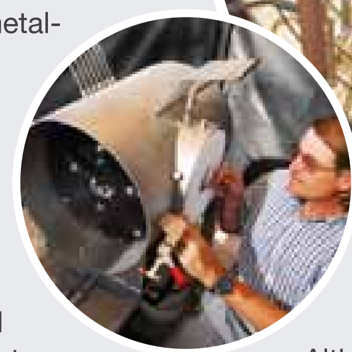
DOE Solar Energy Technology Program has key targets and funded research activities to accelerate the development of PV technology capable of producing electricity at grid parity, ~10¢/kWh. Sandia supports this goal through innovative research and development (R&D), technology development, performance testing and reliability, and market transformation (deployment). The goal of Sandia's efforts is to leverage our broader laboratory capabilities and recent R&D advancements in microsystem-enabled PV and related materials, solar resource forecasting using high-performance computing (HPC), and large-scale (1 kW) integrated PV modules.

Sunshine to Petrol

The Sunshine to Petrol (S2P) team is building capabilities and expertise while establishing viability and the technical roadmap for thermochemical technologies based on concentrating solar energy to provide heat to reach high temperatures that drive thermochemical reactions.

To accomplish this, the team is developing a novel continuous flow, recuperating thermochemical heat engine driven by direct heating of reactive materials by concentrated solar irradiation. The engine converts either carbon dioxide or water to carbon monoxide or hydrogen, respectively—the energy-rich building blocks for producing sustainable synthetic fuels that can be equivalent to today's fossil-derived liquid fuels, with domestic resources and low-net-carbon emissions. To realize this concept, the team must address and solve complex chemical, materials science, and engineering problems associated with the techno-economics of a full system (sunlight to liquid hydrocarbon fuels) prototype thermochemical heat engines and the crucial enabling metal-oxide working materials.

The S2P team, assembled from Sandians in both New Mexico and California and including collaborators from universities across the country, has proven the concept in the laboratory in batch mode, on the computer with detailed reactor models, and in continuous mode on sun in their prototype device—a hand-built precision device currently undergoing tests at the solar furnace at Sandia's National Solar Thermal Test Facility.



The parabolic mirror of Sandia's solar furnace (above) concentrates solar energy onto the receivers of the S2P device (left).

Although S2P is years away from a market-ready device, we envision a program of continuously improved generations of materials, reactors, and S2P systems, a new generation every three years with significant improvements in performance (sunlight-to-fuel efficiency), greater durability, and reduced cost.

In order to meet the administration's aggressive clean-energy goals, cost reductions and improvement in efficiency of renewable technologies must be achieved. Although solar energy deployment has experienced large industrial growth over the last few years, the cost of energy is still higher than needed to achieve this large-scale deployment.

In order to achieve the needed cost reductions, transformational advancements in technology are needed. Developing advanced solar technologies and systems that will deliver electricity at less than 10¢/kWh will provide the U.S. industry with a competitive advantage worldwide. PV systems that meet the 10¢/kWh goal would increase the viability and deployment of solar systems throughout the nation. Key technology breakthroughs would enable PV to economically compete with other forms of electricity generation to meet our future energy demand.

2 Demonstrate, in a working prototype, 12.5% sunlight to syngas (or other intermediate) and analysis for a system design to achieve >6% end-to-end sunlight to fuel and a roadmap to >10% lifecycle sunlight to fuel.

The nation faces a difficult transition to a non-petroleum-fuel-based transportation sector. In the interim, strategic investments are needed to identify ways that clean energy solutions can provide a significant contribution, mitigate climate change risks, and co-exist with petroleum-based fuels. In order to address the nation's vulnerabilities with regard to energy security and from petroleum-based fuels, innovative approaches are needed to ensure diversification in our energy and fuel supply. The Solar-Driven Carbon Capture and Recycle to Fuels program is designed to provide a resource efficient and scalable alternative to augment our current fuel supply base by developing a methodology and implementation of clean, sustainable, and fungible fuels.

Given today's transportation energy infrastructure and the effectiveness of our current suite of liquid fuels, replacement solutions will be both difficult and take time to develop. Sandia has leveraged existing capabilities and resources to begin to answer some of the fundamental questions and approaches to this dilemma. Initial results have shown great promise and the viability of producing clean fuels from the sun and domestic resources at high efficiency and affordable costs, but investments and partnerships will be critical to fully realize the opportunity.

Our multi-institutional Sunshine to Petrol team is working to develop/demonstrate 12.5% sunlight-to-syngas energy conversion and analysis for a system design to achieve >6% end-to-end sunlight to fuel and a roadmap to >10% lifecycle sunlight-to-fuel. The team has developed a wide range of characterization and computational analysis tools, deep expertise on thermochemical metal oxide reactive materials, reactors, and systems and has designed and built a prototype thermochemical engine, the Counter Rotating Ring Receiver Reactor Recuperator, which has been tested at Sandia's NSTTF. In addition to providing a renewable-based fuel, this approach leverages existing solar-based technologies that enable an efficient pathway to marketplace. The methodology is significantly more efficient when compared to other approaches, but also provides a scale-up strategy that leverages the existing infrastructure and supply chains and can deliver a significant percentage of our transportation fuel needs.

3 Develop reactor design and support systems to demonstrate the application of small, modular reactors to fulfill DoD mission goals for energy security.

While not explicitly denoting SMRs, the DoD 2010 Quadrennial Defense Review defines energy security as: "…having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet operational

The small, modular reactor concept (above) places a sealed reactor underground wherever electricity is needed. It does not require the large infrastructure and water supply of a traditional reactor (left).

National Energy Goals[6]

- Reduce energy-related GHG emissions by 17% by 2020 and 83% by 2050, from a 2005 baseline.
- By 2035, 80% of America's electricity will come from clean energy sources.
- Support deployment of one million plug-in electric vehicles on the road by 2015.

needs." To address energy security while simultaneously enhancing mission assurance at domestic facilities, DoD will accelerate innovative energy and conservation technologies from laboratories to military end users. The surety microgrid concept is to place power-generating facilities and energy storage within the military installation. During an interruption of the civilian power grid, the base will be able to operate critical functions and perform its designated operations. The use of renewable-energy power generation sources will free the base from the logistical tail and vulnerability of trucked-in fuel supplies.

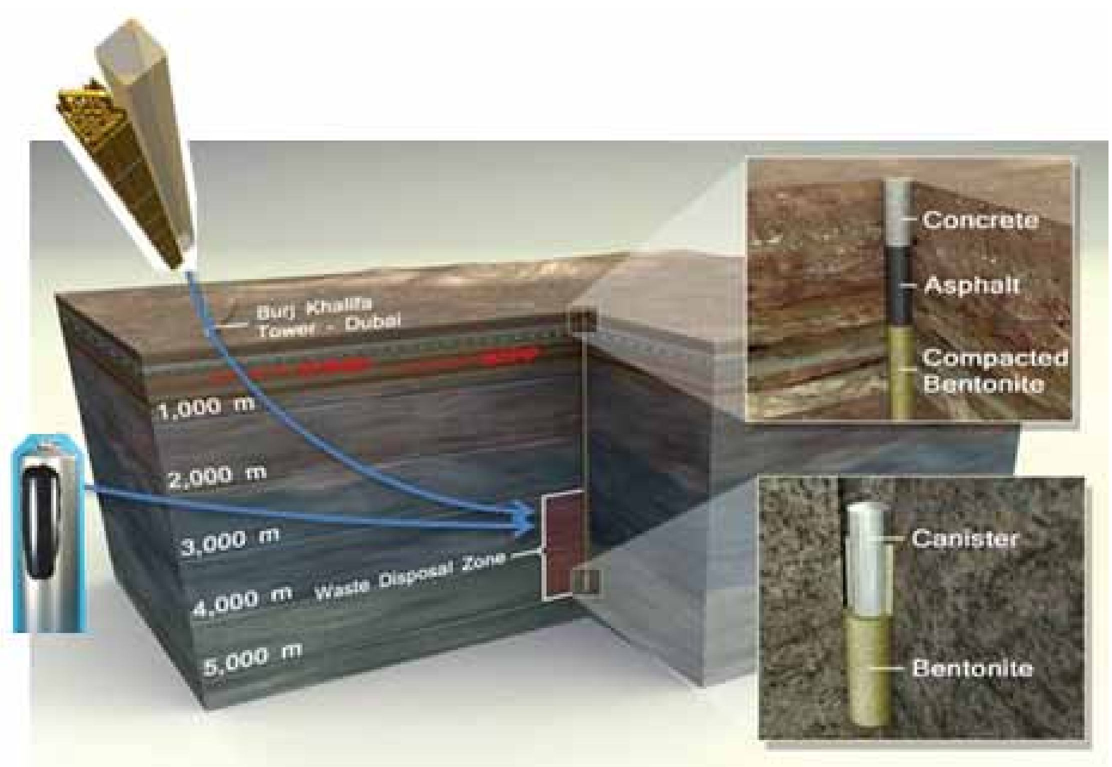
SMRs have considerable DoD appeal—primarily for their matched power output and the possibility of location within DoD bases for grid independence and security. DoD is actively soliciting solutions for energy security for all installations, both forward-based missions and continental U.S. bases. SMRs have DOE interest for their commercial appeal primarily for their expected lower capital costs to first power, their size and modular scalability, and their benefits of carbon-free energy production. DOE is standing up programs to support the demonstration of SMRs. The NRC is awaiting the application for design certification of up to four SMRs: three based on light water reactor technology and one based on sodium technology. Military installations could potentially be used as a test bed to demonstrate and create a market for innovative energy efficiency and renewable energy technologies coming out of the private sector. The capabilities developed at Sandia National Laboratories present an opportunity to provide the systems analysis necessary for the demonstration of nuclear power as an effective solution at the right price for mutual DOE and DoD energy security goals. Sandia's assessments of military energy security, activities in DoD logistic support, SMR design and construction, and reactor safety assessment position us to facilitate the DOE demonstration of an SMR at a DoD base. Sandia's goal is to facilitate the demonstration of commercial SMRs at DoD bases through collaboration with the DOE light-water SMR program. Leveraging the resources inherent to DoD continental U.S. bases and DOE nuclear energy capabilities positions Sandia to lead the demonstration of one solution to clean, safe, secure, energy independence and address a national security issue.

The SM-1 reactor at Ft. Belvoir was the first U.S. reactor to be connected to the commercial electricity grid.

4 Complete a deep borehole disposal system demonstration project with industry that will transform nuclear waste management.

A typical nuclear power plant generates around 20 metric tons of used/spent nuclear fuel in a year. The U.S. nuclear industry generates a total of about 2,300 metric tons of used fuel per year. Over the past four decades, the entire U.S. nuclear industry has produced about 62,500 metric tons of spent nuclear fuel. If used fuel assemblies were stacked end-to-end and side-by-side, this would cover a football field about seven yards deep. In 1982, Congress passed legislation which established the Nuclear Waste Fund. Those who use electricity supplied by nuclear energy would pay for the used nuclear fuel disposal program. For every kilowatt-hour used, consumers of nuclear generated electricity contribute one-tenth of a cent into the waste fund—~$750M per year. Congress assigned responsibility to the DOE to site, construct, operate, and close a repository for the disposal of spent nuclear fuel and high-level radioactive waste. The U.S. Environmental Protection Agency was directed to set public health and safety standards for releases of radioactive materials from a repository, and the NRC was required to promulgate regulations governing construction, operation, and closure of a repository. An Office of Civilian Radioactive Waste Management (OCRWM) was established in the DOE to implement the law.

Until recently, OCRWM was preparing a site at Yucca Mountain, Nevada, for this purpose. Sandia was the lead laboratory that assisted OCRWM in preparing the licensing application that was submitted to the NRC in the summer of 2008. With the closing of the Yucca Mountain site, the nation is exploring the options for the safe disposal on this high-level radioactive waste by means of a Presidential Blue Ribbon Commission on America's Nuclear Future. Deep borehole disposal (DBHD) is a concept that has been discussed for many years, but never pursued



Deep borehole disposal would entail sealing high-level waste several kilometers below the surface, where chemically reducing conditions will reduce the transport of most radionuclides.

Solid State Lighting


Sandia researchers hold up examples of their SSL research. LEDs use only a fraction of the energy of other lights and lasts much longer.

Lighting uses ~22% of U.S. electricity, ~$50B/year. Solid-state lighting (SSL) can reduce that energy use by 3–6 times. SSL devices use semiconductors (crystalline, organic, or polymer light-emitting diodes) for light rather than filaments/plasma/gas. Compared to incandescent lights, SSL devices create visible light with greatly reduced heat generation/parasitic energy loss, less mass provides better shock/vibration resistance than brittle glass tubes and long filaments, and they have much greater wear lifetimes.

SSL devices are replacing incandescents in many applications requiring durability, compactness, cool operation and/or directionality—they're used in modern traffic signals; vehicle, street/parking-lot, and train marker lights; building exteriors; and remote controls.

However, SSL devices remain ~5–10 times away from their potential. Sandia's SSL team studies

- energy-efficiency-limiting mechanisms and defects in SSL materials;
- electricity conversion to light using radically new designs (luminescent nanowires, quantum dots, and hybrid architectures); and
- energy conversion processes in structures that are smaller than light wavelengths.

despite several advantages, due to emphasis on mined repositories and concern regarding retrievability. As the U.S. policy apparatus revisits national policy on nuclear waste management, DBHD system concepts are being seriously considered, and need a leadership coalition to demonstrate feasibility. If adopted, DBHD systems could be a 'game-changer' in nuclear waste management around the globe.

A full-scale demonstration of a DBHD system will:

- help maintain and re-establish U.S. leadership in repository sciences;
- enable closing of the fuel cycle with permanent, secure disposal of nuclear waste;
- address political/regional equity concerns over hosting a single repository by creating a solution that can be practically sited in a large number of locales;
- provide factual data to support analysis of cost savings; and
- create a permanent disposal method that is highly proliferation resistant.

5 Provide for the science-based design tools necessary for industry to reduce carbon dioxide and petroleum footprint of the transportation fleet by 25%.

Transportation by automobiles and trucks accounts for about two-thirds of our oil use[9] and one-fourth of our GHG emissions. The American Clean Energy and Security Act of 2009 describes goals for clean energy, energy efficiency, reducing global warming pollution, and creating clean-energy jobs. A certain and significant part of any path toward reducing both oil use, and concurrently GHGs, is to develop more fuel-efficient power conversion systems for vehicles and accelerate the introduction of low-net-carbon fuels. Because enhanced energy security depends strongly on reducing oil use and oil is primarily used for transportation, efficient transportation will be a key element of any energy security strategy.

The potential impact of fuel-efficiency improvements on reducing oil use and GHG emissions is enormous. As an example, current DOE program targets are to improve light-duty engine fuel efficiency by 50% and heavy-duty engine fuel efficiency by ~25% over the dominate engines on the road in each respective vehicle class. Realized to their fullest potential, such engine fuel-efficiency improvements alone would reduce domestic petroleum consumption by as much as four million barrels per day (20.9% of U.S. total in May 2011[10]) and the total U.S. GHGs by roughly 8%. As a nation, we urgently need to build on and expand such challenging efforts to provide faster innovation, development, and introduction of high-efficiency, clean power sources for vehicles. Such investments are needed to grow jobs and bolster U.S. leadership in transportation.

A national energy goal is to reduce CO_2 emissions by 83% of 2005 levels by 2050.[6] Assuming linear growth from today's emissions, we must achieve over a factor of seven reduction in CO_2 emissions. Additionally, the nation would like to reduce petroleum usage for transportation by 17% at the end of the decade.[6]

Cost-effective emission reductions will be achieved through a combined strategy of improving engine efficiency for both light- and heavy-duty vehicles, expanding the use of low-net-carbon fuels that use the existing transportation

infrastructure, and electrification (i.e., hybrids, fuel cells, or all electric while enhancing vehicle aerodynamics and reducing vehicle weight).

Because no single technology is the panacea for the future, it is incumbent to develop each advanced technology with the expectation that the market will determine the mix of engines powering our vehicles by mid-century. The Transportation Energy element of the Energy Security program area has a breadth of activities devoted to the challenges articulated above. We are working on future internal combustion engines using liquid fuels (either petroleum- or biomass-based), advanced battery materials and technologies including testing of battery packs, and the technologies to support the successful introduction of fuel cell vehicles into the market.

Future internal combustion engines will increasingly be directly injected and/or employ low-temperature combustion strategies. Whatever emerges, fuel economy will significantly improve while meeting all current and future emission standards. However, much needs to be done to enable stable operation across the full speed and load range we expect for transportation. Changing fuels, whether fossil fuel based or biomass based, place an extra burden on achieving optimal performance. For example, homogeneous-charge compression-ignition can combine increased efficiency with low pollutant formation. These engines depend on chemistry to time the combustion process, and yet the scientific understanding of the initiation chemistry is inadequate even for current fuels, and combustion characteristics of biofuels are unknown.

The U.S. Renewable Fuel Standard (RFS2) establishes a clear target for biofuels: 36 billion gallons/year (BGY) by 2022. RFS2 includes a cap of 15 BGY on corn ethanol—leaving a 21 BGY gap that must be met through advanced biofuels generated by converting nonfood biomass, e.g., lignocellulose and algae. Sandia has several programs evaluating biological and thermochemical conversion of lignocellulosic biomass into advanced biofuels. Further, we are a partner in the DOE Joint Bioenergy Institute (JBEI), led by Lawrence Berkeley National Laboratory (LBNL), which has focused on using synthetic biology to develop a biochemical route to advanced biofuels. Another strategic target for Sandia is realizing algae as a viable source of biofuels. We have programs developing new technologies for the entire algal biofuels value chain.

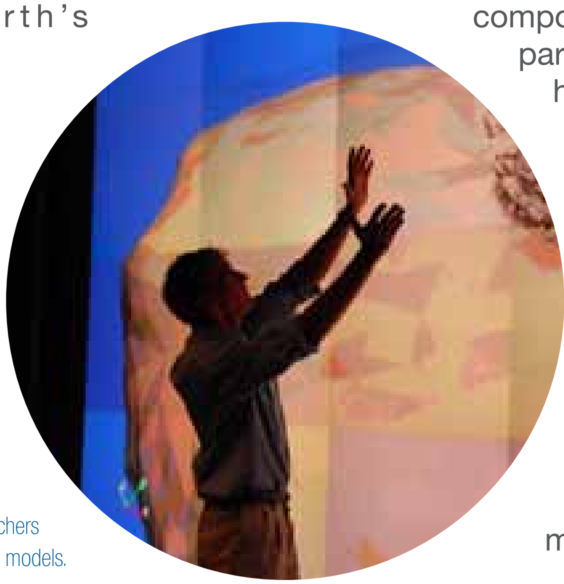
Electrification of the U.S. fleet has already begun with the introduction of hybrid, plug-in hybrid, and pure plug-in electric vehicles—and with fuel cell vehicles only a few years from introduction. For any of these technologies to have significant impact, technological advances are required. We have programs evaluating new material strategies to improve battery lifetimes, a facility used by many industry partners to determine behavior of batteries under adverse and hostile conditions, and a set of activities supporting the introduction of a hydrogen economy for vehicles powered by fuel cells.

The diverse set of activities within the Transportation Energy portfolio coordinates closely with industry, university, and national laboratory partners to ensure the best science and technology is being conducted to support the most critical needs. Providing knowledge and understanding will accelerate innovation and increase impact to address the significant challenges the U.S. transportation sector faces over the next several decades.

Climate Security

The Climate Security program works to understand and prepare the nation for the national security implications of climate change.

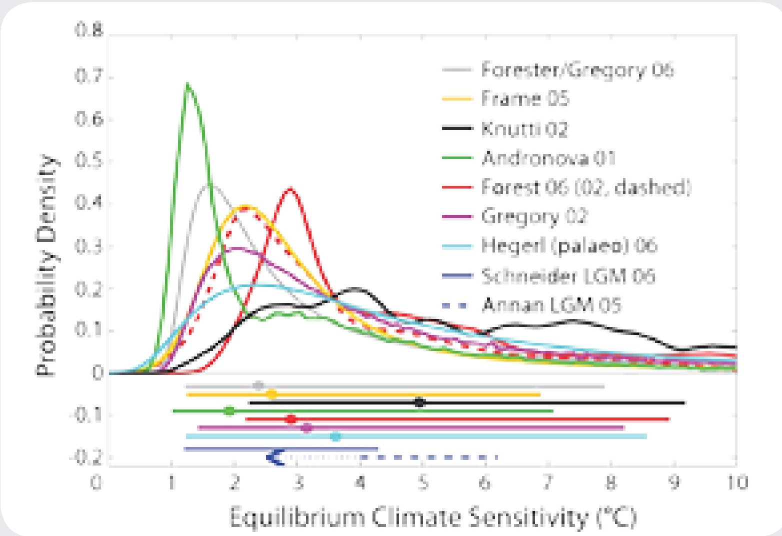
Our nation's fundamental security requires not only military capability and infrastructure, but also stability and predictability in a host of other areas ranging from energy supply, communications, and financial markets to the nation's preparedness for natural disasters and long-term changes in our environment, such as shifts in climate. It is well documented in the geologic record that the Earth's climate is not stagnant but changes continually and sometimes abruptly. Abundant scientific data point to Earth's present-day warming, and the nation must be prepared to deal with specific consequences of an evolving climate. Sandia's many technical capabilities, including geosciences, modeling and simulation, technology development, and data analysis provide a means to assess the effects of climate change on our national security. The impacts may range from international instability, to the need for additional electricity for heating and cooling, to more frequent extreme weather events. Sandia has formulated a Climate Security program, composed of four fundamental parts, to understand and help address the impacts of climate change on the nation.



Sandia researchers review climate models.

Sandia's long history of HPC simulation and analysis, along with interdisciplinary expertise ranging from atmospheric physics to behavioral socio-economic modeling, makes it an ideal source for the comprehensive, integrated analytical support required to address the interacting dynamics of climate change and (inter)national security. A central focus of this effort will be to quantitatively assess the uncertainties of socio-economic ramifications related to climate change, using methodologies derived from Sandia's NW engineering competency. By rigorously quantifying the uncertainty in a model, Sandia researchers can guide climate scientists to areas where an uncertainty will cause the widest variability in outcomes, thereby informing further high-value data-gathering and -analysis activities to support effective responses to climate change. By applying our competency in scalable simulation technology in key dimensions, Sandia can also contribute substantially to reducing critical uncertainties associated with climate—for example limiting to acceptable levels the numerical noise in cloud simulations.

Sandia Studies the Effects of Climate Uncertainties on U.S. States

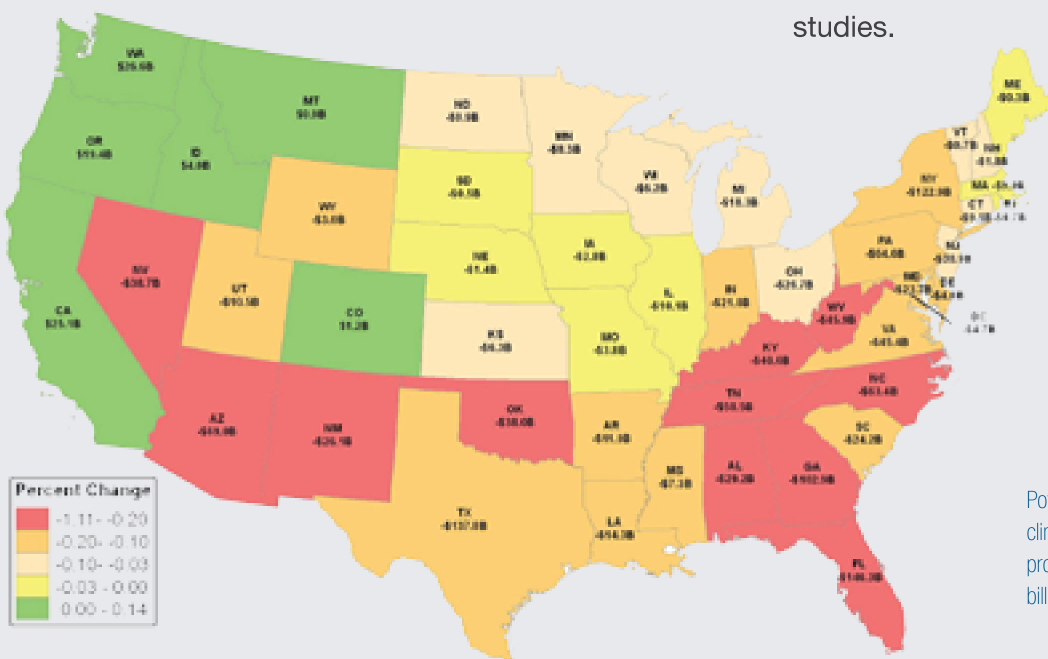


Source: Backus, G., "Assessing Near-Term Risk of Climate Uncertainty: Interdependencies among the U.S. States," Sandia Report SAND2010-2052, May 2010, p. 33.

Climate change's extent/future dynamics are highly uncertain. Global warming models in the UN's Intergovernmental Panel on Climate Change (IPCC) 2007 Assessment Report are skewed toward larger temperature changes (above). These skewed probability distributions illustrate future climatic condition uncertainty despite advances in climate science and the computational modeling of climate dynamics.

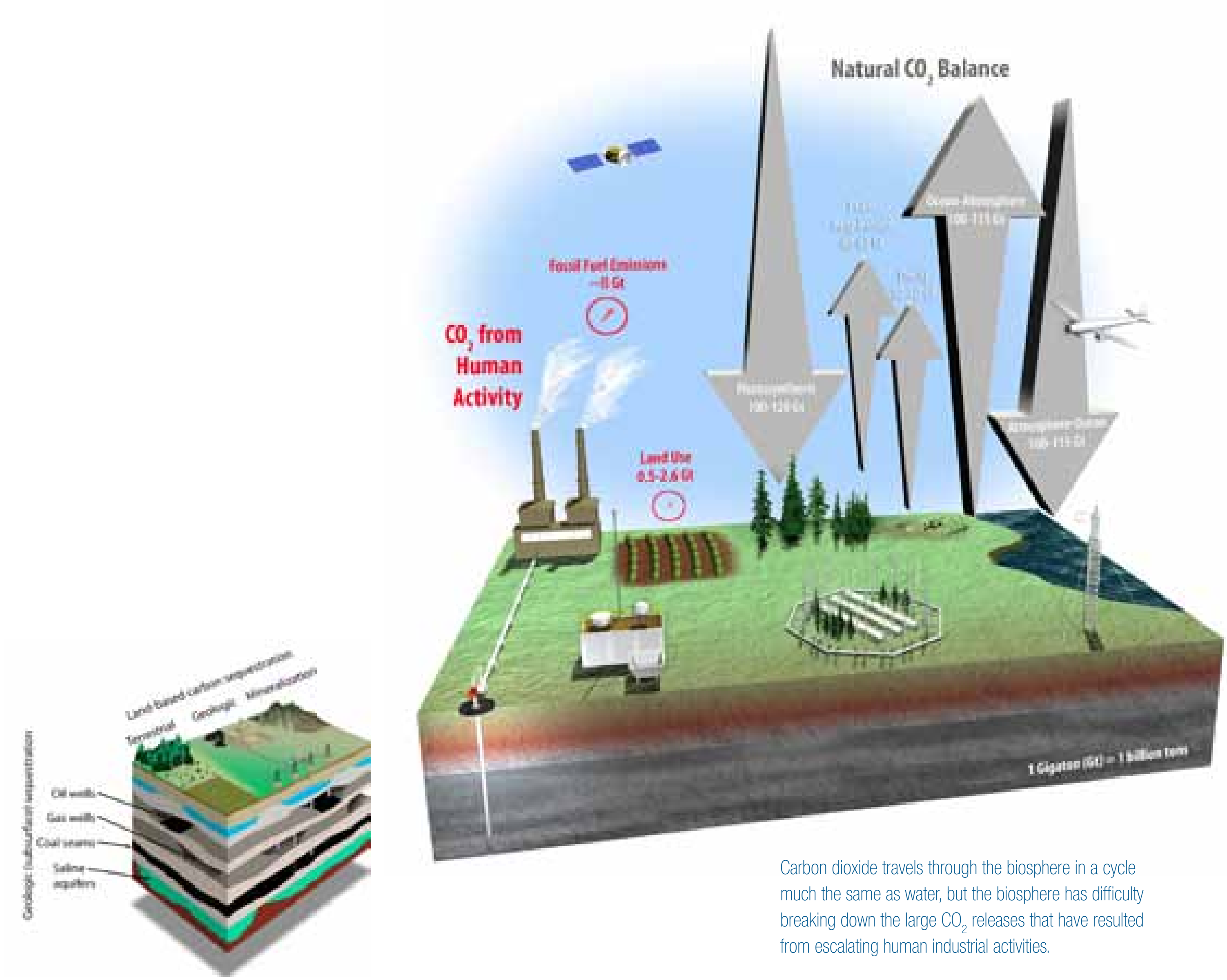
Understanding climate change risk will assist policy makers in choosing actions that could avoid the realization of those risks. Sandia researchers generated the an integrated economic assessment of climate risk among the contiguous 48 states. Using IPCC climate predictions, many Sandia scientists combined their expertise in uncertainty quantification, risk assessment, climate science, hydrology, infrastructure impacts, and macroeconomic analysis to develop a state-level risk assessment of climate change impacts through the year 2050. The most uncertain impact of the predicted climate change characteristic, precipitation, was used to assess economic impacts associated with water availability.

The potentially realized higher temperature and adverse precipitation conditions implied by the climate change probability distribution pose disparate consequences for the states across the U.S. While California and Colorado suffer the negative impacts from the loss of precipitation often noted in previous studies, worse conditions in surrounding states cause population in-migration that lead to a net benefit in California and Colorado economic conditions. In addition to the risk assessment and level of detail, this dynamic interaction among the states is a critical element that is missing from previously published studies.



Risk: the combination of potential consequences and the probability of those consequences occurring.

Potential state level impacts of climate change on gross state product from 2010–2050 in billions of 2008 dollars.



Carbon dioxide travels through the biosphere in a cycle much the same as water, but the biosphere has difficulty breaking down the large CO_2 releases that have resulted from escalating human industrial activities.

Scientists in the Climate Security program area also seek to improve our understanding of Earth's climate processes (e.g., cloud life cycle, cloud-aerosol interactions, radiative processes, etc.) by developing larger, more detailed climate data sets, through broader deployment of sensing and monitoring equipment, and by developing new sensor technologies. These efforts include refining and improving current sensors and developing the next generation of more accurate, sensitive instrumentation. Earth's climate encompasses a vast number of interactions and physical processes. Only by developing a foundational scientific understanding of these interactions and processes can scientists hope to transform our understanding of what the future may hold for Earth's climate.

Water quality and quantity issues exist nationally and globally. These water supply and availability issues will continue to become more important as demand grows and as resource availability is impacted by climate variations. The challenge we face globally is great as water-stressed populations can add to regional instability. As human population increases and climate variations lead to greater water scarcity, limited freshwater resources will force technologies to enhance

Greenhouse Gas Information System

A network of ground-, air-, and space-based sensors will collect GHG emissions data to provide GHGIS with the information necessary to report on climate treaty compliance.

A global monitoring and greenhouse gas information system (GHGIS) would provide U.S. policy makers with data of sufficient accuracy, scale, and timeliness to enter into and assessing compliance with international agreements to limit emissions and enhance GHG sinks. Detection, attribution, and quantification of man-made emissions must occur in the presence of natural sources and must be credible to contribute to verifying international treaties. Such a GHGIS must

- meet specifications in precision, accuracy, spatial resolution, and reporting frequency;
- meet data quality control and quantified uncertainty standards;
- integrate measurements from space, air, land, and sea with bottom-up inventory data, utility and transportation data, and data gathered from U.S. government and international sources; and
- cope with denied territory and the possibility that self-reporting may be in error.

Data must be reconciled and provide input to computer simulations that capture sources, sinks, and model transport in the atmosphere, land, and oceans; carbon-cycle activity; and differentiate natural and anthropogenic emissions. A multilab scoping study for the GHGIS has been completed, and the program recently transitioned from NNSA to DOE Office of Biological and Environmental Research leadership.

water reuse, development of impaired water supplies, and an understanding of competing needs and allocation impacts. Towards this end, Sandia has projects and programs in water treatment to create technologies to address water quality and quantity issues, systems modeling efforts to create decision-support tools to aid in the allocation decisions, water security work to address the safe and secure transport of water in distribution systems, water and energy projects to address the intersection or nexus of these two critical natural resources, and international outreach activities to promote peace and reduce conflict.

Transition from the current fossil-fuel-based economy to a blend of energy sources with a much higher proportion of renewable energy power generation will have two positive effects: creation of a more sustainable energy supply for our nation's future and reduction of CO_2 emissions into the atmosphere. At the same time, our national security and economic prosperity requires continual reliable sources of electricity and transportation energy—even as finding and developing domestic petroleum resources becomes technologically more challenging. Sandia contributes to the fossil-fuel transition security through technologies for safe and secure oil and natural gas production and storage, including unconventional resources such as shale gas and deep offshore deposits. Sandia helps ensure energy security by leading research related to a variety of subsurface energy storage technologies, including serving as the scientific advisor for DOE's SPR.

Development of scientifically sound, reliable, and economically reasonable mitigation technologies is central to strategy for adapting to climate change. Sandia's extensive expertise in the earth sciences, both in the laboratory and in high-fidelity modeling of earth processes, is being used to develop solutions to the technical issues surrounding carbon capture, sequestration, and management. Sandia combines experiments with modeling and simulation at a variety of scales, and encompassing many different interacting physical processes, to develop the basis for fundamental understanding of geological carbon sequestration; this knowledge will be used to predict sequestration performance.

Climate Security Goals

1 Assess U.S. prosperity and security impact risks by modeling climate and human response at the regional level with quantified uncertainty.

Climate instability could create geopolitical disruptions over the next 40 years, changing the global balance of power. Potential socio-economic changes driven by changes in climate must be understood in order to mitigate climate-change impacts on the nation, and, in fact, in the international arena. Largely, these issues have not been addressed in a systematic way. Every year that we wait increases the potential severity of the disruptions and decreases our ability to act effectively. On the other hand, acting imprudently or without the proper scientific foundation could exacerbate global climate instability or cause socio-economic suffering without significantly mitigating the situation. We must understand these issues now in order to implement the least disruptive mitigation policies possible—through reducing humanity's global carbon footprint and/or through adapting to climatic changes that cannot be stopped.

The people of the U.S. need to understand the potential domestic impacts of climate change in order to increase the resiliency of our nation and its economy under potentially challenging circumstances. We must also understand the potential geopolitical impacts of climate instability in order to maintain U.S. national security. In particular, we need to indentify and characterize the impacts of the early stages of climate change, e.g., in the Arctic, and develop policies to successfully adapt.

Global geopolitical impacts of climate instability will be an important component of U.S. security. This ECIS program-area activity seeks to assess the risks to U.S. prosperity and security by modeling climate and human response at the regional level with quantified uncertainty. To accomplish these goals, modeling and simulation activities must

- develop regional U.S. and selected regional global climate models with uncertainty quantified;
- quantify the impact vectors regionally—precipitation, disease, extreme events, etc.;
- evaluate the impacts on humans and their societies, including economic impacts; and
- analyze policy alternatives to mitigate and adapt to changing climate.

The mitigation and adaptation plans that could be created through understanding and characterizing these domestic and global impacts could greatly increase the nation's ability to successfully deal with the human impacts of climate change. It could also provide the U.S. with a global, proactive leadership position in preparing for climate change.

2 Design data-gathering and analysis systems to enable the U.S. to sign a global climate treaty.

The 2009 United Nations Climate Change Conference, commonly known as the Copenhagen Summit, was held in Copenhagen, Denmark, from 7–18 December 2009 to try and forge a global treaty to govern GHG emissions at the international level. One of the reasons this summit failed to achieve the hoped-for results was the lack of an accredited system for monitoring and measuring GHG emissions. Also lacking was a means for reliably distinguishing between natural and man-made GHG emissions. Without the ability to track, accurately measure, and reliably determine the source of GHG emissions, no country was or will be willing to agree to the obligations an international treaty would impose.

An operational and scientifically robust GHG information system (GHGIS) would combine ground-based and space-based observations, carbon-cycle modeling, GHG inventories, meta-analysis, and an extensive data integration and distribution system, to provide information about sources, sinks, and fluxes of GHGs at policy-relevant temporal and spatial

Sandia researchers developed a new filter for removing arsenic from the water supplies of small, isolated settlements

scales. In the U.S. many entities including NASA, National Oceanic and Atmospheric Administration, U.S. Department of Agriculture, DOE national laboratories, and several major academic institutions are partnering to complete a scoping study to determine the technical requirements of such a GHGIS. The ECIS monitoring and sensing program is working to develop data gathering and analysis systems and sensing technologies that will work in concert with those systems to

- enable verification of future GHG emissions treaties,
- refine representations of clouds and aerosols in climate models,
- make credible attributions of GHG emission sources, and
- measure atmospheric carbon and GHG emissions for carbon cycle and terrestrial carbon studies.

To this GHGIS partnership effort, Sandia brings an extensive technology base for remote and in situ monitoring and sensing (satellite sensing, data systems and integration, sensors); new technologies developed or in development for GHG measurements (atmospheric and terrestrial mobile lab, new sensor development programs); a good track record and current funding as Atmospheric Radiation Monitoring Program contributor (North Slope of Alaska Facilities); and Sandia has a lead role in the existing GHGIS partnership.

Sandia and other NNSA laboratories have supported the U.S. Nuclear Detonation Detection System (USNDS) since the early days of the Cold War. Sandia satellite payloads and ground systems are important components of the USNDS. Sandia provides optical and electromagnetic pulse sensors, radio frequency equipment, and the main processors that coordinate all commands, as well as return sensor output back to ground stations. We are now applying this decades-long experience/competency in sensor development and data analysis to other satellite sensing problems of national interest.

The anticipated technology for the eventual measurement system will most likely be primarily satellite based—because key, major GHG emitters are expected to resist in situ measurements for verification. Any GHG emission information system that will serve as the basis for an international treaty must be both transparent and credible.

3 Develop a credible technical path for achieving DOE's 2015 goal of an industrial-scale demonstration of carbon capture and sequestration (10MT/yr).

A growing consensus exists among climate scientists, economists, and policy makers that the link between man-made emissions of GHGs and climate instability is sufficiently likely to motivate global actions. Energy use and energy generation are at the heart of the problem, with the International Energy Agency (IEA) forecasting that global electricity generation will nearly double from 2005 to 2030.[11] The Agency's statistics predict that fossil fuels will remain a significant part of the energy mix up to 2030, comprising roughly 70% of global and 50% of U.S. electricity generation.

One of the solutions being discussed to reduce GHG emissions from fossil fuel energy generation is CO_2 capture and storage (CCS). CCS is a group of technologies for capturing the CO_2 emitted from power plants and industrial sites; compressing this CO_2 ; and transporting it to suitable permanent storage sites, such as deep underground. CCS is in the relatively early phase of development, with several key questions remaining unanswered, including about its costs, timing, and relative attractiveness vs other carbon-lowering opportunities.

Fossil fuels are forecasted to continue to play a major part of the energy mix out to at least 2050, and CCS provides the main abatement lever for stationary fossil-fuel consumers like coal-burning power plants. CCS could also provide the main means of curbing GHG emissions from heavy industrial sectors such as the steel and cement makers and petroleum refineries, which together, account for ~15% of the nation's CO_2 emissions. A 1 GW coal-fired power plant such as the San Juan plant in northwestern New Mexico will emit approximately 10 MT of CO_2 per year. An effective demonstration of CO_2 at this scale is a crucial step toward mitigating the climate impact of these emissions. Carbon sequestration could play a major role in the reduction of GHGs through increased use of clean coal, natural gas, and hydrogen.

Sandia has resources and capabilities such as geosciences, the CRF, material science, advanced simulation, probabilistic risk assessment, and dynamic simulation that, while developed for other purposes such as underground repositories, the NW program, and automobile efficiency research, can be applied to this CCS problem facing the nation and the world.

Our ECIS scientists will partner with DOE's National Energy Technology Laboratory (NETL) to ensure success of the regional partnership and the success of NETL's internal research program through collaborative S&T and partner with regional universities and industry to incorporate new capture and sequestration technology. Sandia also seeks to co-host, with LANL, in New Mexico the 2012 IEA Joint Meeting of the International Capture and Sequestration Networks (there are approximately ten of these international networks spanning areas such as public policy, modeling & simulation, and monitoring). Our partnership efforts will be working toward completing a multi-scale, multi-physics CO_2 sequestration geophysical model and leveraging our unique capabilities into a sustainable R&D program with federal agencies, universities, and industry partners to enable an industrial-scale CCS demonstration (10 MT/yr) by 2015.

4 Joint Venture for Safe and Secure Offshore Petroleum R&D—an industry-government partnership to advance R&D and emergency response for offshore oil & gas exploration and production.

Petroleum is the source of 95% of the nation's transportation-sector fuels (the remaining is 2% natural gas and 3% renewables), and natural gas fuels more than 21% of the nation's electricity generating plants. Clearly, these commodities are essential to U.S. economic prosperity and national security. While much of the petroleum that we consume is imported, a significant fraction is withdrawn from domestic sites like the Gulf of Mexico, and the majority of the natural gas we consume is still produced domestically. In addition, much of the world's offshore drilling expertise is hosted by U.S. companies or companies that employ Americans. Developing technology that can help to ensure safe, secure, and reliable offshore drilling is in the interest of national security and the safety of our citizens.

The offshore oil & gas industry is faced with technical challenges that hamper its safety and reliability such as cost-effective advances in technology that enhance safety, security, and reliability and an understanding of full-system risk and reliability for the offshore environment. In addition, the industry lacks the financial motivation to maintain an enduring R&D competency and an expertise base useful both for preventing and responding to accidents. Sandia and ECIS have capabilities in high-reliability system engineering, drilling, geosciences, material science, advanced simulation, probabilistic risk assessment, and dynamic simulation that we can leverage to assist the industry in surmounting these challenges. In addition, our 60 years of systems-engineering expertise can assist the industry establish emergency-response mechanisms including authorities, roles, and communication systems that will help restore/increase public confidence in the offshore petroleum enterprise.

Sandia can also partner with the DOE and the Department of the Interior—using that same systems-engineering approach—to work with them to develop a predictable regulatory framework for enhanced safety, security, and reliability in the oil & gas industry and a standing response and recovery capability and framework for future incidents. Due the international scope of deep-water oil & gas production, the developments of this joint venture could end up being adopted globally.

5 Deploy technology solutions that make government and private sector success in water safety, security, and sustainability, both domestically and globally.

The safety, security, and sustainability of our fresh/potable water supply are national security issues. Nationally, water is a critical part of our economy through the connection to energy production and to our economic prosperity and security. Globally, the world is challenged by water issues that add stress to populations in many regions of the world—that stress could lead to socio-political instability. Because the global climate/environment is a vast, complex, and interconnected system, the socio-economic-political issues (of which water availability is but one) are also diverse and complex with social, economic, technological, and governance dimensions.

Our goal in the ECIS water activity is to deploy technology solutions that make possible government and private-sector success in water safety, security, and sustainability, both domestically and globally, as measured by direct funding of our water program. In short, we seek to remove water availability as a constraint to human endeavors. In pursuit of this goal, it is necessary to focus on water safety, security, and sustainability issues that address both water quantity and water quality. Solutions to these problems are further complicated by the many different governmental and private-sector parties that control funding for water research and the complicated nature of water issues—ranging from an assumed guaranteed right to a variable cost resource stream. We work with the departments of Energy, Interior, State, and Homeland Security; with private-sector companies; and foreign governments and institutions to address these challenges.

To address these national security issues, Sandia's program focuses on

- water-treatment technology development to improve water quality and quantity and
- systems analysis and modeling to improve understanding and comprehension of diverse sets of information and aid water decision makers.

We apply these technological solutions to water security issues and energy and water problems to advance the state of the art and impact issues that face the nation today concerning future water supplies and adaptation to climate change.

Infrastructure Security

The Infrastructure Security program develops and applies technologies and analytical approaches to secure the nation's critical infrastructure against natural or malicious disruption.

America's critical infrastructures provide the foundation for the nation's economic vitality, national security, and way of life. They frame citizens' daily lives and support one of the world's highest living standards. The systems, facilities, and functions that comprise these infrastructures are sophisticated, complex, and highly interdependent. They are comprised of physical, human, and cyber assets and have evolved over time to be economical and efficient systems. The increasing interconnections and complexity of these systems, subject to natural hazards and coupled with the new malicious threat environment, have created the need for a focus on interdependencies and the consequences they propagate.

Infrastructure disruptions can result from natural disasters, attacks, or poor preparedness/response to a disruptive event.

A key objective of the Infrastructure Security program area is to support the preparedness and protection of our nation and society by providing analyses of the technical, economic, and national security implications of the loss or disruption of these critical infrastructures, and assist in the understanding and technology development of infrastructure protection and infrastructure disruption mitigation, response, and recovery options.

The nation's energy infrastructure, particularly electricity and hydrocarbon fuels, is of special interest because it faces two foundational challenges as we seek to forge a path toward an energy independent and secure future. First, elements of the infrastructure, such as the electricity transmission and distribution network, have not significantly changed since their initial creation over a century ago. It is clear that new approaches are required for the grid to accommodate the integration of intermittent renewable energy sources such as solar and wind. Second, the reliability and resilience of our energy distribution is central to our national security. For example, robust and secure electrical power is essential to domestic military installations.

The programs of the Infrastructure Security program area work to fully understand, sustain, improve, and where necessary revitalize, the interconnected network of energy delivery systems. Sandia's modeling and analysis capabilities allow us to understand the infrastructures' performance under unusual conditions, the effects of interdependencies, and the dynamics of their interconnections. To better understand the complexities of the interconnected infrastructures, we collaborate with private sector infrastructure experts to develop methodologies and tools for characterizing and simulating their performance.

America's energy infrastructure doesn't stop at its borders. A significant portion of the nation's liquid hydrocarbon fuels is imported from areas of the world subject to rapid social and political upheaval. This upheaval can jeopardize key facilities that process these fuels. This program area includes work addressing the protection of key fuel processing facilities and their supporting infrastructure by providing evaluation, physical protection training, and expert advice to the owners and operators of these international facilities.

As America's infrastructures have become more complex and interconnected, their operation and control has become more complicated. Automated control systems, called SCADAs (supervisory control and data acquisition systems), networked across the internet have been widely deployed to operate these infrastructures. These systems, and the internet over which they handle information, are an identified security vulnerability for the infrastructures they control. The Infrastructure Security program area works with several government agencies in the area of cybersecurity to ensure the integrity and availability of the nation's cyber infrastructure.

The performance of the nation's infrastructure is an essential component of the nation's economic prosperity. Through its programs and projects, the Infrastructure Security Program Area seeks to endow the infrastructure with five characteristics: security, reliability, safety, sustainability, and cost effectiveness.

Infrastructure Security Goals

1 Establish and grow critical cyber security capabilities within the Department of Homeland Security with Sandia as the enduring advanced development partner.

The Department of Homeland Security (DHS) has the mission of protecting civilian federal government information networks against a full range of threats. Government networks and servers are repositories of vast amounts of information that, if stolen, could compromise Americans' physical safety and security as well as their privacy and financial security. As the U.S. benefits from the past few decades' technological advances, we increase our dependence on interconnected devices and systems. This dependence creates vulnerabilities, which might be exploited by adversaries ranging from criminal organizations through nation states. The complexity of these interconnected systems and the rate of technological change cries out for a national-lab-level approach to mitigate the risks to our government systems and our critical computer infrastructures.

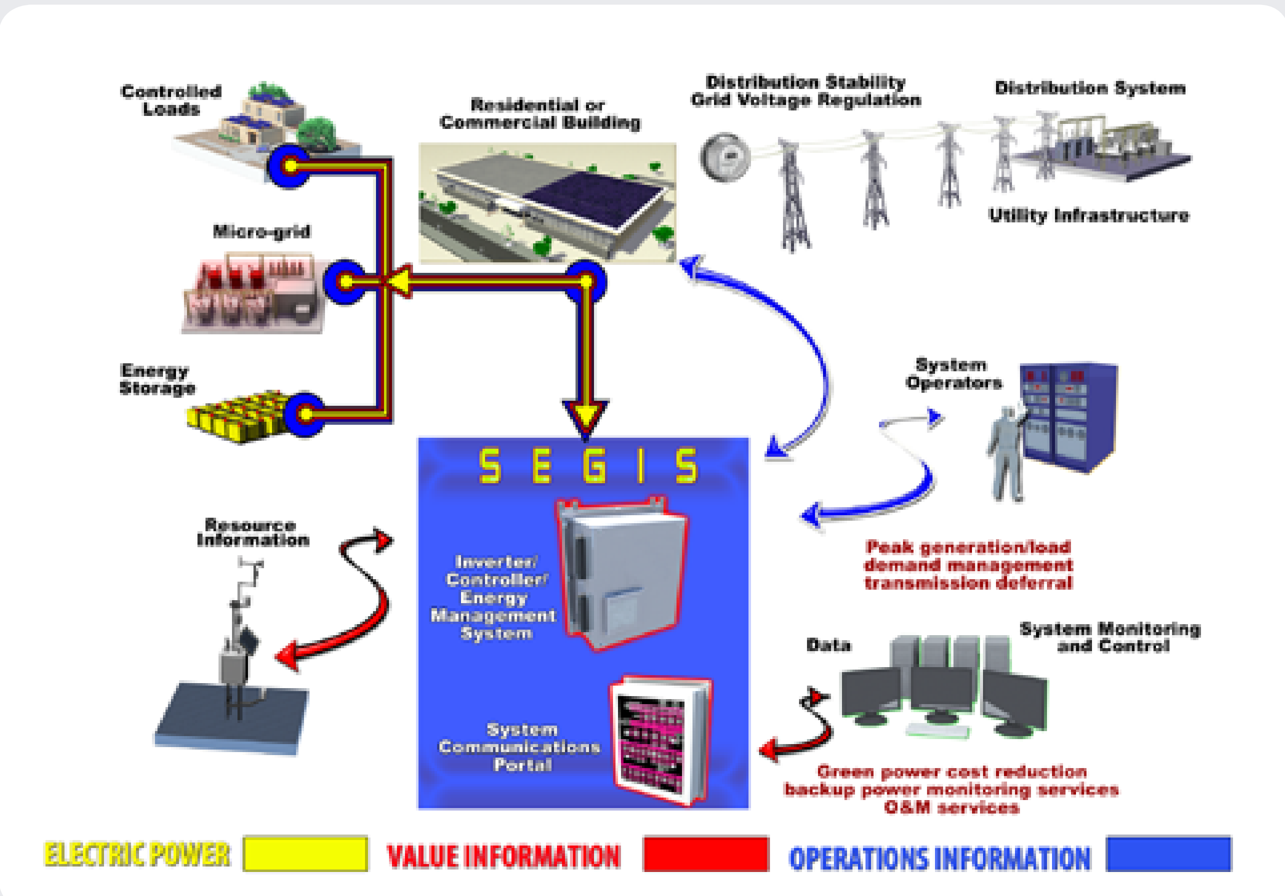
Sandia's goal is to develop game-changing cybersecurity capabilities to support DHS's

Effective cybersecurity is transparent to the legitimate network user, but secure against emergent threats from malicious agents.

Solar Energy Grid Integration Systems (SEGIS)

Sandia's SEGIS program is building new devices at the intersection of very high penetration solar photovoltaic (PV) systems and the "smart grid" of the future. Sandia is partnered with four U.S.-based teams led by power electronics manufacturers and has set the bar for the next generation of PV inverter and system controller functionality. Going beyond simply converting direct current to alternating current system output, these new devices use advanced controls and communications to interact with utilities (smart meters and energy management systems), building loads and appliances, and storage systems, such as plug-in hybrid vehicles or community-level storage, to optimize the value of PV-produced electricity while assuring grid reliability and power quality and safety are maintained. The SEGIS program seeks to seamlessly accommodate the two-way power flows required by wide-scale deployment of distributed energy resources.

SEGIS is a public-private partnership leading to the introduction of new PV components to the commercial market. Sandia engineers developed a technical specification that set the standard for performance and drove partners to assess business opportunities, thereby offering the best product to meet current and future market needs. Sandia's diligent technical oversight of the three-year development process has ensured an aggressive, highly technical approach towards reliability, system integration, and continual product demonstrations during the process. Additionally, through encouraging partnerships with potential customers, such as electric utilities, Sandia has ensured direct applicability of these new products to real market needs.

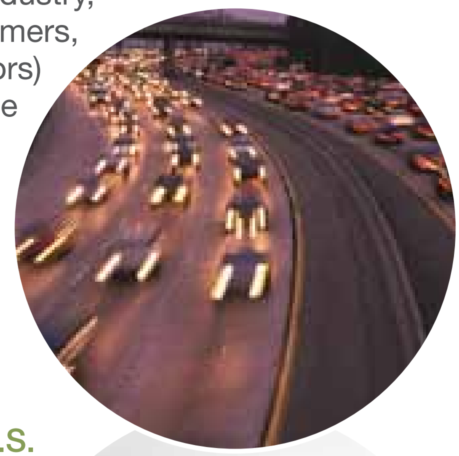


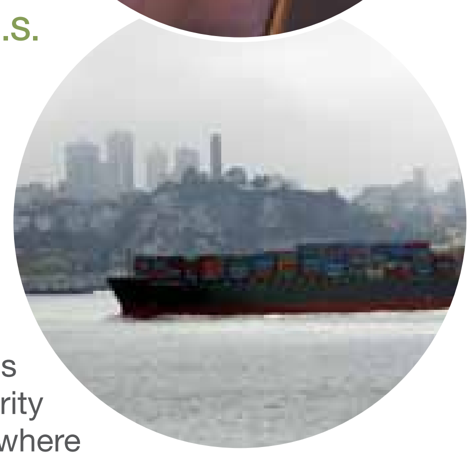
SEGIS seeks to integrate small-scale distributed energy generation into residential construction and have it interact intelligently with the electric grid.

mission of securing the nation's ".gov" domain and defending critical infrastructures (e.g., the electric grid and other energy infrastructure) from cyber-based vulnerabilities. We will evaluate systems with the potential to impact critical infrastructures for supply-chain vulnerabilities and create mitigation strategies for supply-chain-induced risks. We will devise strategies to extend cybersecurity beyond government assets to the telecommunications providers, industry partners and subcontractors, and to global partners. Lastly, we will develop a scalable process to assess and improve the cybersecurity performance of government agencies and critical infrastructures, with the objective of providing agencies a mechanism for sharing threat, compromise, and mitigation data.

Our goal is to build/use a threat model in order to guide development, acquisition, and operation of a protective system. The complexity and scale of this system will be unprecedented; it must scale over a wide range of attributes: network size, data sensitivity, communications capacity, geographical distribution, and operational authorities. Sandia is contributing to the solution by providing architectural designs based on threat models. We are providing much needed scalability to the efforts to address the cyber risks. We are tackling the big problems, like the supply-chain risk, which are so challenging as to be largely deferred by the other contributors to cybersecurity.

Sandia is partnering with the University of Vermont and an array of Vermont stakeholders (utility companies, private industry, residential and industrial consumers, policymakers, and regulators) to create a test bed of the nation's first statewide, 21st-century energy infrastructure. This Vermont initiative will require innovation in a broad spectrum of areas including Sandia's cybersecurity competencies.





2 Increase resilience of U.S. critical infrastructure systems by providing government, regulatory, and industry stakeholders with increased understanding of interdependencies and risk.

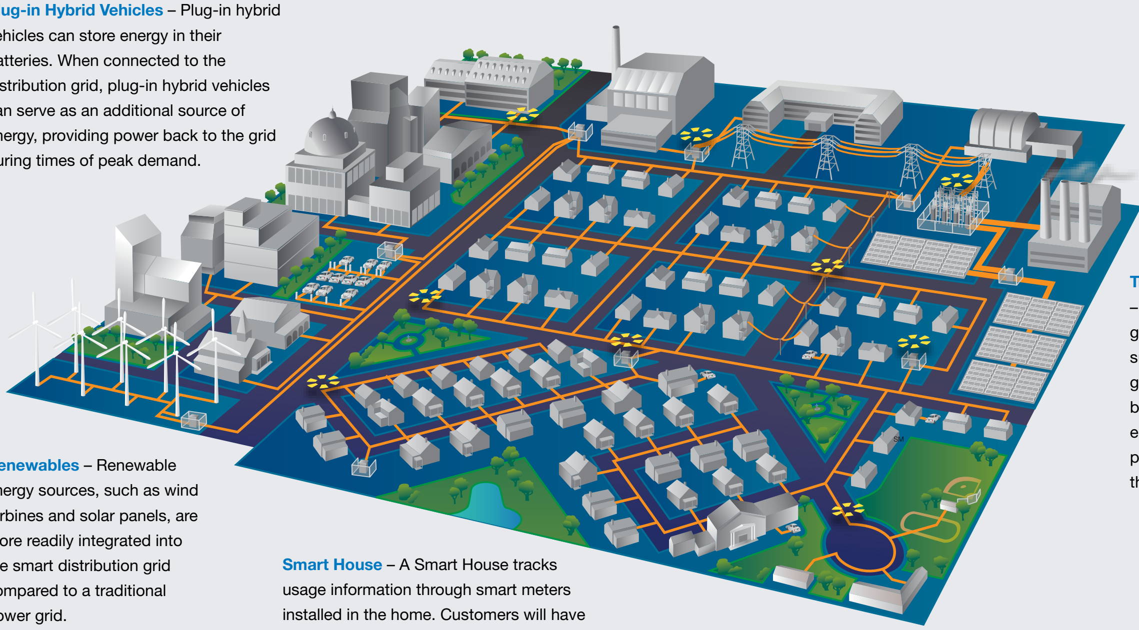
America depends on its infrastructure—not only for its continuing economic prosperity but, in this day and age where just-in-time delivery applies not only to manufacturing and industry but to energy and food supplies as well, for the survival of its urban population. Disruptions can come from many causes—some natural, some accidental, and some that are maliciously intentional. Hurricane Katrina showed us how the disruption of the gulf-states petroleum infrastructure has national repercussions. The September 11th attacks were essentially localized, but have had acute and long-term effects on a national and international scale. When the Interstate 35W bridge collapsed in Minneapolis, it took three months to clear the debris from the Mississippi. If that collapse had happened on the lower Mississippi, the disruption of barge traffic up and

Mesa del Sol and the Microgrid Concept

In a world of skyrocketing electricity demand and rising prices, consumers will assume an active role in purchasing, using, and possibly reselling their energy. Communities, office parks, military bases, and universities are choosing microgrids that incorporate these concepts, but many microgrid hardware, software, and control systems haven't been tested in real-world situations.

The New Energy and Industrial Technology Development Organization (NEDO) plans to implement microgrids in Japan. Forest City's Mesa del Sol project provides a real-world test bed. NEDO will supply advanced hardware and software for generating and controlling the flow of electricity and information between the microgrid and the main grid. New Mexico utility PNM will install PV and energy-storage within the microgrid and provide advanced metering on several homes. NEDO will construct a demonstration home with smart metering, rooftop PV, energy storage, and communicate energy usage and cost information at the consumer level. The Aperture Center, Mesa del Sol's business center, will test microgrid hardware and software at the commercial level.

Sandia and PNM jointly led use-case development for the NEDO team members and U.S. side collaborators. The use-case analysis promoted a common understanding between the technical teams and led to the generation of requirements for the individual system components. During the NEDO microgrid collaboration, Sandia will promote energy policy and data format standards that support renewable energy incorporation and distribution. NEDO plans to collect various microgrid data points during three consecutive years of operation for performance evaluation. Sandia will use these data measurements for PV system performance modeling, energy system control studies, and anti-islanding experiments. The collaboration between Sandia and NEDO provides several opportunities to leverage existing expertise and perform joint research on distributed renewable resources.



Source: Nationalgrid.com

down the river could have had similar national consequences. America has endured these disruptions before and will again.

Critical infrastructure, infrastructure whose disruption will put many lives at risk, suffers not only under the threat of direct interruption but also from disruption via the interruption of another element of the infrastructure on which it depends. The nation must be prepared for disruption to its critical infrastructure—and in order to do this, we must understand the interdependencies between the infrastructure's disparate systems. We must understand if some systems are more at risk than others and why. We need to know if evolving interdependencies increase or change the risks to critical systems. Are the trends toward more vulnerable conditions/configurations? Or less? How will critical infrastructure disruptions impact national security?

Understanding the linked, interdependent nature of the nation's critical infrastructure in order to enhance preparedness, protection, response, recovery, and mitigation is a hard problem—one that requires the capabilities of a national laboratory. It is through HPC modeling and analysis that Sandia can quantify and qualify the interactions of political, health, social, economic, and technical systems. Simulation can couple the effects of socio-economic systems (power networks, distribution systems, transportation links) to physical systems (climate, weather, geology, geography) to understand large, complex data sets and capture nonlocal, nonintuitive interdependency effects at multiple simultaneous scales and resolutions. By studying these infrastructure systems and their effects on each other in simulation, we can advise policy makers and industry stakeholders on how to mitigate disruption effects and build resiliency into the national system.

3 Reduce the risk of energy supply disruptions from globally strategic sources to the U.S. and to key overseas installations.

The U.S. economy and national infrastructure depends heavily on our imports of oil and gas resources. Liquid fuels will be a critical part of world energy supplies for the foreseeable future (55% today, 60% in 2035). The loss of 1.5 million barrels per day (1.7% of supply) would imply a price increase of 17% if that supply loss could not be made up from other sources; a loss of 5 million barrels per day would imply a price increase to $125 per barrel.[12] The economic consequences of such oil price shocks depend on how strong the economies of key countries are at the time of the supply interruption and how long an interruption lasts.

Because energy drives the U.S. economy and transportation keeps it rolling, our national security and economic prosperity demands that we address the security needs of the top tier oil-supplying countries immediately. The Global Critical Energy Infrastructure Protection (G-CEIP) is a U.S. interagency program that seeks to ensure the supply of energy to the U.S. by securing critical energy and infrastructure sites across the world. G-CEIP targets facilities that supply our nation with more than one million barrels of petroleum per day and currently has contact with oil-industry operators in Saudi Arabia, Kuwait, the United Arab Emirates, Qatar, Azerbaijan, and Kyrgyzstan. Additional sites can potentially include Nigeria, Mexico, and Columbia. In addition, other selected oil and natural gas facilities, airports, seaports, solar plants, and other facilities that create or distribute natural energy resources could be included in the G-CEIP program.

Sandia has more than 30 years of experience with projects that utilize "denial" strategies—born out of our NW protection experience. Recent attacks on the global oil infrastructure are forcing a change of protection strategy—industrial vs performance-based high security. Even now, our Sandia staff in the G-CEIP program are getting "boots on the ground" experience identifying critical needs for our R&D mechanisms to solve.

4 Design and demonstrate 30% renewable energy penetration into the energy surety microgrid within five years.

The present electricity grid is based on a foundation created more than 100 years ago. The infrastructure is geographically fixed, power sources are centralized and dispatchable (completely controllable), the loads are largely predictable, and the control of power flow at the load is essentially an open-loop—making it vulnerable to terrorist attacks, natural disasters, infrastructure failures, and other disruptive events. Further, this grid model limits renewables and other distributed energy sources from being economically and reliably integrated into the grid because it has been optimized over decades for large, centralized power generation sources. While a national RPS (renewable-energy portfolio standard) has yet to be established, many states are forging ahead with their own programs and policies. California's RPS is the most ambitious state renewable energy standard in the country. Established in 2002, the program required electric corporations to increase procurement from eligible renewable energy resources by at least 1% of their retail sales annually, until they reached 20% by 2010.[13] On April 12, 2011, the Governor signed a new law that requires California utilities to increase their renewable energy resource purchases to 33% by the end of 2020.[14]

The energy surety microgrid is a Sandia-developed grid architecture that moves away from unidirectional power and limited information flow and, rather, adopts closed-loop controls and an agent-based architecture with integrated communication networks. Adding a feedback component to the input signal establishes an intelligent power-flow control and provides a basis for integrating renewables and distributed power sources into the grid. This bold approach will enable a self-healing, self-adapting, self-organizing architecture and allow a trade-off between storage in the grid and information flow to control generation sources, power distribution, and loads. Incorporating agent-based, distributed, nonlinear control to maintain reliable energy distribution while minimizing the need for excessive storage or backup generation will be a revolutionary step towards extreme penetration

Smart Power Infrastructure Demonstration for Energy Reliability & Security (SPIDERS)

The fragile, aging, fossil-fuel-dependent electricity grid limits the DoD's ability to command, control, deploy, and sustain forces—posing a significant threat to national security. Today's warfighter cannot

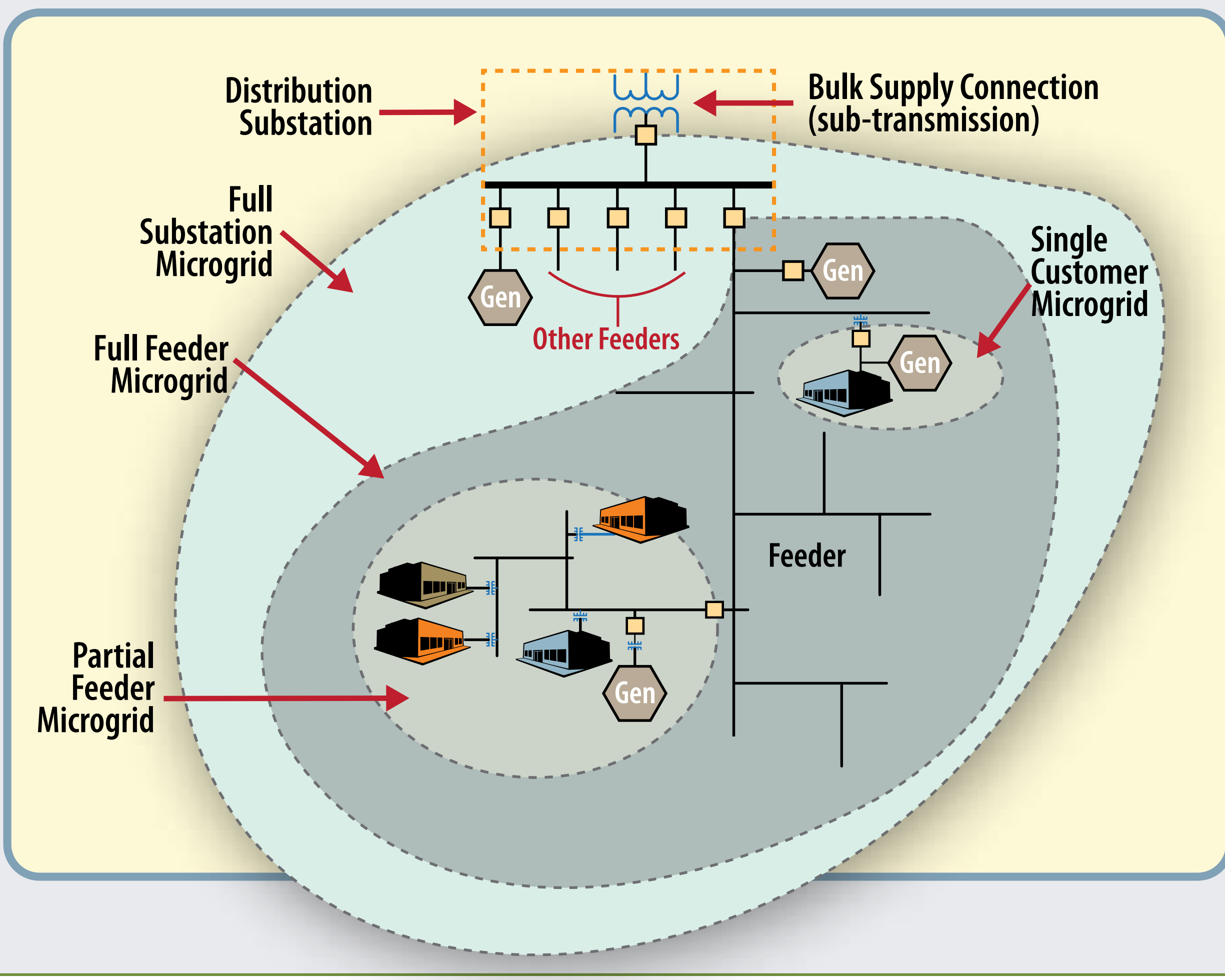
- protect task-critical assets from power loss due to cyber attack;
- integrate renewable/distributed-generation electricity to power task-critical assets in times of emergency;
- sustain critical operations during prolonged power outages; and
- manage installation electrical power and consumption efficiently, to reduce petroleum demand, carbon "bootprint," and cost.

Sandia is contributing the microgrid and dynamic control elements of the SPIDERS joint capabilities technology demonstration project—the first-ever to have DoD-DOE-DHS sponsorship. SPIDERS uses current DOE smart grid, energy efficiency, renewable energy, and energy storage efforts via demonstration and early deployment of energy technologies on military installations.

This whole-of-government solution to the DoD energy challenge has subsequent potential for immediate transfer to commercial utilities and the industrial sector.

Microgrid

A small-scale version of a centralized electrical grid; implemented at a local level and taking advantage of locally generated power sources (photovoltaics, small wind, biomass, small hydro, combined heat and power, and energy-storage). A microgrid can be tied to the larger grid, yet retains the ability to independently supply energy in the event the larger grid experiences power interruptions or price fluctuations.



of renewable energy sources into the U.S. energy infrastructure. The development of dynamic nonlinear source models, scalable agent-based architectures, and multi-time-variant simulations will be key components to this solution. By advancing these sciences and technologies, we are enabling reliable, resilient, secure, and cost-effective microgrids and interconnected microgrids making up the smart grid of the future.

5 Develop and use energy security systems analysis/ assessment tools and a sustainable implementation business model to meet DoD/DOE/DHS defined energy security objectives.

The nation's security is compromised by the fact that a large majority of the energy we consume comes from foreign sources. Our security is placed in jeopardy by foreign competition for the energy resources and international instabilities and conflicts. DoD Energy Assurance seeks to develop and apply tools to conduct comprehensive vulnerability assessments of critical missions at military installations. The conceptual designs will eventually demonstrate the ability of the base to support critical off-base infrastructure such as first responders, hospitals, etc. as an element of the community disaster-response options.

The military with its disciplined, structured prototyping and acquisition processes provides an excellent forum in which to demonstrate concepts to the more diverse civilian community. In addition, interlinking of military installations within a region will be an option for improved national energy interdependence and security. The tools allow us to understand the interdependencies within an installation and to identify gaps in energy reliability, availability, and security. The utility and benefit of energy management against a physical and cyber threat will be explored. Use of alternative energy sources or supply will be considered with the goal of making the installation independent from external supply.

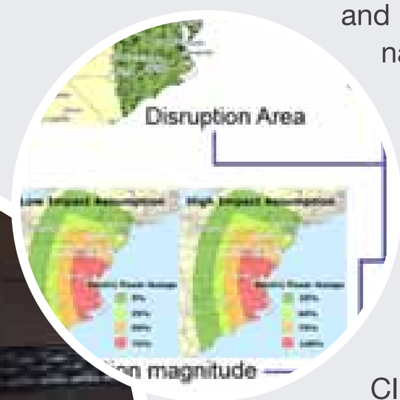
This development effort will use current installation assessment experiences (18 military installations) and integrate with national critical infrastructure simulations to go from national to regional to local energy infrastructure interdependencies and then to greater understanding of how they affect critical missions at military bases. The nation has complex interdependencies and a heavy reliance on private industry. The tool will also assist in the development of conceptual designs that will provide decision makers a risk vs cost basis for selecting the optimal solution for a given design basis threat.

National Infrastructure Simulation and Analysis Center (NISAC)

NISAC is a Department of Homeland Security (DHS) modeling, simulation, and analysis program comprising personnel in Washington, D.C., Sandia, and Los Alamos, and jointly led by Sandia and LANL. NISAC prepares analyses of critical infrastructure and key resources (CIKR). NISAC provides analyses of interdependencies and consequences of infrastructure disruptions across all 18 CIKR sectors at national, regional, and local levels. NISAC developed/employs tools, including process-based systems dynamics models, mathematical network optimization models, physics-based models of existing infrastructures, and high-fidelity agent-based simulations of systems.

Physical, human, and cyber assets make up CIKR infrastructures.

The complexity of these systems, subject to natural hazards, coupled with the new threat environment, has created a need for a focus on interdependencies, vulnerabilities, and the consequences a failure propagates. NISAC supports the preparedness and protection of our nation by providing analyses of the technical, economic, and national security implications of the loss or disruption of CIKR, and assist in understanding infrastructure protection, mitigation, response, and recovery options.



Infrastructure disruption models.

Enabling Capabilities

The Enabling Capabilities program area provides a differentiating science understanding that supports ECIS SMU and Sandia National Laboratories mission technologies now and into the future.

Enabling Capabilities is unique among ECIS' four program areas. The other three areas each focus on one (albeit large) research area to bring Sandia's research and engineering capabilities to bear on the problem and help the nation forge a solution. The Enabling Capabilities program area is organized to support the other ECIS areas in pursuit of their goals. The program area is home to four activities that are designed to cut across the other three ECIS areas. The scientists and engineers in the Discovery Science and Engineering activity pursue fundamental research that has applications in multiple program areas. Because Enabling Capabilities has connections interwoven throughout the ECIS SMU project teams, this discovery science can easily find more than one application.

The Systems Analysis activity takes the opposite perspective. It looks "from the top" at the results of project teams and "weaves" them into coherent systems, and where two or more systems may be isolated, this activity looks for interconnections. The Systems Analysis activity takes a complex, adaptive system-of-systems approach to forge meeting points between research efforts in the ECIS SMU and throughout the nation's energy/climate research enterprise to foster a "larger view" among the participants.

The Regulatory and Policy activity interfaces between the ECIS program areas (and the SMU management) and national regulatory and policy bodies. ECIS researchers could devise an excellent solution to an energy/climate problem, but if it does not satisfy the requirements of national policy or the current regulatory environment, it may not become accepted by industry or the American consumer. The members of this activity can either work with the policy or regulatory authority to understand how the new technology can meet the energy/climate need with some modification to the policy/regulatory structure or work with the research staff to modify the technology so that it can still provide a workable solution with the modifications necessary to fit into the existing regulatory/policy structure.

Recognizing the need to re-evaluate the way the U.S. spurs innovation, the National Academies released a 2006 report, "Rising Above the Gathering Storm," that included the recommendation to establish an ARPA-E (Advanced Research Projects Agency—Energy) within the DOE. ARPA-E is modeled after the successful Defense Advanced Research Projects Agency (DARPA), the agency responsible for technological innovations such as the Internet and the stealth technology found in the F117A and other modern fighter aircraft.

ARPA-E was created to be a catalyst for such a transformation, and to do so with fierce urgency. Our nation's history is replete with examples of pioneers and entrepreneurs who took risks. These innovators often failed initially, but quickly learned from those failures, competed against each other, and innovated in both technology and business to create the largest industrial base the world has ever seen. ARPA-E's goal is to tap into this truly American ethos, and to identify and support the pioneers of the future. With the best R&D infrastructure in the world, a thriving innovation ecosystem in business and entrepreneurship, and a generation of youth that is willing to engage with fearless intensity, we have all the ingredients necessary for future success.

The ECIS ARPA-E activity is tasked with working with the scientists and engineers of the ECIS program areas to form partnerships with industry, academia, and entrepreneurs to develop research proposals that will win grant awards from ARPA-E.

Enabling Capabilities Goals

1 Deepen fundamental science and engineering competencies in key strategic areas to enable ECIS mission objectives and goals.

Our nation faces serious, looming challenges in the areas of energy, climate, and infrastructure security, on which this document has focused. The President has identified them, and the seven to which the ECIS SMU program area scientists and engineers can apply their expertise are described at the beginning of this strategic plan. However, focused, applied research and analysis can only bring us so far. Many of the challenges cannot be solved with improvements to current technologies or extrapolations from them—they require an understanding of the foundational characteristics of materials, energy, and their interactions.

The Enabling Capabilities program area supports this kind of foundational research at facilities such as the

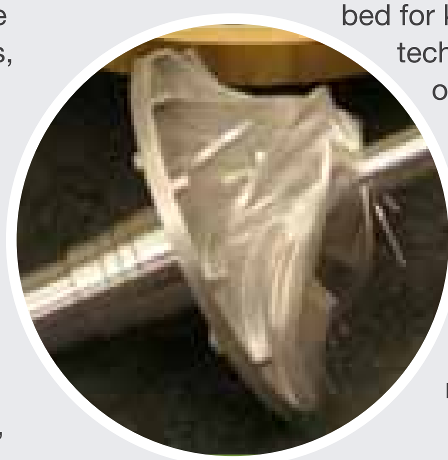
- Center of Integrated Nanotechnologies (CINT),
- MESA (Microsystems Engineering, Science, and Applications) facility,
- CRF (Combustion Research Facility),
- Ion Beam Laboratory,
- Processing and Environmental Technology Laboratory,
- Computer Science Research Institute, and
- Integrated Materials Research Laboratory.

With these facilities, Sandia has extensive, in some cases unique, state-of-the-art laboratory facilities for understanding combustion science; material growth; fabricating microsystems; semiconductor processing; and characterizing structural, electronic, and optical materials. The combination of facilities is unparalleled anywhere in

Supercritical CO_2 and the Brayton Cycle

Sandia is researching advanced supercritical CO_2 (S-CO_2) Brayton cycle power conversion systems for next-generation power reactors. The S-CO_2 Brayton cycle takes advantage of non-ideal gas behavior at the critical point to achieve efficiencies near 50%—but at only 700 °C. The combination of lower temperatures, high efficiency, and high power density (in this regime, S-CO_2 is near water's density) allows us to develop very compact, transportable systems that are affordable because they require only standard engineering materials (stainless steel), less material is required, and because the small size allows for advanced, modular manufacturing processes.

We demonstrated stable, controllable operation near the critical point over a range of conditions using modular, reconfigurable hardware to construct a range of compression and Brayton-cycle configurations, and also to serve as a test bed for key bearing, seal, and controller technology necessary for loop operations. Future testing will measure performance at different compressor inlet conditions—but still near the critical point and explore surge conditions. We will also test gas-foil bearings and different seals to measure the compatibility of these seals with gas-foil bearings and to measure seal leakage flow rates.



The compressor wheel (shown full size) operates at 75,000 rpm. Our S-CO_2 test loop can generate 120–150 KW within ~66% efficiency.

the world. In addition to special lab facilities and equipment, we have cultivated substantial personnel expertise, in parallel, over decades, in a broad range of physical science, chemistry, materials science, and engineering disciplines. This collection of expertise—that can be brought together into large, comprehensive teams—is very rare.

It is through the use of these facilities by our collection of unique scientific and engineering capabilities that we can understand and develop the foundational scientific principles of novel materials and processes into the technology of tomorrow that can surmount the challenges that we face in energy, climate, and infrastructure protection that can secure and sustain our nation.

2 Nurture discovery science for fundamental breakthroughs in:

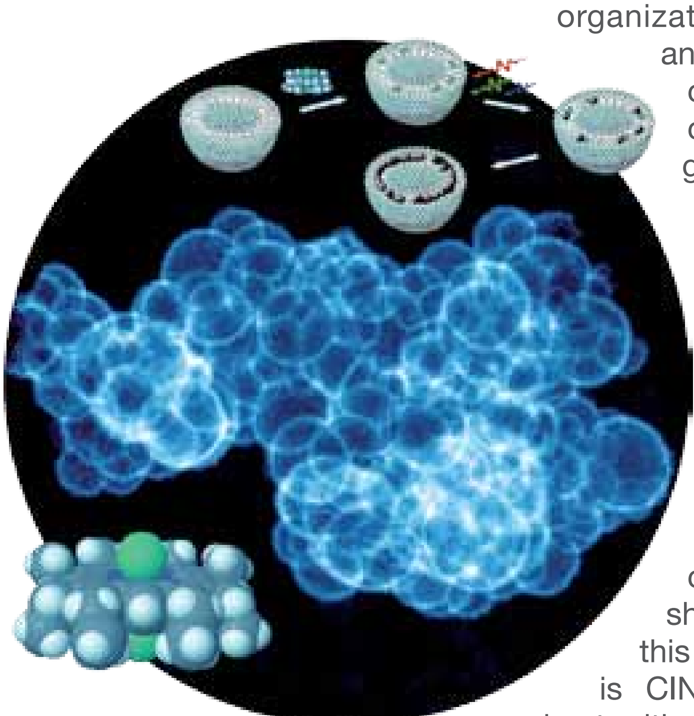
- Interfacial science
- Quantum phenomena
- Materials physics
- Bioscience
- Gas-phase chemistry
- Nanomaterials systems and architecture
- Math algorithms

In order to develop solutions to the energy, climate, and infrastructures challenges defined by the President and described in this document, the existing Sandia facilities and capabilities described above in Goal #1 are a good start, but also not the complete answer. We will need to develop new facilities, new capabilities, and expand or establish partnerships with other research institutions (national labs, universities, industry). Sandia must establish these laboratory centers because the research they will undertake is so novel that no facilities currently exist to pursue them to their potential.

In order to nurture this discovery science and engineering, Sandia seeks to leverage its expertise to

- establish an energy storage research center, in particular on bio-inspired materials for energy storage (joint with Pacific Northwest National Laboratory, PNNL) and foundational electrochemistry;
- develop an international collaboration for nuclear fusion systems research in support of ITER in the critical area of plasma-materials interactions;

- establish a core DOE Office of Basic Energy Sciences (BES) Material Science program start in strong light-matter interactions and another to investigate the growth and electron transport of graphene;
- develop successful scientific focus area in arid-land ecology of fungal microbial communities for improved cellulolytic processes for more efficient biofuels production;
- start an DOE Office of Fusion Energy Science user center for low-energy plasma diagnostics;
- grow fundamental math/ computer science research in data-centric analysis and uncertainty quantification and develop strategy to inject advances into mission organizations/applications; and start a BES center for advanced crystalline materials growth science.



2009 R&D 100 winner - NanoCoral materials made of platinum to enhance fuel cell performance.

In all of these efforts, Sandia would seek out collaborative partnerships with other institutions in order to better leverage all available capabilities. A shining example of this collaborative spirit is CINT, which we co-host with LANL. Sandia will continue to nurture and grow this relationship and expand CINT's impact on Sandia's mission areas and our partnerships with industry. Another area in which Sandia can nurture and support discovery science is in our extensive HPC capacity. With new exascale machines like Red Storm open to the broader scientific community through open-source codes, Sandia can expand the role and impact of HPC into a wider range of DOE/Sandia mission areas (energy, climate, infrastructure assurance) that positions Sandia in a leadership role for the DOE complex in exascale planning and execution that is integrated across both Advanced Scientific Computing Research and Advanced Scientific Computing programs.

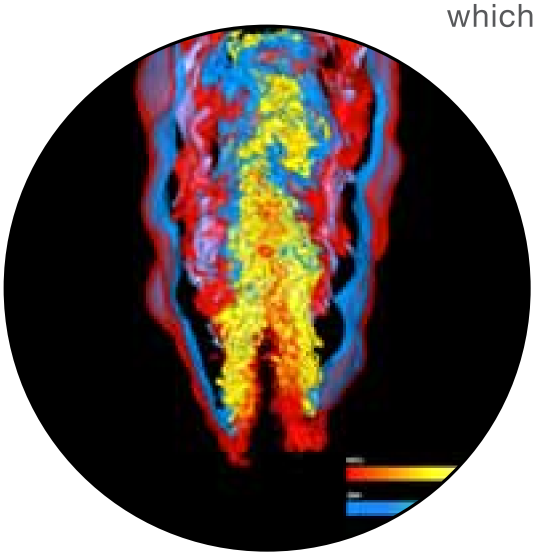
3 Determine capability needs for SMU and support capability development through targeted Laboratory-Directed Research & Development (LDRD) projects.

The ECIS LDRD investment area (IA) focuses on R&D that creates options for its program areas: Energy Security, Climate Security, Infrastructure Security, and Enabling Capabilities. Coupling S&T is critical to the success of our SMU and a differentiating expertise that we bring to the nation.

The ECIS LDRD IA seeds and initiates transformative approaches that provide real solutions to our key national challenges as articulated by the President. The ECIS LDRD IA focuses on ideas that would be considered too risky for the direct-funded program funding areas. The ECIS IA LDRDs develop and create products and capabilities to incubate solutions for future program needs.

The ECIS LDRD IA portfolio currently supports a number of these national-challenge research goals. Future LDRD awards will address priorities to the IA where gaps exist in the current research/investment portfolio. ECIS IA LDRDs should be revolutionary and span the gap from concept demonstration to prototype demonstration, and in all cases the LDRD must provide and document new knowledge.

The ECIS LDRD IA strongly encourages multidisciplinary partnerships that include both S&T and mission technology efforts and which draw from capabilities and expertise from across the Labs such as HPC capabilities and engineering testing capabilities. Projects that build bridges to future use of enabling facilities such as the CRF; NSTTF; HPC; Environmental Test; CINT, and the MESA facility are also encouraged. Other forms of partnering that are encouraged include external collaborations with key universities, other national laboratories, and other R&D institutions, as well as internal collaborations that pair senior experienced staff with staff who are relatively new to Sandia.



Combustion Research Facility scientists have developed high-performance computing codes to better understand a wide variety of combustion phenomena including spray combustion, flame dynamics, and reacting flows.

4 Accelerate industry development of transformational energy technologies through ARPA-E.

The widespread use of fossil fuels has long driven the engine of economic growth and, consequently, has significant national security implications. Looking toward the future, the nation that successfully grows its economy with more efficient energy use, a clean domestic energy supply, and a smart energy infrastructure will lead the global economy of the 21st century. ARPA-E was created within DOE to be a catalyst for such a transformation, and to do so with fierce urgency.

ARPA-E has rapidly created a portfolio of innovative, high-risk R&D projects targeted to address the nation's technological gaps and leapfrog over current approaches in the energy sector. By using its initial American Recovery & Reinvestment Act (ARRA) funding to selectively launch only one percent of the game-changing ideas submitted by entrepreneurs nationwide, ARPA-E is using a nontraditional approach that complements the established DOE energy programs.

Sandia can further accelerate innovation by engaging current and future ARPA-E innovators that otherwise might not benefit from our intellectual resources and relevant capabilities. Our strategy involves three simultaneous approaches:

1. build relationships with current ARPA-E investigators on projects where we can add value;
2. explore partnerships with innovators in the group of highly-ranked but unfunded ARPA-E proposals to pursue scientifically sound, high-risk R&D of keen interest to ARPA-E; and
3. contribute technical leadership to ARPA-E to shape future directions as this agency becomes established within DOE.

The suite of Sandia facilities described in the sections above, the innovative spirit ignited within the Laboratories by the initial ARPA-E solicitations, and ability to work in precompetitive or proprietary modes will enable Sandia to deliver the critically needed innovation for our nation's energy security.


CINT

Key Facilities

Many of Sandia's unique research facilities are available for use by industry, universities, academia, other laboratories, state and local governments, and the scientific community in general. User and collaborative facilities are a unique set of scientific research capabilities and resources whose primary function is to satisfy DOE programmatic needs, while being accessible to outside users.

The National Solar Thermal Test Facility (NSTTF) primary goal is to provide experimental engineering data for the design, construction, and operation of unique components and systems in proposed solar thermal electrical plants, which have three generic system architectures: line-focus (trough and continuous linear Fresnel reflector systems), point-focus central receiver (power towers), and point-focus distributed receiver (dish-engine systems). In addition, the NSTTF can provide high heat flux and temperatures for materials testing or aerodynamic heating simulation; large fields of optics for astronomical observations or satellite calibrations; a solar furnace; and a rotating platform for parabolic trough evaluation. The NSTTF is sponsored by the DOE Office of Energy Efficiency and Renewable Energy (EERE); significant recent infrastructure improvements were funded by the ARRA.

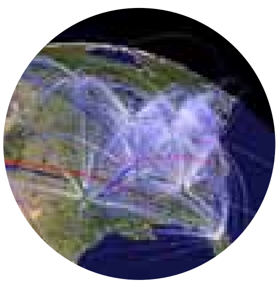
The Joint BioEnergy Institute (JBEI) is a San Francisco Bay Area scientific partnership led by LBNL and including Sandia, the University of California campuses of Berkeley and Davis, the Carnegie Institution for Science, and the Lawrence Livermore National Laboratory. JBEI is sponsored by the DOE SC with a mission to advance the development of the next generation of biofuels—liquid fuels derived from the solar energy stored in plant biomass. JBEI is focused on the efficient conversion of lignocellulosic biomass, the most abundant organic material on the planet, into these biofuels. JBEI is organized into four divisions: Feedstocks, Deconstruction, Fuels Synthesis, and Technologies.

The Combustion Research Facility (CRF) is an internationally recognized DOE SC-sponsored collaborative research facility. CRF scientists, engineers, and technologists conduct basic and applied research aimed at improving our nation's ability to use and control combustion processes. Research ranges from studying chemical reactions in a flame to developing laser diagnostics for combustion-science research. Most of the CRF's work is done in collaboration with scientists and engineers from industry and universities. Visiting researchers collaborate with the CRF staff and bring with them experience and knowledge that enhances and brings new approaches to collaborative research.

Sandia's Battery Abuse Testing Laboratory (BATLab) is at the forefront of testing the limits of what batteries can safely handle and provides critical data for developing the next generation of batteries—doing everything imaginable to batteries (e.g., crushing, piercing with nails, heating to boiling) in the lab to make sure that once a battery is in commercial use, it will be safe and reliable. The BATLab tests cells from the size of a laptop computer battery up to packs weighing several hundred pounds. The BATLab team has been recognized for its ability to perform scientific analysis and a full range of measurements. The BATLab is sponsored by DOE EERE.

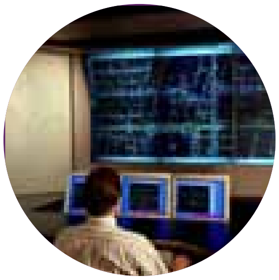
Supercomputing Capability

The new **Red Sky supercomputer** debuted as the 10th fastest supercomputer on the Top500 list, with a sustained performance of 429.9 teraflops and an estimated power usage effectiveness of 1.035. Red Sky is intended to be a capacity machine. It wasn't designed with the full-system job as its target, but to run many smaller jobs. With Red Sky, Sandia wanted a design that could accommodate a higher degree of scalability than is typical in the HPC world. Red Sky is intended to be broadly available to the entire Laboratory and to outside collaborators.



The National Infrastructure Simulation and Analysis Center (NISAC) is a DHS-sponsored modeling, simulation, and analysis program comprising personnel in Washington D.C. and from Sandia and Los Alamos national laboratories. NISAC analyzes critical infrastructure and key resources, including their interdependencies, vulnerabilities, consequences, and other complexities. NISAC provides strategic, multidisciplinary analyses of interdependencies and the consequences of infrastructure disruptions across critical infrastructure and key resource sectors at national, regional, and local levels. NISAC experts have developed and are employing tools to address the complexities of interdependent national infrastructures, including process-based systems dynamics models, mathematical network optimization models, physics-based models of existing infrastructures, and high-fidelity agent-based simulations of systems.

The Photovoltaic Systems Evaluation Laboratory (PSEL) is a multi-user, multi-sponsor facility that conducts research in PV cells, modules, and arrays and performs detailed, comprehensive analysis in PV systems design, optimization, and characterization in real-world scenarios. PSEL conducts research on behalf of the DOE, DoD, and other customers, often in collaboration with industry/academic partners. PSEL supports developing domestic and international standards that reduce market barriers to greater adoption of solar technologies while also improving operator/installer safety as well as system reliability and functionality. PSEL's testing, analysis, and validations provide unbiased evaluations of current and proposed standards. PSEL also has a demonstrated history of appropriately handling proprietary data.

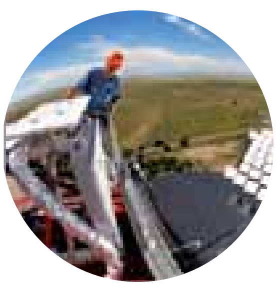


The National Supervisory Control and Data Acquisition (SCADA) Test Bed is a DOE Office of Electricity Delivery and Energy Reliability-sponsored resource to help secure our nation's energy control systems. It combines state-of-the-art operational system testing facilities with research, development, and training to discover and address critical security vulnerabilities and threats to the energy sector. Sandia R&D efforts range from autonomous agent systems applied to SCADA, to cryptographic security, system assessment, and red-team activities. Sandia is able to complement its communication and control capabilities with actual generation and load facilities for distributed energy resources.

The Center for Integrated Nanotechnologies (CINT) is determining the scientific principles that govern the design, performance, and integration of nanoscale materials. CINT's emphasis is on exploring the path from scientific discovery to the integration of nanostructures into the micro and macro worlds. This involves exploring, experimentally and theoretically, nanoscale behavior; developing many synthesis and processing approaches; and understanding new performance regimes, testing new designs, and integrating nanoscale materials and structures. Integration is key to exploiting nanomaterials, and the scientific challenges that it poses are at the heart of CINT's DOE SC-sponsored mission. Our activities bring together university faculty, students, other national laboratory scientists, and industrial researchers to propose, design, and explore integrating new nanoscale materials into novel architectures and microsystems.

The Distributed Energy Technologies Laboratory (DETL) conducts research with industry and academic partners to integrate emerging energy technologies into new and existing electricity infrastructures. DETL's DOE EERE-sponsored research spans generation, storage, and load management at the component and systems levels and examines advanced materials, controls, and communications to achieve a reliable, low-carbon electric infrastructure. DETL's reconfigurable infrastructure simulates many real-world scenarios (e.g., island and campus grids, remote operations, and scaled portions of utility feeders and the transmission infrastructure). DETL researchers analyze the effects of high penetration of renewable technologies and distributed energy on the grid and resolve issues of grid interconnectivity, controls, security, safety, performance, reliability, and interoperability.

Sandia's Leadership in Federal Energy Research Efforts



Sandia also uses the Solar Tower for high-temperature materials tests.

Concentrated Solar Power

CSP offers a utility-scale, firm, dispatchable renewable energy option that can help meet the nation's demand for electricity. Worldwide, CSP activity is rapidly scaling, with approximately 14,500 MW in various stages of development in 20 countries. The DOE EERE's Solar Energy Technologies Program CSP subprogram seeks to lower costs and advance technology to the point that CSP is competitive in the intermediate power market by 2015–2017 and in the baseload power market by 2020–2022. Two national laboratories, NREL and Sandia, manage the R&D support for the U.S. CSP industry with critical R&D to meet cost, reliability, performance, and manufacturability challenges. R&D is conducted through cost-shared contracts with industry, universities, and other national laboratories. In addition, the CSP subprogram develops partnerships with federal and state agencies, as well as throughout the solar industry, to encourage the deployment of CSP technologies by addressing land and transmission issues.

Solid-state light-emitting device (LEDs).

Energy Frontier Research Center for Solid-State Lighting Science

Lighting consumes roughly 22% of U.S. electricity, a roughly $50B/year cost to the U.S. consumer. SSL is an emerging technology with the potential to reduce that energy consumption by a factor of 3–6 times. Despite a decade's enormous progress, however, SSL remains a factor of 5–10 times away from this potential.

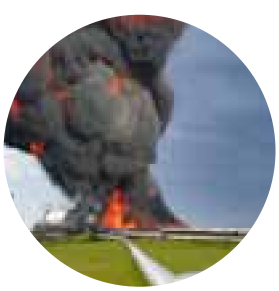
Sandia's Solid-State Lighting Science (SSLS) a DOE SC Energy Frontier Research Center (EFRC) will accelerate advances in this fundamental science by exploring energy conversion in tailored photonic structures. Drawing on Sandia's long history of SSL R&D, and working closely with its university and industry partners, the SSLS EFRC will

- work to understand the mechanisms and defects in SSL semiconductor materials that presently limit the energy efficiency;
- investigate conversion of electricity to light using radically new designs, such as luminescent nanowires, quantum dots, and hybrid architectures; and
- study energy conversion processes in structures whose sizes are even smaller than the wavelength of light.

Sandia's BATLab tests batteries to failure so that industry can produce safer products.

Energy Storage Systems

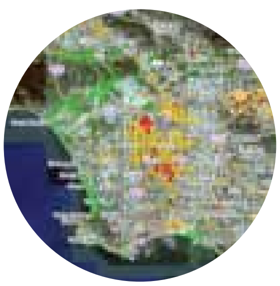
Over three decades, the DOE Energy Storage Systems (ESS) research program, managed by Sandia, has evolved successful battery and power sources research, engineering, and testing, especially as storage technologies relate to electric utilities, renewables, and grid security. ESS activities include research over an entire, integrated, battery storage system, including power electronics and controls. From that research, DOE and Sandia project managers have conducted very successful utility storage demonstrations that have resulted in numerous commercial products. The ESS research program includes responsibility for the development of an even broader range of utility-related efforts, including innovative storage technologies such as flywheels and compressed air energy storage. ESS project reports have become the defining documents for the benefits of energy storage and are cited regularly by storage experts around the world. Working in close partnerships with industry, academia, and governments, the ESS Program continues to lead in world-wide efforts that address energy issues through energy storage.



Global Critical Energy Infrastructure Protection

Critical energy infrastructure comprises the production, storage, refining, processing, and distribution of fossil fuels. Broadly speaking, the entire concept may even underpin all related infrastructure including essential services from health and human services to the integrity of financial networks and systems. Numerous instances of attacks on overland oil and gas pipelines by militants in places like Colombia, Iraq, and Nigeria amplify the vulnerability of overland energy networks to deliberate physical attacks because such systems traverse remote, mostly uninhabited areas and cover great distances which make monitoring difficult. In modern energy infrastructure, digitalization is necessary for smooth and efficient functioning. However, this heightens cyberspace threats to the infrastructure elements—especially since they have become more interoperable, remotely accessible, and less costly through the use of open software standards and protocols to achieve cost efficiency. Few operators possess the resources to track cybersecurity threats, and some rely only on automated services provided by their distributed control systems or commercial software vendors.

Sandia's programs have long supported technologies and protocols that facilitate nonproliferation and secure control of nuclear materials. Sandia also supports programs that assist Russia to safely manage and control nuclear materials from dismantled Soviet-era weapons systems. Sandia is applying this well-developed capability and recognized leadership in critical infrastructure protection, cybersecurity, and energy systems solutions to enhance national security by helping energy supplier nations secure their critical energy infrastructure.



Modeling shows geospatial structures of pandemic influenza.

National Infrastructure Simulation and Analysis Center

NISAC is a DHS Office of Infrastructure Protection modeling, simulation, and analysis program jointly led by Sandia and LANL, integrating the two laboratories' expertise in the modeling and simulation of complex systems for evaluating national preparedness and security issues. NISAC prepares analyses of critical infrastructure and key resources (CIKR)—providing analyses of interdependencies and consequences of infrastructure disruptions across all 18 CIKR sectors at national, regional, and local levels. NISAC developed/employs tools, including process-based systems dynamics models, mathematical network optimization models, physics-based models of existing infrastructures, and high-fidelity agent-based simulations of systems.

Physical, human, and cyber assets make up CIKR infrastructures. The complexity of these systems, subject to natural hazards, coupled with the new threat environment, has created a need for a focus on interdependencies, vulnerabilities, and the consequences a failure propagates. NISAC supports the preparedness and protection of our nation by providing analyses of the technical, economic, and national security implications of the loss or disruption of CIKR, and assist in understanding infrastructure protection, mitigation, response, and recovery options. NISAC activities include infrastructure modeling and analysis, decision support tools, knowledge management, and fast turnaround analyses.

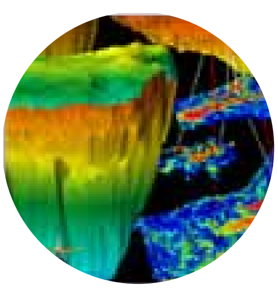
Ocean Power magazine.net

Ocean Energy

The DOE's Water Power Program supports the development of advanced water power devices that capture energy from waves, tides, ocean currents, rivers, streams, and ocean thermal gradients. Sandia, through a partnership with several national laboratories and academic institutions, leads two of the four topic areas awarded under a $9M grant and will provide technical support in a third topic area. The topic areas are Supporting Research and Testing for Marine and Hydrokinetic (MHK) Energy, Environmental Assessment and Mitigation Methods for MHK Energy, Supporting Research and Testing for Hydropower, and Environmental Assessment and Mitigation Methods for Hydropower. The Sandia-led effort will pursue a diverse research agenda in MHK systems and will collaborate with Argonne National Laboratory and Oak Ridge National Laboratory (ORNL) on conventional hydropower. In partnership with ORNL, PNNL, and NREL. WPP activities will evaluate new device designs and conduct basic research in materials, coatings, adhesives, hydrodynamics, and manufacturing to assist industry in bringing efficient technologies to market.

Smart Power Infrastructure Demonstration for Energy Reliability and Security Joint Capabilities Technology Demonstration

The Infrastructure Program Area of the ECIS SMU is participating in the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capabilities Technology Demonstration (JCTD)—a combined agency (DOE, DoD, DHS) demonstration effort for energy security at three military installations. SPIDERS combines several DOE efforts: smart grid, cyber security, energy efficiency, renewable energy, and energy storage via demonstration and early deployment of energy technologies on military installations. ECIS's Infrastructure Program Area is contributing to the design of the microgrids and cyber security architectures of the SPIDERS JCTD. The Army Construction Engineering Research Lab is the Technical Manager for the project. Juan Torres (6111, Energy Systems Analysis) serves as the Deputy Technical Manager. Sandia is the lead systems engineering lab (among five overall DOE labs).



Sandia's geologists and modelers work together to help SPR officials understand the nature of underground salt domes.

Strategic Petroleum Reserve

The 727-million-barrel U.S. SPR is the largest stockpile of government-owned emergency crude oil in the world. Established in the aftermath of the 1973–74 oil embargo within the DOE Office of Fossil Energy, the SPR provides the President with a powerful response option should a disruption in commercial oil supplies threaten the U.S. economy and it provides a national defense fuel reserve. The SPR stores crude oil in solution-mined salt domes because they offer the lowest-cost, most environmentally secure way to store crude oil for long periods of time. Because the salt caverns are 2,000–4,000 feet below the surface, geologic pressures seal any cracks that develop in the salt formation, assuring that no oil leaks. The natural temperature difference between the top of a cavern and the bottom (a distance of around 2,000 feet) keeps the crude oil continuously circulating, giving the oil a consistent quality. Sandia is the technical leader for geology, geomechanics, and computational modeling issues related to the SPR.

Industrial Partnerships Strategy

Industrial partnerships are key to achieving our mission objective of accelerating U.S. industry's innovation, development, and successful deployment of energy solutions to the nation's most challenging problems.

Energy-related problems are so complex that solutions will require ECIS to collaborate with various institutions, particularly industry partners. The SMU can achieve widespread impact from its work through industry partners as industry delivers solutions to the nation's energy problems through their products and infrastructure. Through these partnerships, Sandia provides expertise and technology to meet industrial needs. By applying ECIS capabilities to industrial problems, Sandia gains new perspectives on national energy, climate, and infrastructure issues and industry can market more robust, new, and/or improved products. This benefits ECIS as well as other Sandia national security mission applications. Industry partnerships are also the primary mechanism for commercializing ECIS technologies in meeting mission sponsors' expectations.

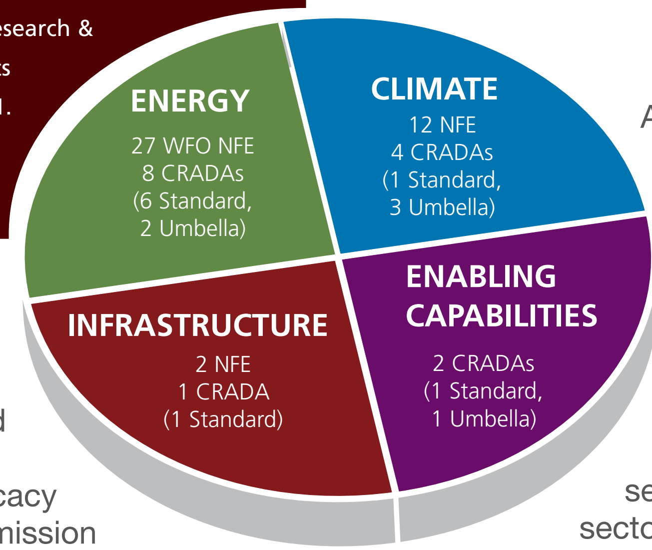
The importance of industrial partnership to the ECIS mission is reflected in our ten-year objective to: **accelerate U.S. industry's innovation, development, and successful deployment of energy solutions to the nation's most challenging problems through seamless integrations of Sandia's science, engineering, and security expertise by leveraging and integrating across our U.S. government-sponsored programs and relationships and by partnering with industry academia and other labs.**

ECIS SMU partnerships with industry should lead to one or more of the following outcomes for every ECIS program area:

- Sandia research and technology incorporated/

ECIS Industry Portfolio by Program

Current industry portfolio includes Work for Others (WFO), Non-Federal Entities (NFE) and Cooperative Research & Development Agreements (CRADAs) as of April 2011.



commercialized in industry's products and infrastructure,

- industry advocacy for ECIS mission programs and research,
- industry insights that provide directions for Sandia research, and
- industry's insights and support that establishes Sandia as a provider of technically sound and objective information to policy makers.

The specific outcome or outcomes desired from industry will vary across the ECIS program areas and even within subprograms. As such, each program area will identify and pursue its own specific industry partners that can help achieve its individual goals and objectives. Securing these partners will require that the expertise and technologies offered by ECIS significantly improve industry's ability to deliver to their customers. That is, the partner must have a strong reason for wanting to work with Sandia. Once the partnerships are in place, ECIS must work intensely to meet deliverables to our partners on the time scales required by industrial competition.

Although the types and numbers of industry partners will vary across ECIS program areas, each area will have a few key partners. These key partners are expected to come from the nuclear power industry, the automotive industry, the petroleum industry, public utilities, the power generation sector, the physical security sector, the renewable energy sector, and possibly the cyber infrastructure sector. Others will also emerge as industry engagement progresses. In the near- and long-term, the ECIS SMU is committed to developing key partnerships with these industry targets to ensure its strategic objectives, goals, and milestones are met.

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Acronyms

ARPA-E	U.S. DOE Advanced Research Projects Agency–Energy
ARRA	American Recovery and Reinvestment Act
ATLAS II	Accurate Time-Linked data Acquisition System
BATLab	Battery Abuse Testing Facility
BES	U.S. DOE Office of Basic Energy Sciences
BGY	billion gallons per year
CCS	carbon (dioxide) capture & storage (or sequestration)
CIKR	critical infrastructure & key resources
CINT	Center for Integrated Nanotechnologies
CRADA	cooperative research and development agreement
CRF	Combustion Research Facility
CSP	concentrated (or concentrating) solar power
DARPA	Defense Advanced Research Projects Agency
DBHD	deep borehole disposal
DETL	Distributed Energy Technology Laboratory
DHS	U.S. Department of Homeland Security
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
ECIS	Energy, Climate, & Infrastructure Security
EERE	DOE Office of Energy Efficiency & Renewable Energy
EFRC	Energy Frontier Research Center
ESS	Energy Storage Systems (DOE research program)
FE	U.S. DOE Office of Fossil Energy
FY	fiscal year
G-CEIP	Global Critical Energy Infrastructure Protection (program)
GHG	greenhouse gas
GHGIS	greenhouse gas information system
HPC	high-performance computing
IA	investment area
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JBEI	Joint BioEnergy Institute
JCTD	joint capabilities technology demonstration
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LDRD	Laboratory-Directed Research & Development (program)
LLNL	Lawrence Livermore National Laboratory
MELCOR	Methods for Estimation of Leakages & Consequences of Releases
MEMS	micro-electronic & micro-electromechanical systems
MESA	Microsystems Engineering Science & Applications (facility)
MHK	marine & hydrokinetic

NASA	National Aeronautics & Space Administration
NEDO	New Energy & Industrial Technology Development Organization (in Japan)
NETL	National Energy Technology Laboratory
NFE	nonfederal entity
NISAC	National Infrastructure Simulation & Analysis Center
NNSA	National Nuclear Security Administration
NRC	U.S. Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NSTTF	National Solar Thermal Test Facility
NW	nuclear weapon(s)
OCRWM	U.S. DOE Office of Civilian Radioactive Waste Management
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PSEL	Photovoltaic Systems Evaluation Laboratory
PV	photovoltaic(s)
PWh	petawatt-hour
R&D	research & development
RFS2	U.S. Renewable Fuel Standard (revised)
RPS	renewable (energy) portfolio standard
S&T	science & technology
S2P	Sunshine to Petrol (program)
SC	U.S. DOE Office of Science
SCADA	supervisory control and data acquisition (systems)
S-CO_2	supercritical CO_2
SEGIS	Solar Energy Grid Integration System
SES	Stirling Energy Systems (of Phoenix, Arizona)
SMR	small, modular reactor
SMU	Strategic Management Unit
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability & Security
SPR	U.S. Strategic Petroleum Reserve
SSL	solid-state lighting
SSLS	Solid-State Lighting Science (center)
USNDS	U.S. Nuclear Detonation Detection System
VAWT	vertical-axis wind turbine
WFO	Work for Others (type of contract)

Sandia National Laboratories

A Department of Energy National Laboratory

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