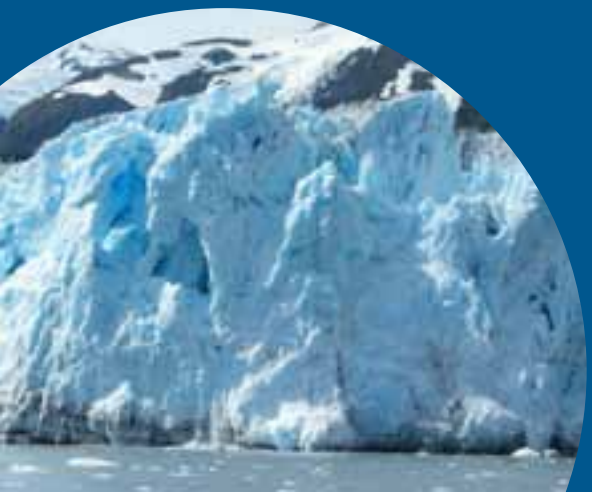
Energy, Climate, & Infrastructure Security

Executive Summary



Sandia National Laboratories

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

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

ENERGY, CLIMATE, & INFRASTRUCTURE EXECUTIVE SUMMARY

STRATEGIC FRAMEWORK

ECIS STRATEGIC MANAGEMENT UNIT

FACILITIES & RESEARCH

Purpose of the Plan

The FY11–FY14 Strategic Plan provides the necessary strategic direction and a framework within which we can achieve our goals. It is intended to provide the guidance and focus for the development and implementation of our programs. We believe that this plan will help each of us, and Sandia as a whole, have significant impact in securing our nation's energy future, achieving our vision, and providing Exceptional Service in the National Interest.

For more information please contact:
Bob Hwang, Deputy to the Vice President
Energy, Climate, and Infrastructure Security
E-mail: ecis@sandia.gov
Website: energy.sandia.gov

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. SAND# 2011-4565 P. Last updated 7/28/2011.

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.

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.

ENERGY, CLIMATE, & INFRASTRUCTURE STRATEGIC MANAGEMENT UNIT (SMU)

Vision

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

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.

High Watt/Gram, Ultra-Thin c-Si Photovoltaic Cells

Climate modeling

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.

PROGRAM AREAS

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

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 to 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 MISSION

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

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 MISSION

To develop and apply analytical approaches to secure the nation's critical infrastructure against natural or malicious disruption.

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 MISSION

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

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 Nanotechnolgies (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.

U.S. DEPARTMENT OF
ENERGY

For more information please contact:
Sandia National Laboratories
Energy, Climate, and Infrastructure Security SMU

Website: energy.sandia.gov
E-mail: ecis@sandia.gov

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.