ENERGY AND GLOBAL SECURITY

STRATEGIC PLAN 2015

GRID INNOVATION

SECURE AND RESILIENT INTEGRATED INFRASTRUCTURE

COMPUTATIONALLY ENHANCED MOBILITY

SAFE, SECURE, AND SUSTAINABLE NUCLEAR ENERGY SYSTEMS

SCALING AND SECURING CONNECTIVITY: EMBARKING ON THE INTERNET OF THINGS R&D

APPLIED MATERIALS AND MANUFACTURING

WATER

Argonne NATIONAL LABORATORY

Message from Mark Peters

Associate Laboratory Director
Energy and Global Security

For the men and women of the Energy and Global Security directorate at Argonne National Laboratory, the questions come naturally. What is next? How do we get there? What role can we play in securing the future of our country through high-quality science and engineering?

The challenge of charting a course to that future is substantial, but the brilliant minds of EGS propel us forward. Harnessing the power of those great minds and uniting their brilliance behind a vision for a more prosperous, secure, and resilient future is the task this directorate took on late last year.

We asked ourselves, what are the challenges that must be addressed in energy and security next year? Next decade? Next century?

What follows is the result of months of work by the EGS team. Combining the input of many across the directorate, we developed a framework that will guide our scientific inquiry over the coming years as we address the most pressing technical challenges facing our nation.

The immediate initiatives build on our knowledge and technical insight in nuclear energy and nonproliferation, secure and resilient infrastructure, and transportation to sustain and accelerate the progress we have made in these core areas. In the longer term, emerging initiatives will be explored to help create the future electric grid; secure and grow the Internet of Things; innovate in applied materials and manufacturing; and ensure the supply of one of our nation's most critical and threatened resources: clean and abundant water.

Through decades of dedicated and innovative research, EGS has cemented its reputation as the home of world-class applied science and engineering by maintaining its focus on the most important questions facing our country. This strategic plan represents our best thinking on how to guide our directorate forward as we build on that reputation and perform the critical research that will enable the future of our country's energy and global security.

This effort will be challenging, but the rewards are great. By leveraging the innovative thinking, profound curiosity, and deep insight of this directorate, I am confident we will achieve our mission to deliver solutions to our nation's greatest challenges in energy and global security.

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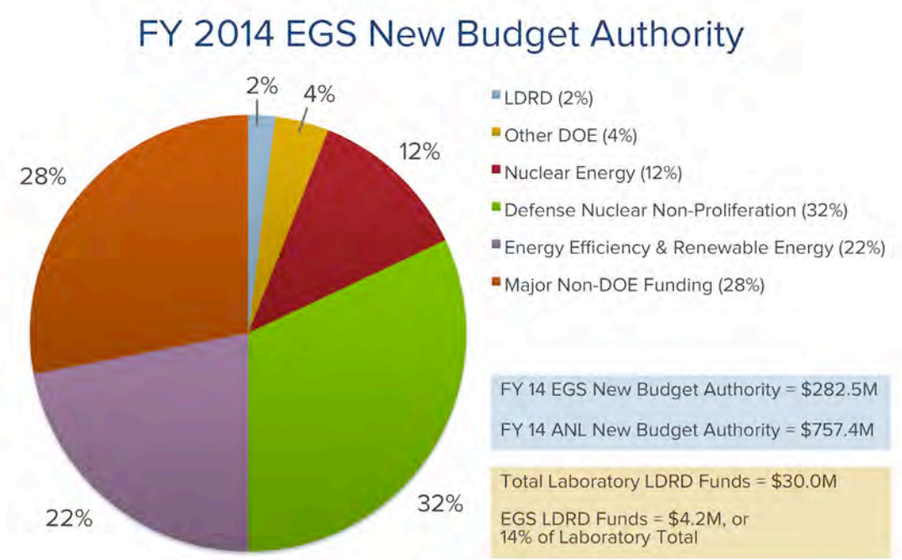
LIST OF **ACRONYMS**

AF	Advanced Fuels
AGHCF	Alpha Gamma Hot Cell Facility
ALCF	Argonne Leadership Computing Facility
ALD	atomic layer deposition
AMO	Advanced Manufacturing Office (EERE)
APS	Advanced Photon Source
ASI	Advanced Sensors and Instrumentation
BES	Basic Energy Sciences (DOE)
BETO	Bioenergy Technologies Office (EERE)
CAV	connected and automated vehicle
CEPA	Communications, Education, and Public Affairs (Argonne)
CFD	computational fluid dynamics
CI	Office of Counterintelligence (Argonne)
CIRA	Center for Integrated Resiliency Analyses
CNM	Center for Nanoscale Materials
CSE	Chemical Sciences and Engineering division
CTR	Center for Transportation Research
CWMD	Countering Weapons of Mass Destruction
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOS	U.S. Department of State
DOT	U.S. Department of Transportation
EERE	Office of Energy Efficiency and Renewable Energy (DOE)
EGS	Energy and Global Security directorate
EPSA	Office of Energy Policy and Systems Analysis (DOE)
ES	Energy Systems division
EV	electric vehicle
EVS	Environmental Sciences division
FIE	Field Intelligence Element
FCO	Fuel Cycle Options
FCT	Fuel Cell Technology Office (EERE)
FY	fiscal year
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
GSS	Global Security Sciences division
GTO	Geothermal Technologies Office
GTRI	Global Threat Reduction Initiative
HEU	highly enriched uranium
HPC	high-performance computing
IA	Intelligence Analysis division
IAEA	International Atomic Energy Agency
ICME	integrated computational materials engineering
IDC	International Data Corporation
INL	Idaho National Laboratory
IOT	Internet of Things
IT	information technology
IVEM	Intermediate Voltage Electron Microscopy facility
IWFO	Intelligence Work for Others
JAERI	Japan Atomic Energy Research Institute
JCESR	Joint Center for Energy Storage Research
JH-APL	Johns Hopkins Applied Physics Laboratory
KAERI	Korea Atomic Energy Research Institute
LANL	Los Alamos National Laboratory
LDRD	Laboratory Directed Research and Development
LEU	low enriched uranium
LLNL	Lawrence Livermore National Laboratory
LW-SMR	light water cooled small modular reactor
LWR	light water reactor
M&S	modeling and simulation
MCS	Mathematics and Computer Sciences division
MERF	Materials Engineering Research Facility
MOU	Memorandum of Understanding
MPACT	Material Protection, Accounting and Control Technologies
MRWFD	Material Recovery and Waste Form Development
MSD	Materials Science division
NE	Nuclear Engineering division, nuclear energy
NFST	Nuclear Fuels Storage and Transportation
NGA	National Geospatial-Intelligence Agency
NNSA	National Nuclear Security Agency
NRC	U.S. Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NSTec	National Security Technologies
OE	Office of Electricity (DOE)
OGA	other government agencies
onVCP	online virtual community platform
ORNL	Oak Ridge National Laboratory
OTD	Office of the Director (Argonne)
PNNL	Pacific Northwest National Laboratory
R&D	Research and development
RD&D	Research, development, and demonstration
RFP	Request for Proposal
RISC	Risk and Infrastructure Science Center
ROI	return on investment
SAA	Systems Assessment and Analysis
SMR	Small modular reactor
SNL	Sandia National Laboratories
SRII	Secure and Resilient Integrated Infrastructure
STI	Science and Technology Innovations
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TATS	Technical Assessment Translation Services
TRACC	Transportation Research and Computing Center
TRL	technology readiness level
UC	University of Chicago
UMTRI	University of Michigan Transportation Research Institute
UFD	Used Fuel Disposition
VERIFI	Virtual Engine Research Institute and Fuels Initiative
VTC	video teleconference
VTO	Vehicle Technologies Office (EERE)
WBC	World Business Chicago
WFO	Work for Others
XMAT	extreme materials beamline (Advanced Photon Source)
XSD	X-ray Science division

I. **INTRODUCTION**

Argonne's Energy and Global Security (EGS) directorate is taking on unprecedented challenges as it addresses domestic and global sustainable energy and security. This strategic plan describes our priorities in growing Argonne's market share in this very broad mission space. Leveraging collaborations with other researchers at Argonne as well as with experts from industry, academia, and other government laboratories, the EGS directorate's scientists and engineers deliver innovative research and technologies that enable access to affordable, environmentally clean energy and limit the risk from diverse threats to national and global security.



The EGS budget represents 37% of Argonne's budget.

EGS comprises four divisions—Global Security Sciences, Energy Systems, Nuclear Engineering, and Intelligence Analysis; three centers—Risk and Infrastructure Science Center, Center for Transportation Research, and Center for Integrated Resiliency Analyses; and three user facilities—the Transportation Research and Analysis Computing Center, Intermediate Voltage Electron Microscope, and National Security Facility.

Following is an overview of the EGS directorate's budget for fiscal year FY 2014.

The directorate is financially healthy; our new budget authorization (income) for FY 2014 was $282.5 million. This increase is relatively modest compared to our FY 2013 income of $270 million. EGS receives funding from a diverse set of sponsors including 14 U.S. Department of Energy (DOE) program offices and 15 other federal agencies; in addition, approximately 5% of our funding comes from non-federal, Work-for-Others sponsors. Four sponsors account for about 80% of the directorate's funding. These are DOE-National Nuclear Security Administration (32% of EGS funding), DOE-Energy Efficiency and Renewable Energy (22%), DOE Office of Nuclear Energy (12%) and the U.S. Department of Homeland Security (10%).

Using the Advanced Photon Source, an Argonne-led research team found that when uranium dioxide (UO_2) melts, the number of oxygen atoms around uranium changes from eight-fold to a mixture of six- and seven-fold, which alters how it interacts with other materials. The discovery about the atomic structure of UO_2 will help scientists select the best computational model to use when simulating severe nuclear reactor accidents.

II. OVERVIEW

This *Strategic Plan* presents a framework for the Energy and Global Security directorate's pursuit of initiatives that will enable access to affordable, environmentally clean energy and limit the risk from diverse threats to national and global security. Our *Plan* was developed through a series of meetings with EGS directorate and division management. It articulates our mission, vision, and goals and seven strategic initiatives that will guide the development of the EGS R&D portfolio in the coming years.

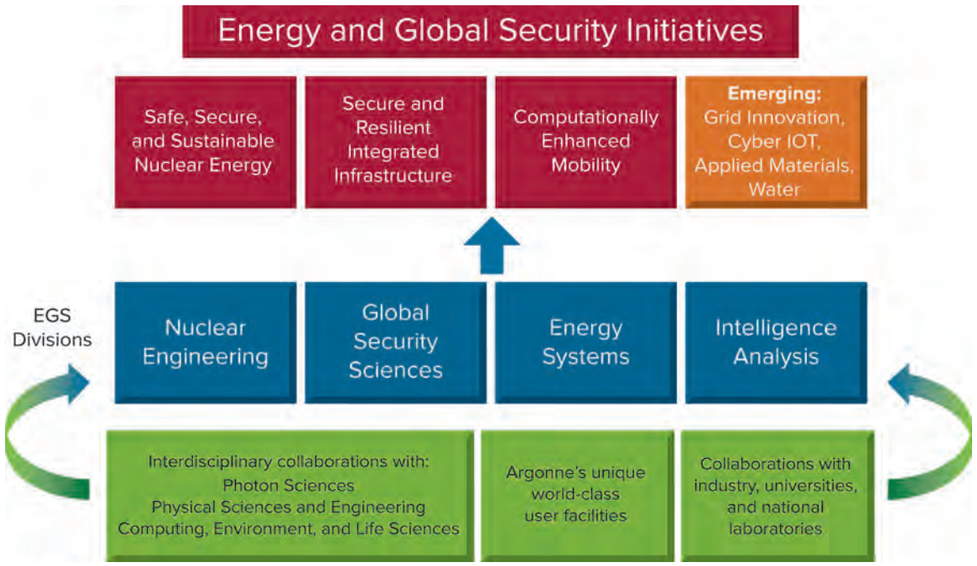
Three of these leverage the EGS core capabilities in nuclear energy, transportation, and national security. They also align with Argonne's existing major initiatives—Nuclear Energy and Security and Sustainable Transportation—and will provide the foundation for growth in our core competencies. The three EGS core initiatives are:

- Safe, Secure, and Sustainable Nuclear Energy Systems;
- Secure and Resilient Integrated Infrastructure; and
- Computationally Enhanced Mobility.

In addition to these core initiatives, EGS has identified four emerging initiatives that leverage the capabilities of the directorate and laboratory. These will also support the future growth of the directorate. The emerging initiatives are:

- Grid Innovation;
- Scaling and Securing Connectivity—Embarking on the Internet of Things (IOT);
- Applied Materials and Manufacturing; and
- Water.

The following chart shows how these seven initiatives map to the laboratory and EGS directorate strengths.



Argonne has partnered with the Metropolitan Water Reclamation District of Greater Chicago (MWRD) to determine the typical sources and distribution of microbial communities in Chicago-area waterways. The seven-year study is recording changes in the Chicago River's microbial communities as the MWRD takes steps to disinfect its discharge water from two of its treatment plants and parts of the Tunnel and Reservoir Plan. The goal is to help prevent blooms of bad bacteria in the water.

III. **MISSION, VISION,** AND **GOALS**

OUR **MISSION**

Employing world class facilities, we apply unique expertise in science, engineering, and information systems to deliver environmentally sound solutions to our greatest challenges in energy access and global security.

OUR **VISION**

Lead the world in providing energy technology and security solutions that enable a more prosperous, secure, and resilient future.

OUR **GOALS**

The goals of the EGS directorate are to:

- Reduce world dependence on fossil energy by developing technologies that increase clean energy supplies and enhance the efficient use of energy and natural resources.
- Enable the realization of nuclear energy as a carbon-free energy source that is cost-competitive, safe, and secure.
- Leverage Argonne's science, engineering, and analysis expertise to prevent misuse of nuclear, biological, chemical materials, and cyber technology; build secure and resilient infrastructure; and produce new energy solutions for national security operations.
- Provide trustworthy, actionable analysis to
  - Protect physical and cyber infrastructure.
  - Prevent misuse of nuclear, chemical, and biological materials or technology.
  - Prevent and mitigate actions, both natural and deliberate, that would result in mass destruction, disruption, or suffering.
  - Minimize risks to our environment and economic well being.
  - Promote advanced energy systems.

Argonne's Natural Convection Shutdown Heat Removal Test Facility (NSTF) is one of the world's largest test facilities for ex-vessel passive decay heat removal in advanced nuclear reactors The air-cooled NSTF is a state-of-the-art, large-scale facility for evaluating the performance capabilities of containment cooling systems while also providing reactor designers with data to validate computer simulations. Over 200 radiant heaters within the heated cavity (seen here) are used to supply a heat flux that can mimic the walls of a nuclear reactor.

IV. **CORE STRATEGIC INITIATIVES**

The Energy and Global Security directorate has identified three core initiatives as the focal points for growth in our R&D portfolio:

- Safe, Secure, and Sustainable Nuclear Energy Systems,
- Secure and Resilient Integrated Infrastructure, and
- Computationally Enhanced Mobility.

Our choice of these core initiatives was based on the following criteria:

- Multidisciplinary, multi-division, and multi-directorate effort;
- Clear and significant return on investment;
- High impact in addressing long-term energy and/or global security challenges; and
- High merit for garnering laboratory-level resources.

SAFE, SECURE, AND SUSTAINABLE NUCLEAR ENERGY SYSTEMS

Background and Motivation

Nuclear energy is the only carbon-free energy source that is proven, reliable, and expandable. It currently contributes about 20% of electricity generation in the United States and about 15% worldwide. Its use is growing in several countries, notably China, and a number of countries have initiated comprehensive nuclear power programs. The vast majority of nuclear power plants in operation or under construction employ light water reactor (LWR) technology. The United States has a strong interest in ensuring that nuclear programs worldwide—but especially in new entrant countries—are developed within the desired safety and security framework, including regarding the control of nuclear materials and technology.

Although LWR plants generate electricity safely and reliably, building them is a complex endeavor and they require substantial infrastructure and maintenance. The fuel they discharge must be safely and securely managed both in the short term and over the longer term.

Most of the leading nuclear nations are implementing recycle technologies to manage used nuclear fuel. In addition, their plans call for partial or full transition to fast neutron reactors because these reactors enable the recycling and consumption of *all* the fissionable nuclides in used nuclear fuel. Fuel recycling using fast reactors would greatly improve/facilitate waste management and would substantially increase the use of uranium when compared to the LWR fuel cycle in which fuel is not re-used.

Nuclear engineer Mitch Farmer holds a piece of corium from a nuclear reactor severe accident experiment, in which molten core debris, or corium, erodes the concrete floor of a containment building. Farmer is seen next to an eroded test section.

Researchers from the Nuclear Energy division are at the forefront of developing technologies for nuclear separations, waste management, and non-proliferation to achieve sustainable nuclear energy systems. Electrochemical engineer Magda Tylka prepares a glovebox for testing pyroprocessing, a high-temperature method of recycling reactor waste into fuel that was pioneered at and is being developed by Argonne.

As the leader of the worldwide efforts to control nuclear proliferation, ensure the security of nuclear materials, and promote safe operation of nuclear power plants worldwide, the United States has a major stake in assuring that future nuclear energy systems meet stringent safety and security standards. This can only be assured if the United States undertakes the *timely* development and commercialization of advanced fast reactors so they can be available as an alternative to systems whose deployment would adversely affect U.S. interests in nuclear safety, security, and nonproliferation.

Strategy and Opportunity

Argonne will grow its role in the safe and secure application of nuclear energy for power generation and other applications worldwide. An International Nuclear Safety and Security Center (INSSC) will be established to integrate and expand relevant capabilities and programs at Argonne, as well as to carry out cooperative international projects aimed at enhancing the safety and security of nuclear energy applications to electricity generation, water treatment, isotope production, medical procedures, and space exploration.

Argonne will also promote a focused program of research, development, and demonstration (RD&D) targeting the commercialization of a U.S. fast reactor design for domestic and international use. Construction and operation of a test/demonstration fast reactor is a crucial element of this program and will be pursued as an Argonne-led partnership among government agencies, industry, national laboratories, and universities.

Near-term Objectives (0–3 years)

Objectives for the first three years of this initiative call for the laboratory to:

- Establish the INSSC as a vehicle for integrating and promoting Argonne's capabilities as they are relevant and apply to nuclear safety, nonproliferation, and security in power generation and other applications of nuclear energy.
- Develop new projects advancing safety and security of nuclear energy systems; projects would apply Argonne strengths in nuclear and chemical engineering, nuclear energy materials, computational modeling and simulation, environmental and risk assessment, accident behavior, emergency preparedness, and detection/diagnostic technologies.
- Build support in the nuclear community for a focused DOE-Nuclear Energy (DOE-NE) program to demonstrate advanced reactor technology through participation in the planning study for an advanced test/demonstration reactor in the United States.
- Increase Argonne's role and funding in advanced-reactor fuels and materials research, advanced recycling methods and associated safeguards, modeling and simulation, and detection and diagnostic systems.
- Establish strategic partnerships with other national laboratories, universities and industry to foster increased support in DOE and Congress for an advanced fast-reactor design and demonstration project in the United States.

Long-term Objectives (3–5 years)

Objectives for the longer term (beyond three years) are to:

- Achieve national and international recognition for the INSSC; secure funding from multiple sponsors for INSSC projects.
- Demonstrate value and impact of INSSC for the safety and security of nuclear power programs.
- Secure technical leadership for a project to design, license and build an advanced test/demonstration fast reactor.
- Demonstrate advances in reactor performance, safety, and nuclear waste management through the operation of the test/demonstration fast reactor.

Support for activities related to nuclear energy plant safety and security will be sought from a diverse sponsor base, including DOE-NE (LWR-Sustainability, Fuel Cycle R&D, Nuclear Energy Enabling Technologies, and International Programs); the National Nuclear Security Administration (NNSA); U.S. Department of State; commercial organizations developing nuclear energy technologies (e.g., Westinghouse, GE-Hitachi, Areva, and NuScale Power); nuclear utilities/generating companies (particularly larger utilities such as Électricité de France); the U.S. Nuclear Regulatory Commission (NRC); and foreign regulatory agencies; and government agencies establishing and fostering national nuclear energy programs (including their technical support organizations/institutes).

Support for advanced reactor RD&D will be sought primarily from DOE-NE; complemented by support from vendor/supplier organizations pursuing advanced reactors (GE, TerraPower, Westinghouse, Areva); and foreign agencies or laboratories charged with advanced reactor development (e.g., Korea Atomic Energy Research Institute, Japan Atomic Energy Research Institute, and French Atomic Energy Commission); and foreign regulatory agencies and their technical support organizations.

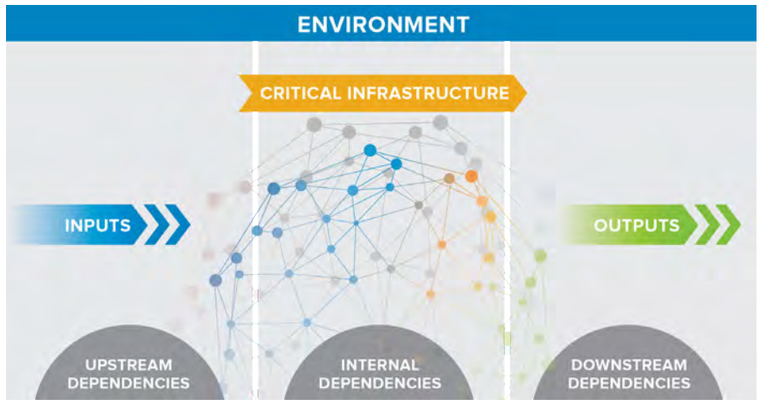
SECURE AND RESILIENT INTEGRATED INFRASTRUCTURE

Background and Motivation

On February 13, 2013, the White House released Presidential Policy Directive (PPD) 21 – Critical Infrastructure Security and Resilience. Its objective is to advance "a national unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure." Our society depends on the provision of reliable, secure, and efficient services by that infrastructure. However, it is rapidly aging and growing more insecure, becoming more vulnerable to natural disasters, accidents, and deliberate destructive acts. Further, the demands on our infrastructure are ever changing and thus, our infrastructure must adapt to 21st century requirements. According to PPD 21,

> *Critical infrastructure must be secure and able to withstand and rapidly recover from all hazards. Achieving this will require integration with the national preparedness system across prevention, protection, mitigation, response, and recovery.*

To be successful, we must strengthen existing and build new infrastructure using strategic forethought, modern design, next generation materials and techniques, and engineering methods that optimize interdependencies and respond to rapidly changing needs.



The Secure and Resilient Integrated Infrastructure initiative increases understanding of cascading and escalating impacts among critical infrastructure based on comprehensive analysis of upstream, internal, and downstream dependencies.

Strategy and Opportunity

EGS will create the Secure and Resilient Integrated Infrastructure (SRII) User Facility, that will encompass a broad set of capabilities and expertise and serve as a user facility for both internal and external researchers and practitioners. It will provide researchers and stakeholders from across the globe with a critical combination of experimentation, computation, engineering, and analysis tools essential to building a secure, resilient, and cost-effective infrastructure.

Argonne possesses the right combination of expertise, capabilities, world recognition, and customer trust necessary to establish this foundation for the success of the SRII initiative. We envision contributions and cross-collaborations from several Argonne organizations:

- The Risk and Infrastructure Science Center (RISC), the Center for Integrated Resilience Analyses (CIRA), and the Global Security Sciences (GSS) and Energy Systems (ES) divisions can provide infrastructure, social, behavioral, economic, security, and systems analysis.
- The Environmental Sciences (EVS) division can provide environmental security, climate research, and natural resources analysis.
- The ES and NE divisions can provide expertise in structural, fluid-structure, and electrical simulations, testing, and design expertise.
- ES and the Chemical Sciences and Engineering (CSE) divisions can contribute expertise in tribology and surface chemistry.
- The Mathematics and Computer Science (MCS) and GSS divisions and the Argonne Leadership Computing Facility (ALCF) can contribute applied math, scientific and high-performance computing, visualization, and software engineering expertise.
- The Materials Science (MS) division and Nanoscale Science & Technology (NST) division, as well as the Center for Nanoscale Materials (CNM) and the Advanced Photon Source (APS), can contribute materials research, development, and testing expertise.
- The Materials Engineering Research Facility (MERF) can be used to develop techniques for materials scale-up and process engineering.
- The NE and High Energy Physics (HEP) divisions can contribute environmental sensors, electronics, and electrical systems expertise.

The President's FY 2015 budget request relevant to infrastructure resilience reaches nearly $380 billion, including $56 billion requested for an Opportunity, Growth, and Security Initiative; $302 billion for a surface transportation infrastructure program; $2.5 billion for global climate change research; and $18 billion to address homeland security/critical infrastructure/key resources.

Near-term Objectives (0–3 years)

We plan to leverage our existing relationship with the U.S. Department of Homeland Security (DHS) through Argonne's RISC to ensure early success. We will

- Expand and fortify core analysis capabilities with the strong science and engineering expertise resident throughout the laboratory.
- Begin tackling the challenge of simulating the interdependencies of select infrastructure segments to ensure robust predictions and engineered solutions; the new Integrated Infrastructure Forecaster will represent the first multi-sector computational infrastructure analysis tool of its kind.
- Place an early emphasis on applying our capabilities to the nation's complex and vulnerable electric grid; the EGS directorate has invested considerable effort in promoting a high-performance national grid simulator, and there is emerging and rapidly growing interest with many potential customers including the U.S. Department of Defense (DOD) and commercial electricity providers.
- Continue investment in the emerging grid initiative (see Section V); accelerate and reinforce its success by establishing Argonne's unique position as the DOE laboratory that is best suited for designing the secure and resilient grid of the 21st century.

City of Chicago infrastructure.

Long-term Objectives (3–5 years)

The SRII User Facility will be well established and globally recognized as the "gravitational" center of research, development, testing, and evaluation of integrated infrastructure.

- For the first time, the SRII User Facility will have all the key expertise and capabilities to address the full complexity of tightly coupled and interdependent infrastructure networks.
- This unique approach to securing infrastructure will permit us to grow Argonne's contribution beyond current robust analysis of vulnerabilities and consequences to leading the globe in designing and building new, secure, and resilient infrastructure.
- In addition to the 16 existing critical infrastructure sectors defined by DHS, we anticipate that the "Internet of Things" (IOT), which is tightly coupled with cybersecurity, will emerge as a dominant global infrastructure concern. Funding the emerging IOT initiative (described below in Emerging Initiatives) at an appropriate level in the near term is a wise investment for combining that mission into the SRII initiative. Given that cyber and physical infrastructure are inextricably linked, fulfilling the objective of addressing comprehensively integrated infrastructure requires such incorporation.

COMPUTATIONALLY ENHANCED MOBILITY

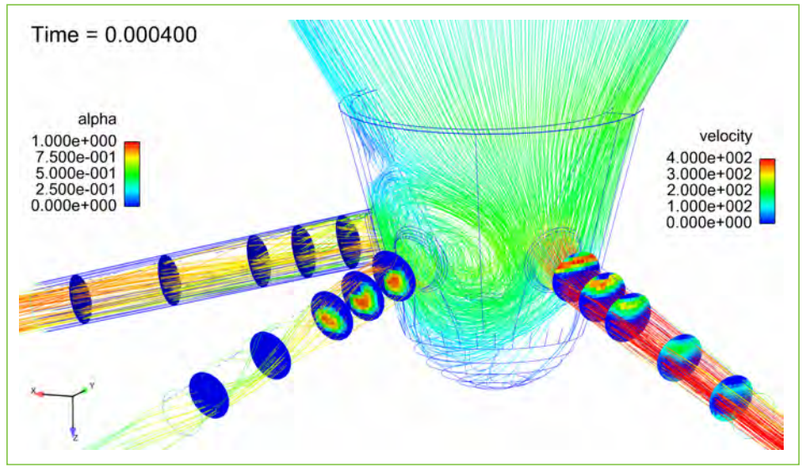
Background and Motivation

Argonne differentiates itself by applying both fundamental science and applied engineering expertise coupled with its unique facility capabilities—the Advanced Photon Source (APS), ALCF, the Advanced Powertrain Research Facility (APRF), the Electric Vehicle-Smart Grid Interoperability Center, and the Transportation Research and Analysis Computing Center (TRACC)—to create solutions for accelerating the pathways to sustainable transportation.

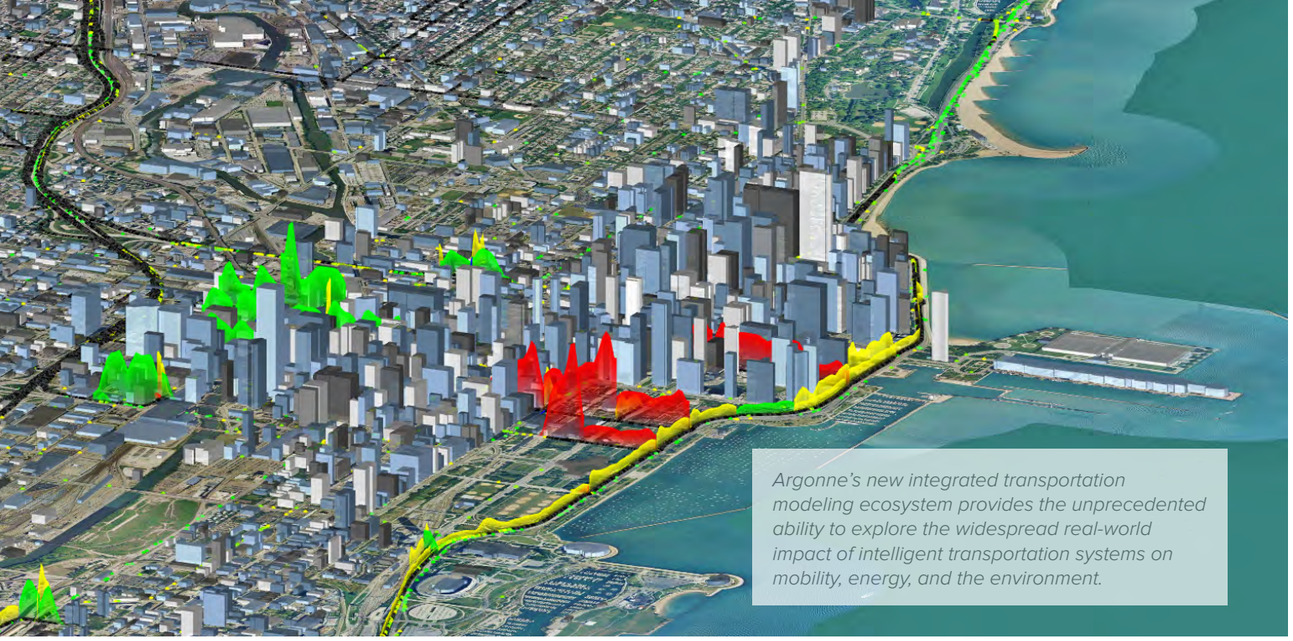
Carbon energy use in transportation must be dramatically reduced to address environmental issues and global security concerns. Greenhouse gas regulations for light-, medium-, and heavy-duty vehicles are requiring a pace of invention, efficiency gains, and technology adoption that is unprecedented. Speed-to-market for advanced technologies is required and model-based engineering development tools are among the enablers. Moreover, vehicles that are able to communicate with each other and with the infrastructure reduce congestion, improve safety, and aid energy efficiency. Technology development and computational ability allows vehicle automation and infrastructure connectedness. The emergence of connected and autonomous vehicles (CAVs) is a mobility paradigm shift.

Two near-term opportunities exist for Argonne:

- The Virtual Engine Research Institute and Fuels Initiative (VERIFI) at Argonne is positioned to become a leader in the co-design of engines and fuels using highly predictive engine-fuel simulations. The VERIFI activity is aimed at shrinking the combustion engine development cycle for speed-to-market. These netted efficiency gains will enhance the overall transportation system. An umbrella of activities at Argonne supports this initiative:
  - Combustion chemical mechanisms in the CSE division,
  - Spray research at the APS, computational fluid dynamics (CFD) modeling in the ES division, high-performance computing (HPC) in the Mathematics and Computer Science (MCS) division and the ALCF that permits end-to-end combustion engine simulations including uncertainty quantification.
- CAV technology research dovetails with several of Argonne's key strengths including
  - Traffic and energy modeling at small and regional scales
  - Sensor and device development
  - Urban planning; transportation system analysis for eco-signaling or lanes
  - Cyber security
  - Big data management with HPC and visualization
  - Infrastructure resiliency
  - Building and grid connectedness
  - Codes and standards for procedures and methodology
  - Quantification of benefits
  - Behavior modeling and policy (insurance, liability, and legislation).



As part of the VERIFI work, a computer-generated visualization shows the multidimensional flow inside the fuel injector sac and the orifice of a multi-hole diesel fuel injector, which accounts for injector needle lift and wobbling. Such visualizations reveal plume-to-plume variations in spray velocity and the two-phase nature of fuel flow.



Argonne's new integrated transportation modeling ecosystem provides the unprecedented ability to explore the widespread real-world impact of intelligent transportation systems on mobility, energy, and the environment.

Strategy and Opportunity

The strategy for this initiative is to:

- Position Argonne as the leader in co-development of engines and fuels by promoting VERIFI through laboratory marketing and communication; developing additional in-house expertise; expanding functionality within computation and simulation tools such as VERIFI and Autonomie so they remain at the forefront of the engine development process; and expanding the customer base to showcase the benefits and establish an ongoing clientele.
  - Dating back five-plus years, national laboratories, along with the DOE Vehicle Technologies Office (VTO), have been defining the needs for model-based engine and combustion simulations that could reduce the development time of advanced technologies and better predict the emissions and energy levels of a final product—thereby garnering speed-to-market at a lower cost. Industrial support for the initiative is widespread. Early results communicate that six months to two years could be shaved from the typical product development process. Argonne is uniquely positioned to align with auto manufacturers, truck makers, engine suppliers, and component suppliers to apply our multidisciplinary expertise and user facility access to the potential customers' technical challenges.
  - This marketplace need is long term given daunting greenhouse gas goals that reach to 2050. Several other national laboratories have unique strengths that will complement this initiative; our strategy is for Argonne to lead this effort, with a supportive and as-needed role for the other national laboratories. Incremental investment to expand current knowledge and capabilities, with consideration of an Argonne-branded next-generation engine/fuel simulation code, will strengthen our current leadership position.
  - Although DOE VTO provides some limited funding on this activity, the significant funding growth will result from industrial partnerships.
- Develop and position Argonne as a key research partner in CAVs for government agencies, academia, technology providers, and transportation planning agencies; promote leveraged capabilities at the U.S. Department of Transportation (DOT) and DOE's Office of Energy Efficiency and Renewable Energy (EERE) for advanced technology evaluations (vehicle and infrastructure with the consumer behavior demand element) at large scale using HPC (Autonomie and POLARIS software tools); and expand the capability of Argonne modeling tools to multiple cities and regions for wider audience capture.
  - Demonstrations of self-driving on-highway vehicles date back nearly a decade, with advertising enticements that exceed 50 years. Hardware development, on-board computing capability, communication to the road infrastructure, and enhancements in transportation modeling with HPC are enabling inroads to be made into the execution of a self-driving car experience, under certain driving operations. Regulatory action for enhanced safety and revenue-generating opportunities are further encouraging deployment of technologies.
  - Argonne must align strategically with partners that are well established in this research space, such as Carnegie Mellon, University of California at Riverside, and the University of Michigan Transportation Research Institute (UMTRI) by promoting our unique, multidiscipline expertise as a strong contributor to the partnership. Similarly, metropolitan planning agencies present an opportunity for engagement with improved roadways, driver communications, and technology deployments based on comprehensive transportation system modeling provided by Argonne. Existing and increasing government funding from DOT, DOE, and DOD must be aggressively pursued at all levels of laboratory management.

Near-term Objectives (0–3 years)

Objectives for the first three years of this initiative call for the laboratory to:

- Develop and internally fund several 12-month pilot programs with industrial companies to demonstrate VERIFI benefits.
- Build ongoing support for the VERIFI user facility with proactive lab promotion activity for greater brand awareness.
- Continue to support visiting scholar exchange programs and the postdoc staffing model to further expand international knowledge of VERIFI's capabilities.
- Decide on Argonne-led development of an open-source Combustion CFD code for massive parallelization computational capability with funded execution plan, as appropriate.
- Position Argonne as a leader in the CAV research space using existing transportation and energy modeling capabilities with promotion for greater brand awareness
- Partner with UMTRI for a student exchange and collaborative research with uptake of Argonne modeling tools.
- Retain expert staff with supplemental funding (if necessary) to keep the expert knowledge and a competitive edge while expanding functionality and application of tools.
- Explore application of CAV technology to:
  - Argonne for sustainable campus demonstration,
  - DOT for engagement on connected vehicle demonstration pilots (with a Request for Proposal due January 2015),
  - Local urban planning and metro-transportation agencies, and
  - DOE for energy modeling of CAV technologies.

Argonne's rapid compression machines allow researchers to characterize critical aspects of real fuels used in combustion engines, encompassing a range of conditions relevant to modern engine operation. Once developed, such model fuels (surrogates) are then validated for use in engine simulations.

Long-term Objectives (3–5 years)

- Diversify funding sources for VERIFI with marketing and subsequent capture of oil and energy sectors, DOD, U.S. Environmental Protection Agency, DOT, and Asian market customers.
- Establish Argonne as the go-to laboratory for engine simulations, with an international reputation, bringing talent and sustained funding.
- Own the large-scale traffic and energy modeling research space for transportation planning agencies and urban planners with a toolkit of CAV modeling services and products.

The DOE EERE Transportation Working Group (TWG), which was formed at the request of the Deputy Assistant Secretary of the Office of Transportation in 2014, has included engine and combustion CFD predictive modeling and CAVs into the budget request process with a stated desire to greatly increase the research work plan for the national laboratories. Argonne holds a prominent role in the TWG and champions both initiatives with leadership, as evident to DOE and the other national laboratories. Although support for ongoing work is anticipated, the scale of funding is unknown. Additional funding sponsors will be sought from industry and component suppliers for VERIFI as the Argonne user facility that will address their critical business requirements. Funding diversification for CAVs will best be accomplished by enhancing the DOT Joint Program Office relationship and growing partnerships with the transportation planning agencies for traffic and energy system consideration.

V. EMERGING INITIATIVES

EGS has identified four emerging initiatives that will contribute to the directorate's research and development (R&D) portfolio:

- Grid Innovation,
- Scaling and Securing Connectivity—Embarking on the Internet of Things R&D,
- Applied Materials and Manufacturing, and
- Water.

GRID INNOVATION

Dramatic changes are under way in grid technologies that will have huge impacts on the operation and business of the grid. Argonne already enjoys a large and diverse portfolio of power grid–relevant projects. We have received more than $10 million from DOE for grid or grid-related modeling and analytics and $2.5 million from DOE to simulate the impacts of electric vehicles on the grid. Furthermore, a large existing effort within the EGS Risk and Infrastructure Science Center (RISC) is funded by DHS that addresses grid-relevant threats and consequences.

However, these existing contributions—important as they are—are insufficient to position Argonne as a leader in grid innovation.

EGS plans to increase its market share and its impact on protecting and rebuilding the national power grid by launching a grid simulation user facility centered at the laboratory. We have already observed rapidly growing interest in such a facility from DOE, DOD, and the utility industry.

The user facility would integrate relevant data and computer models into operational tools for planning and operations, identification and mitigation of vulnerabilities, and emergency response; it will also address additional important problems as they emerge and become stakeholder priorities. Success will require identifying the laboratory's unique strengths early in the launch process and attracting partner institutions that can complement our strengths and broaden our reach across sponsor space, including DOE, DOD, DHS, and the utility industry.

Chicago city lights at dusk.

SCALING AND SECURING CONNECTIVITY: EMBARKING ON THE INTERNET OF THINGS R&D

While possibly creating efficiencies in areas such as advanced manufacturing and infrastructure design, production, and resilience, the IOT also creates new and unknown technological, economic, and security risks to the nation and, more broadly, the world.

By merging and extending our science, engineering, scientific simulation, and complex analysis capabilities, Argonne can become the preeminent national laboratory for scaling and securing connectivity for the imminently disruptive IOT. In the near term, we will build on our existing strengths in analysis and optimization of interdependencies and connectivity in the grid, transportation, water, and physical infrastructure sectors. To maintain thought leadership in these existing strengths, it is critical to acknowledge the existence of historically non-communicating objects in the physical world (e.g., automobiles) that will become new information systems.

The Internet of Things (IOT) is the network of physical objects accessed through the Internet, as defined by technology analysts and visionaries... The IOT is connecting new places—such as manufacturing floors, energy grids, healthcare facilities, and transportation systems—to the Internet.[1]

[1]*Defense Systems Agency Strategic Plan 2014–2019 (Version 2), accessed September 22, 2014, http://www.disa.mil/~/media/Files/DISA/About/Strategic-Plan.pdf*

Over the longer term, we will apply our existing leadership in energy storage, nanomaterials, scientific simulation and applied mathematics, and detection technologies to lead IOT research and development. We will eventually expand our leadership role by incorporating other emerging areas of expertise at the laboratory such as connected and autonomous systems, energy harvesting, and the Secure and Resilient Integrated Infrastructure initiative to broaden the solution space and anchor Argonne's ownership of securing and scaling the IOT.

The International Data Corporation predicts the global market for solutions to challenges posed by the Internet of Things will grow to more than $7 trillion in the next half decade. Competing nations, including China and the United Kingdom, are making investments in the billions of dollars—and with plans to increase funding. Tackling such a complex problem involves integrating disparate disciplines and applications and requires multidisciplinary science and technology working closely together to produce practical and robust solutions—which is the strength of the DOE national laboratories.

APPLIED MATERIALS AND MANUFACTURING

Our strategy for the Applied Materials and Manufacturing initiative is to position Argonne as a leading technology developer with the advanced manufacturing industry and government sponsors and clients. Argonne already has separate but sizable nuclear and non-nuclear applied materials activities totaling approximately $9 million per year. This initiative will unite these activities, support the creation and sharing of facilities and capabilities across directorates, and provide an end-user focus to existing strengths in basic materials research and characterization capability. Argonne's combined abilities in predictive modeling and rapid evaluation of innovative new material designs may enable a "materials by design" paradigm and better position Argonne to remain at the forefront of major new advances in applied materials.

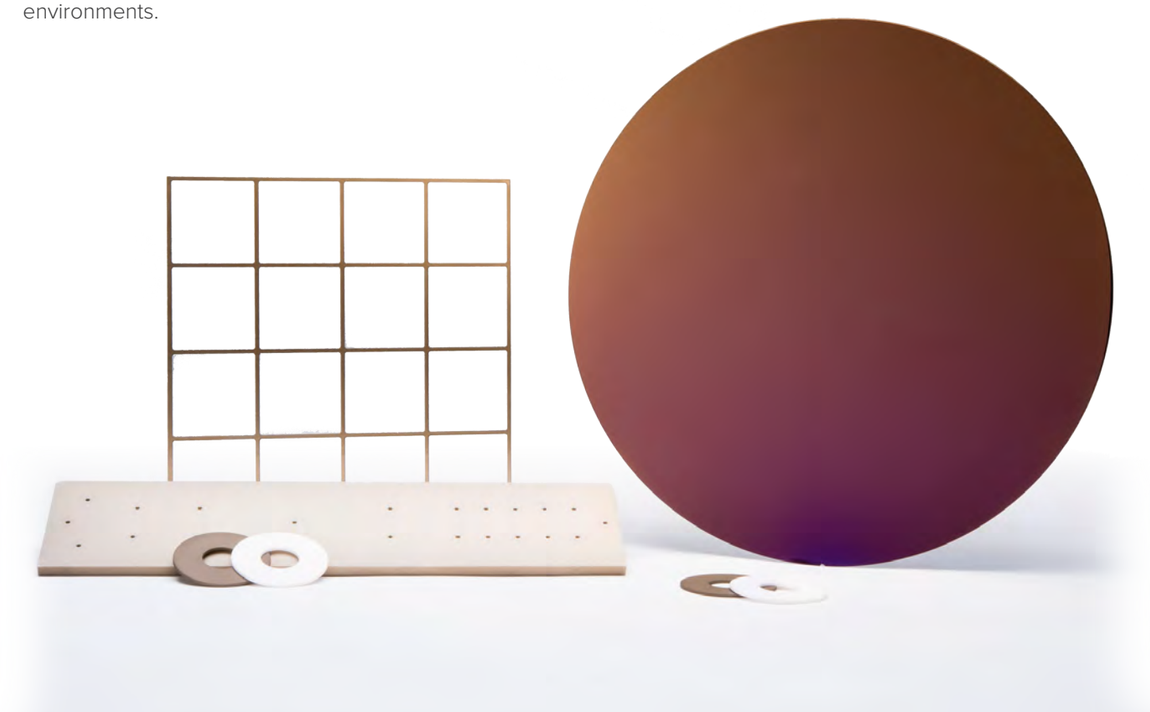
The non-nuclear activity is focused in four areas:

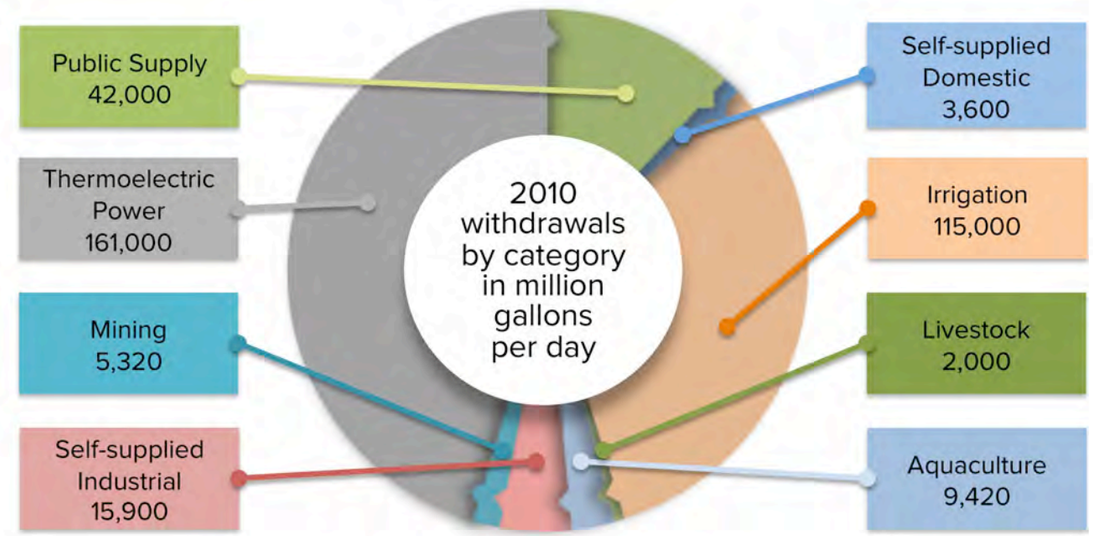
- Nanostructured materials, which includes:
  - Atomic layer deposition (ALD), plasma ALD, and sputtering techniques to synthesize and/or coat membranes, thin films, and particles;
  - Process design for scaling up meso-structured battery materials, especially cathode materials; and
  - Electrospinning nanorods of targeted compositions, diameters, and crystal structures.
- Sustainable manufacturing, which includes:
  - Reclamation of carbon-fibers and polymeric materials from polymer matrix composites;
  - Separation and recovery of polymeric materials from end-of-life durable goods, such as consumer electronics and vehicles; and
  - Development of efficient alternatives to high-temperature, heat-treating processes such as boriding and nitriding.
- Biological processing of biomass, including materials for improved conversion and separation efficiency and synthesis of fuels.
- Validation of integrated computational materials engineering (ICME)-predicted metallic microstructures.

Argonne has a unique opportunity to increase the fundamental understanding of nuclear energy materials behavior and to apply the resulting insights to the design, synthesis, and testing of materials with improved properties and performance, including accident-tolerant and higher burn-up fuels. Integration of *in situ* characterization tools with multiscale modeling and simulations will enable the development of high-performance materials for applications in extreme nuclear environments; it will also enable correlation of atomic and nanoscale structure with physical and mechanical properties of nuclear materials with predictive understanding. The restart of the Intermediate Voltage Electron

Microscopy (IVEM) Facility in the NE division with DOE-NE funding is a key step in positioning the laboratory to expand in this area. Operation of the IVEM Facility can be leveraged to pursue development of the extreme materials beamline (XMAT) at the Advanced Photon Source. This facility could simulate many years' worth of bulk radiation damage from neutrons and fission fragments in just days and will enable *in situ* examination of microstructure evolution during irradiation and under imposed variations of stress, temperature, and chemical environment. XMAT's ability to isolate single physics effects also makes it essential to the development and validation of predictive, science-based models of materials behavior in nuclear environments.

The discovery and development of novel materials is enabling dramatic improvements in manufacturing for industries such as photovoltaics, catalysis, and energy storage. Argonne's expertise in this area is unparalleled. Argonne's scientists and engineers employ atomic layer deposition to develop new nanophase materials whose properties are tailored specifically to meet the needs of industry. Examples of Argonne's many successes include nanocomposite charge drain coatings for electron-optical devices (shown here) and carbon nanotube-metal sulfide nanophase materials for energy storage.





45% of all water withdrawals are for power

The Energy Sector withdraws more freshwater than any other sector in the United States.

WATER

Significant opportunities are emerging in the public and private sector to tackle water stewardship: the U.S. Department of Energy has identified the energy-water nexus as an emerging activity that require substantial R&D investment in the coming years, and DOE's Water Energy Nexus report has identified reclaimed water as a core opportunity for managing water.

Recognizing the potential opportunities in water stewardship, Argonne recently founded the Urban Water Alliance as a regional water partnership to address critical issues in water management. Other founding members include The University of Chicago, Northwestern University, and the University of Illinois-Urbana Champaign; as well as partners Metropolitan Water Reclamation District of Greater Chicago, the City of Chicago; and other major Great Lakes and Midwestern research universities and institutes.

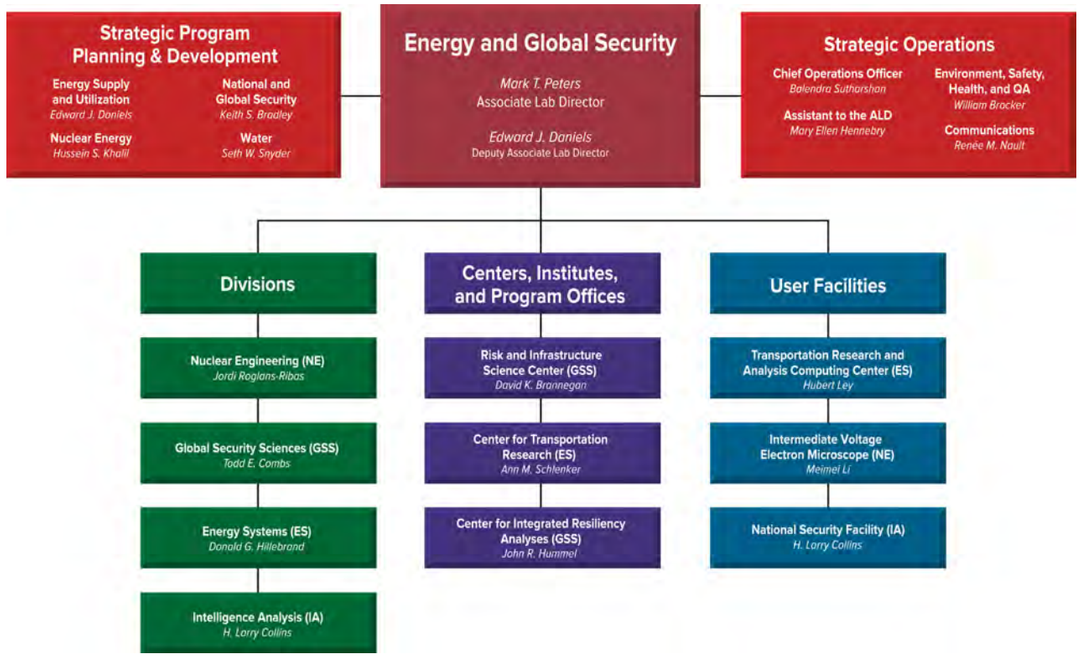
The Urban Water Alliance will bring in experts from other divisions and directorates across the lab to help build and refine data and to develop or enhance existing modeling and analysis tools to understand the balance between water supply and demand and quality. Modeling will be a primary source for evaluating risk in water systems and determining gaps between emerging demand and water supply. The decision tools will identify gaps in infrastructure and technology performance of sensors and detectors, water treatment, and nutrient recovery. The partnership will also focus on the development of technology for recovery and reuse of water, energy, and nutrients from used water, thereby enabling reused water to compete economically with fresh, clean water.

Technician Mike Furlan checks the chilled water temperature for Argonne's Materials Engineering Research Facility. The facility develops manufacturing processes for producing advanced battery materials in sufficient quantity for industrial testing.

VI: **ENERGY** AND **GLOBAL SECURITY ORGANIZATION**

EGS comprises four research divisions—Nuclear Engineering, Global Security Sciences, Energy Systems, and Intelligence Analysis; three centers—the Risk and Infrastructure Science Center, the Center for Transportation Research, and the Center for Integrated Resiliency Analyses; and three user facilities—the Transportation Research and Analysis Computing Center, Intermediate Voltage Electron Microscopy-Tandem Facility, and the National Security Facility. Descriptions of the missions, capabilities, and strategies of each division, center, and user facility follow the EGS organization chart.

Energy and Global Security Organization Chart



RESEARCH DIVISIONS

Nuclear Engineering Division

Argonne's Nuclear Engineering (NE) division's primary mission is to advance the design and operation of nuclear energy systems. NE and its precursors at Argonne have led the development of civilian nuclear power systems since the dawn of the nuclear age. The division conducts analytical and experimental research in nuclear reactor and fuel cycle systems, nuclear nonproliferation and national security, and environmental management.

NE also applies its nuclear energy–related expertise to current and emerging programs of national and international importance. Extensive capabilities in engineering experimentation, modeling, and analysis are applied in the development of diverse engineering systems and the assessment of their performance, safety, and economics.

The U.S. Department of Energy (DOE) is the primary supporter of the division's activities through programs managed by the Office of Nuclear Energy (DOE-NE) and the National Nuclear Security Agency (NNSA). Other DOE offices and sponsors from a broad range of U.S. government agencies, commercial organizations, and foreign organizations also support NE activities.

Programs and Capabilities. The NE division conducts nuclear energy research that advances national goals in the following program areas:

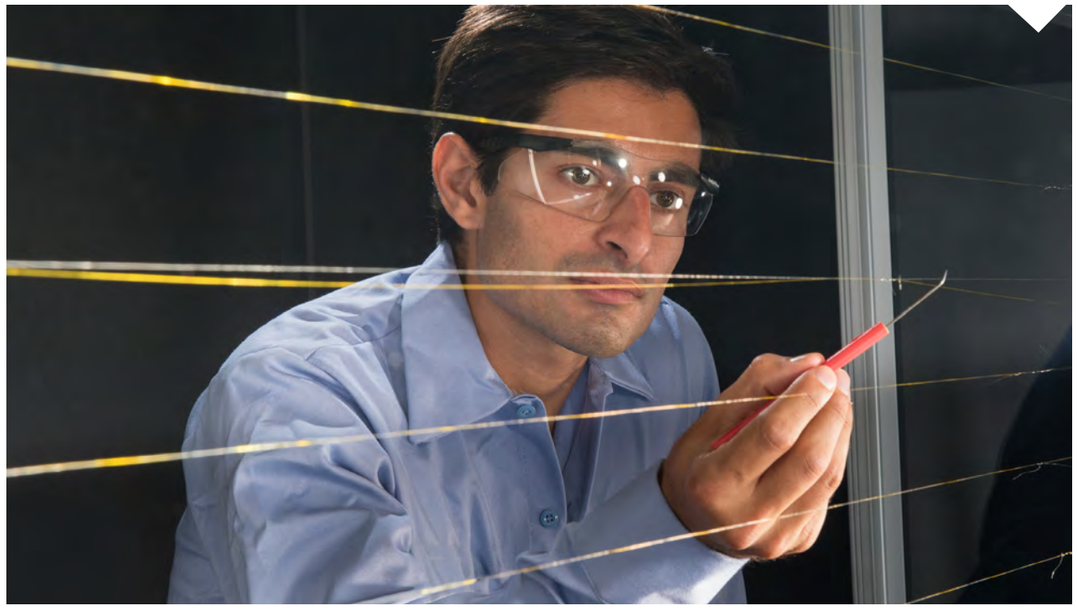
- **Nuclear Reactor Technologies.** NE provides the national leadership for DOE NE's multi-laboratory Advanced Reactor Technologies (ART) R&D Program, which is advancing the technologies and design of future-generation reactor systems. NE also performs research on the aging of light water reactor (LWR) structural materials to verify reactor safety and to support the extension of plant lifetime.
- **Fuel Cycle Technologies.** NE contributes technical leadership and expertise in several areas (campaigns) of DOE-NE's fuel cycle R&D program, including the assessment of future fuel cycle options; safe management and disposition of used nuclear fuel, recovery of material from used fuel for recycle to advanced reactors, and development of improved fuels for LWRs and advanced reactors.
- **Science and Technology Innovations (STI).** NE's primary contribution to DOE-NE/STI R&D is the advancement of nuclear reactor modeling and simulation methods using high-performance computing capabilities. NE also performs competitively awarded STI research in the areas of Reactor Materials and Advanced Sensors and Instrumentation. NE also operates the Intermediate Voltage Electron Microscopy-Tandem Facility with support from the DOE-NE STI Office.

NE division personnel make extensive contributions to programs sponsored by DOE's NNSA. The largest of these is the research reactor conversion program supported by the NNSA Office of Material Management and Minimization (NA-23). It encompasses broad efforts to convert U.S. domestic reactors and international reactors to the use of low-enriched uranium (LEU) fuel. It also includes the development of technologies to replace use of highly enriched uranium (HEU) in the production of the medical isotope Mo-99; this effort supports the secure, dependable, domestic production of Mo-99. The NE division also carries out research on sensors, instrumentation, and safeguards as part of the proliferation detection efforts of the NNSA Office of Nonproliferation and Arms Control (NA-24). The division also provides technical support for the NNSA Office of Global Material Security (NA-21) and for the Material Disposition under NA-23. The NE division also supports programs on transportation cask certification and material transportation tracking, under the primary sponsorship of the Office of Environmental Management (EM) of DOE.

NE division activities sponsored by U.S. government agencies other than DOE include the following:

- **Materials Research in Support of Light Water Reactor Safety and Regulation.** Key areas of research include studies of stress corrosion cracking and steam generator tubing integrity. The U.S. Nuclear Regulatory Commission (NRC) is the primary sponsor.
- **Technical Assistance to the International Atomic Energy Agency (IAEA).** The NE division fulfills Argonne's role as host institution for U.S. participation in the International Atomic Energy Agency's (IAEA's) Nuclear Power Training Program. With support from the U.S. Department of State, NE conducts training courses that support the safe, peaceful uses of nuclear energy by IAEA Member States. The division also administers the IAEA Fellowship program, coordinates participation at IAEA meetings, and assists in outreach activities aimed at increasing U.S. representation at the IAEA.
- **Technical Support for Off-Shore Oil Exploration and Recovery.** The NE division contributes engineering analysis and experimentation expertise to the U.S. Department of the Interior and to the oil industry. This work is currently focused on the characterization and mitigation of risks associated with deep-ocean drilling for oil. Tools and methods developed for nuclear safety/risk assessments are being applied to the engineering systems used in underwater drilling for and extraction of oil.

Argonne nuclear engineer Craig Gerardi works with fiber-optic distributed temperature sensors in the MAX fluid dynamics facility. This facility provides high-resolution data to develop computational tools that model fluid flow and heat transfer within complex systems such as the core of a nuclear reactor.



The NE division carries out technical work for commercial and international organizations. Activities range from providing engineering support for advanced reactor and fuel cycle facility design to the analysis and modeling of the performance, safety, and economics of diverse engineering systems. The largest international sponsor of NE division activities is currently the Korea Atomic Energy Research Institute (KAERI), which supports NE's participation in the design and licensing of the Prototype Generation IV Sodium-cooled Fast Reactor (PGSFR).

Overview of the Division's Strategy. NE is Argonne's lead division for the EGS core initiative on Safe, Secure, and Sustainable Nuclear Energy Systems and is a key participant in the emerging initiative on Applied Materials and Advanced Manufacturing. The Division will continue to pursue the growth of its funding and impact in its current mission areas supported by DOE and Work-for-Others (WFO) programs. Other areas of significant opportunity for the division include:

- **U.S. Military Use of Nuclear Energy.** NE's expertise in nuclear reactor and fuel cycle systems can support U.S. Department of Defense (DOD) programs and interests in nuclear power. Small nuclear reactors are being considered as a source of power for U.S. military sites and for remote and/or temporary applications. Technologies of interest include mobile reactors and reactors for rapid deployment and disassembly: supporting this initiative will require unique and innovative designs. Argonne can provide extensive technical support in the design, analysis, and assessment of such unique nuclear systems.
- **Nuclear Safeguards.** Argonne will work to create an organizational focus for nuclear safeguards activities at the lab and to develop related capabilities so that new opportunities can be pursued more effectively. Funding for safeguards activities will be sought from the NNSA Offices of Nonproliferation and Arms Control (NA-24) and Research and Development (NA-22).
- **Economics of Energy Sources.** NE will work with other Argonne divisions to
  - Develop a policy support capability to evaluate the economics of energy sources, with a focus on the enabling factors for nuclear power; and
  - Provide technical analysis support for planning the national energy mix. Elements of this capability extend beyond technical and economic ones, to societal aspects such as safety, security, and environmental considerations and concerns.
- **Isotope Production and Utilization.** Argonne has developed a strong set of interdisciplinary capabilities in isotope production and use in several divisions. We will work to develop new programs in this area, consisting of R&D support for industrial partners or government agencies in isotope programs. Partnership with commercial companies and the University of Chicago should strengthen prospects in this area.
- **Non-nuclear Applications.** The recent NE division success supporting the U.S. Department of the Interior and the oil industry indicates that NE's capabilities in both engineering experimentation and modeling and analysis are of potential interest to diverse industries, as well as government agencies involved in their development or regulation. New program development efforts will seek to identify and develop such opportunities.

Argonne's success in the geospatial sciences stems from the integration of world class science and industry leading technical expertise in geographical information systems and remote sensing, resulting in the unparalleled fusion of classified and unclassified geospatial data and analytics. This integrated approach to geospatial applications has resulted in unique solutions to nuclear, chemical, biological, security, environmental, and energy problems. Seen here are GIS analyst Joe Adduci (left) and nuclear engineer John Arnish, both of the Global Security Sciences division.

Global Security Sciences Division

The Global Security Sciences (GSS) division delivers actionable, defensible, and powerful information and technologies to decision makers who impact and shape our global security. Innovative decision support tools (including simulation models), databases, and analytical methodologies are developed and used to provide quantitative information to decision makers in the areas of national and homeland security, infrastructure assurance, emergency preparedness, social dynamics, and policy analysis. Research areas include: national and homeland security, infrastructure assurance, emergency preparedness, social dynamics, and policy analysis.

The division is a vibrant, interdisciplinary research community dedicated to the advancement of world-class science and engineering capabilities to protect, mitigate, respond to, and recover from all threats. We use an interdisciplinary and all-threat approach that enhances our ability to deliver insight and rigor into the most pressing and challenging global security risks and issues of our time.

GSS solutions include analyses, technologies, and tools to better inform global security risks and issues. These risks and issues include, for example, climate change, cyber and physical infrastructure systems, human conditions and disease, nonproliferation, and terrorism. GSS is home to four centers with core, cross-cutting capabilities within the division and across the laboratory:

- **Center for Integrated Resilience Analyses (CIRA)** focuses on cross-cutting tools and strategies to inform community and regional resilience.
- **Center for Strategic Security (CSS)** focuses on technical nonproliferation policy support and security systems and assessments.

Computational scientist Jonathan Ozik discusses a model associated with the LakeSim effort. LakeSim is a modeling tool that uses high-performance computing to analyze the energy and transportation needs of a planned 600-acre development project on Chicago's South Side.

- **Risk and Infrastructure Science Center (RISC)** focuses on infrastructure science, cyber analysis and operations, threat analysis, and emergency preparedness.
- **Systems Science Center (SSC)** focuses on integrated analytics and social and behavioral systems.

Programs and Capabilities. GSS relies upon a heavily diversified sponsor base. FY 2014 budgets reflect a sponsor composition of 41% U.S. Department of Homeland Security (DHS); 25% DOE; 17% U.S. Department of Defense (DOD); 5% Non-Federal; and 13% Other Federal. Research is conducted in the following areas:

- **Infrastructure Science.** Enhancing infrastructure resilience. Our largest program conducts research and analysis that enhances infrastructure resilience and reduces the risk of damage or destruction from climate change, natural hazards, accidents, and/or terrorist threats. Key focus areas include:
  - **Resilience Analysis.** We support efforts by DHS, DOE, and the U.S. Army Corps of Engineers to analyze critical infrastructure protection and resilience measures across all infrastructure sectors and for all threats. These combined efforts have produced user-focused interactive tools (e.g., Protective and Resilience Measures Dashboards, the Federal Protective Service Dashboard for achievement of standards, Special Events and Domestic Incidents Tool) that support critical infrastructure protection and resilience decisions. The tools enable infrastructure stakeholders (owners/operators, policymakers, program managers, etc.) to assess infrastructure resilience/protection and investigate the implications of adding to and/or augmenting existing capabilities.
  - **Prioritization.** We support numerous prioritization activities that emphasize rigor, transparency, and defensibility. Current work includes developing business rules and a framework to support rapid development of the Infrastructure of Concern lists for impending or current incidents (sponsor: DHS Office of Cyber and Infrastructure Analysis); prioritizing shortfalls in biodefense processes, technologies, and procedures (sponsor: DHS Office of Science and Technology); and developing criteria, scales, and a methodology to prioritize infrastructure in support of the National Critical Infrastructure Prioritization Program (sponsor: DHS Office of Cyber & Infrastructure Analysis).
  - **Dependency and Interdependency Analysis.** We conduct considerable analysis of dependencies and interdependencies of physical and cyber infrastructure for both DHS and DOE. We have developed an analytical framework for lifeline infrastructure impact models (e.g., PolFast, EPFast, NGFast) that are being integrated to understand the dependent and interdependent nature of different critical infrastructure systems and the cascading impacts of disruptions. Our analytical approach includes gaining an understanding of the interconnectedness of cyber infrastructure (both physical and virtual) with critical infrastructure and the potential impacts on business operations caused by a disturbance.
- **International Nonproliferation Capacity Building.** This research encompasses programs to strengthen global export/trade control and implementation efforts regarding nuclear safeguards. We engage foreign partners bilaterally and regionally to conduct and establish export control training programs and to promote adoption and implementation of the Additional Protocol. We develop information technology (IT) tools to support export control and safeguards personnel. We engage international organizations (the World Customs Organization and the International Atomic Energy Agency) to promote and strengthen nonproliferation efforts. Sponsors include DOE's Office of Nonproliferation and Arms Control (NNSA) NA-24 and U.S. Department of State Bureau of International Security and Nonproliferation (ISN).
- **Chemical Stockpile Emergency Preparedness Program.** The Chemical Stockpile Emergency Preparedness Program (CSEPP) is a long-standing activity in support of a national initiative involving the U.S. Army Chemical Material Command and the Federal Emergency Management Agency. Established in 1988, the CSEP Program enhances emergency planning for the unlikely event of a release of a hazardous chemical weapons agent from one of the Army's chemical weapons storage installations.
- **Logistics Modeling.** For more than two decades, we have developed a portfolio of modeling tools to simplify the movement of equipment, cargo, or personnel through a supply chain. The Logistics and Process Analysis Tool combines the capabilities of two existing discrete modeling tools—Enhanced Logistics Intra-Theater Support Tool and the Process Analysis Tool—into one comprehensive analysis system. The current primary sponsor is DOD.
- **Radiation Detection System Testing and Evaluation.** Our programs support radiation detector testing, evaluation, verification and validation, and data analysis. We develop and maintain IT systems in support of this initiative, and we are active in data mining projects. IT systems are developed by IT specialists, and tests are designed and conducted by radiation detection experts and test scientists for detector testing programs. The sponsor is the DHS Domestic Nuclear Detection Office Systems Engineering and Evaluation directorate.

Overview of the Division's Strategy. GSS is Argonne's lead division for the EGS core initiative, Secure and Resilient Integrated Infrastructure (SRII), and the emerging initiative, Scaling and Securing Connectivity—Embarking on the Internet of Things R&D. The division also has a key role in the emerging initiative of Grid Innovation. Strategic priorities for GSS are as follows:

- **Secure and Resilient Integrated Infrastructure.** We envision a user facility comprising a broad set of capabilities and expertise for use by both internal and external researchers and practitioners. It will provide researchers and stakeholders from across the nation with a critical combination of experimentation, computation, engineering and analysis tools essential for building secure, resilient, and cost-effective integrated infrastructure.
- **Healthcare, Health, and Infectious Disease Modeling.** We have current and recently completed work in this area for sponsors including GE Healthcare, Pfizer, DHS, and the National Institutes of Health. Our work has included modeling the spread of methicillin-resistant *Staphylococcus aureus* (MRSA) infection and cellular-level modeling of pulmonary vascular disease. Our efforts use our expertise in agent-based modeling and simulation. We see significant growth potential in this area with both current and new sponsors. Our strongest competition is from (1) universities doing publication-focused, as opposed to policy-focused, work; (2) Los Alamos National Laboratory; and (3) consulting companies using commercial tools to produce lower-commitment, lower-fidelity models.

Process chemist Trevor Dzwiniel sets up a 20-liter jacked reactor for large-scale preparation of electrolyte materials for lithium-ion batteries. Reactors and other instruments in Argonne's new Materials Engineering Research Facility produce large quantities of materials for industrial validation.

Energy Systems Division

The Energy Systems (ES) division conducts applied energy research to strengthen the economy, protect the environment, and enable energy independence and national security. From invention through demonstration, ES actively forms critical alliances with industrial partners, universities, other national laboratories and other Argonne divisions to conduct research, development, and demonstration (RD&D) in a number of areas, including transportation technology and systems, applied materials, and advanced manufacturing and systems analysis. ES is home to the Center for Transportation Research (CTR) and the Transportation Research Analysis and Computing Center (TRACC), a national user facility operated for the U.S. Department of Transportation (DOT).

Programs and Capabilities. DOE's Office of Energy Efficiency and Renewable Energy (EERE) is the primary sponsor of the ES division, with funding delivered through a number of EERE program offices including the Vehicle Technologies Office (VTO), Advanced Manufacturing Office (AMO), Fuel Cell Technology (FCT) Office, and Bioenergy Technologies Office (BETO). The focus of the division's research includes (1) transportation technology, (2) applied materials, and (3) systems assessment and analysis.

- **Transportation Technology Research.** The transportation technology research program for DOE is described more fully in the CTR section. The division also conducts research for DOT; it sponsors the TRACC, also described below. However, VTO is the primary sponsor for the majority of our transportation technology research including:
  - Advanced vehicle technology competitions train future engineers and automotive leaders and accelerate the development and demonstration of technologie of interest to DOE and the automotive industry.
  - Advanced combustion including a computational fluid dynamics and fuel chemistry predictive model, fuel spray analysis, and the Virtual Engine Research Institute and Fuels Initiative;
  - Advanced vehicles technology including component-in-the-loop testing, vehicle and component benchmarking, vehicle electrification, vehicle energy and traffic modeling, vehicle simulations and controls, and vehicle thermal management;
  - Vehicle-grid interoperability including connectivity and communication, the Electric Vehicle (EV)-Smart Grid Interoperability Center, and specification and test procedures; and
  - Friction, wear, and lubrication technologies including lubricants, nanoadditives, and superslick and superhard coatings.
- **Applied Materials Research.** The applied materials activity is focused in four areas:
  - Nanostructured materials, including membranes, thin films, and particles coated or synthesized using atomic layer deposition;
  - Sustainable manufacturing, including reclamation of fibers from composites and separation of polymeric end-of-life materials;
  - Biological processing of biomass for improved conversion and synthesis of fuels; and
  - Validation of metallic microstructures predicted by integrated computational materials engineering.

Sponsorship for these activities is provided by WFO, EERE (AMO, VTO, and BETO), DOE's Basic Energy Sciences (BES) Energy Frontier Research Centers (EFRCs), Advanced Research Projects Agency-Energy (ARPA-E), and Argonne (Laboratory Directed Research and Development, Tech Mat Funds, and division royalties).

- **Systems Assessment and Analysis.** Systems Assessment and Analysis (SAA) is a very high-impact area with sponsors that include VTO, the DOE Policy office, FCT, and BETO. SAA growth has been steady and is likely to continue into the future. SAA includes the following:
  - **Life Cycle Analysis.** Analysis of transportation fuels and vehicle systems on a life cycle basis through the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model is considered the gold standard and a DOE core competency. It allows a better understand of the breadth and magnitude of impacts from introduction of advanced vehicle technologies and new fuels. Life cycle analysis (LCA) also provides the granularity needed to investigate policy implication and evaluate R&D decisions.
  - **Biofuel Analysis.** Biofuels are a key component of a comprehensive strategy of transportation fuels. Key questions exist, however, regarding the life cycle energy and environmental benefits. GREET provides insight into the relative impacts of each stage in the supply chain of biofuel production, from farm-to-wheels, providing a comparative performance. BETO recognizes Argonne as possessing a core competency in biofuel LCA.
  - **Market Assessment.** Argonne researchers investigate the market potentials of advanced vehicle and fuel technologies with a range of economic and market analysis tools and forecasting models to provide program assessments on energy, economic, and emissions impacts.
  - **Water Use and Quality Assessment.** Argonne has quantified relationships between energy production and the water use, water quality, and water resource availability with development of an analytical framework tool. This tool permits analysis to identify region-specific future production scenarios that are able to meet increased energy demand while maintaining water sustainability.

Overview of the Division's Strategy. ES leads EGS core initiatives in the following areas: (1) computationally enhanced mobility, (2) grid innovation, (3) applied materials and advanced manufacturing, and (4) water.

EERE is the major sponsor for the ES division. EERE is currently changing its business model; it is engaging with the national labs and is identifying the "core" and "enabling" capabilities at the labs that will be used to guide future funding decisions with increased laboratory collaboration.

We are actively engaged with the various offices of EERE as it adapts to its new business model to ensure that Argonne's capabilities are appropriately reflected in EERE's planning process. We anticipate growth opportunities in BETO, VTO, and AMO and with other other government agencies, such as DOT, on related initiatives:

- **EERE-BETO** has identified several emerging areas where Argonne has enabling capabilities including innovative separations, catalyst design and recovery, novel processing of waste streams for fuels and co-products, sustainable system design, and model development (e.g., GREET).
- **EERE-VTO** considers the Materials Engineering Research Facility (MERF) at Argonne an EERE Core Capability with the potential for longer-term direct funding. Current funding is projected to be between $2–3 million, which is received from the DOE VTO battery materials scale-up program. MERF can facilitate parts of the EGS directorate's applied materials science and process/manufacturing research development programs and can also provide an opportunity for growth with funding provided by the current sponsor, VTO. It supports our expansion into emerging manufacturing technologies for battery materials production, including advanced reactors and coating technologies that complement our work on atomic layer deposition. We plan to collaborate on an upcoming funding opportunity announcement (FOA) on advanced battery manufacturing with PPG Industries, Inc.

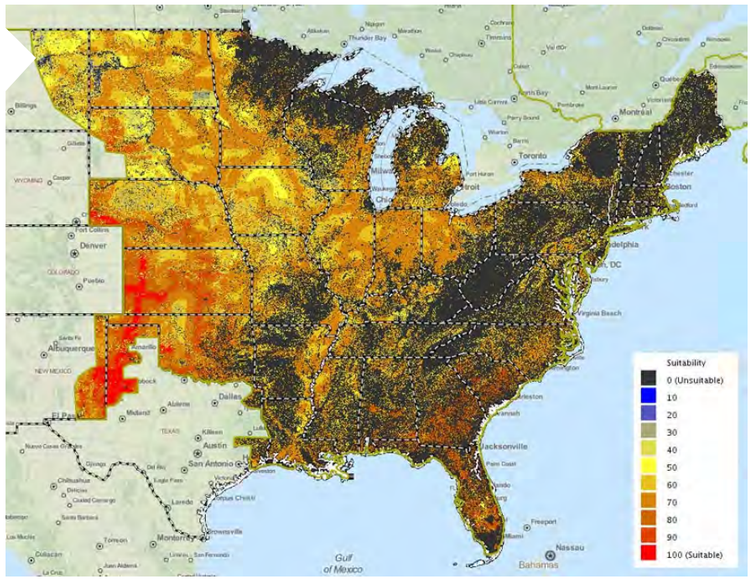
Materials scientist Osman Eryilmaz loads engine pistons into a magnetron sputtering deposition chamber for coating with Argonne's nano-composite thin films. The coating provides wear protection on piston skirt surfaces.

The division has executed a Memorandum of Understanding with the National Renewable Energy Laboratory and Oak Ridge National Laboratory to pursue collaborative programs in transportation technology. The team has developed two white papers that have been incorporated into the EERE-VTO project planning cycle. The topics are (1) natural gas for transportation, and (2) connected and autonomous vehicles.

- **EERE and DOE's Office of Electricity (OE)** are planning a major initiative in "grid modernization," and EGS is actively involved in supporting this planning process. Grid integration is a DOE thrust area, and we currently have programs in this space that are funded by VTO (EV Interoperability), the Wind program, and OE. Argonne has developed a substantial capability and is well known for its grid analysis and more recently, for its work on EV-smart grid interoperability. Argonne was named as the U.S. EV-Smart Grid Interoperability Center in an agreement between DOE and the European Commission Joint Research Center to cooperate on technology and standards for grid connectivity and communication. The centers are facilitating harmonized EV standards in the United States and European Union in the interest of meeting national energy efficiency objectives and supporting our shared multinational automotive manufacturers and suppliers.

  The recent Asian-Pacific Economic Cooperation meeting in May 2014 resulted in a recommendation for cooperative EV-grid interoperability centers between the United States and China. In July 2014, the United States and China signed an agreement similar to the one signed by the United States and European Union. Global cooperation in EV-grid interoperability provides Argonne with an insider view of global developments. All of these centers/activities are expected to evolve into grid integration support centers for standards and technology because of the applicability of interface technologies currently under development and close ties to industry.

- **EERE-AMO** is putting forward opportunities in the next few years that we believe will support our applied materials program.



An example of a "suitability map" for solar energy deployment. Red areas are more suitable, while brown areas are less suitable. Recently, researchers from the Energy Systems division developed a new software tool called the Energy Mapping Tool that can provide stakeholders with the ability to identify geographic areas with higher densities of clean energy resources, which could potentially provide a significant amount of new power generation in the future. This would also provide important information for transmission grid planning.

Intelligence Analysis Division

The Intelligence Analysis (IA) division provides support and facilities to combat foreign intelligence activities targeted at laboratory personnel, information, and technologies and at the work Argonne performs for its diverse group of sponsors. The IA counterintelligence program conducts threat assessments and provides threat deterrence, security briefings, and debriefings and training. IA is home to the National Security Facility, a flexible, state-of-the-art field intelligence unit facility that contains multiple national security networks, video teleconference capability, high-resolution graphics support, a fully powered and cooled data center, multi-level training facilities, and conferencing facilities.

Programs and Capabilities. Argonne's Office of Counterintelligence (CI) and its Field Intelligence Element (FIE) are located within the IA division. Under the direction of the U.S. Department of Energy's Office of Intelligence and Counterintelligence (DOE-IN), the CI focuses on combating foreign intelligence and terrorist activities targeted against the personnel, information, and technologies based at Argonne National Laboratory, Fermi National Accelerator Laboratory, Ames Laboratory, New Brunswick Laboratory, and DOE's Office of Science Support Center-Chicago. CI's responsibilities include detecting, deterring, and counteracting the attempts of foreign powers to obtain information from the laboratory illegally; working closely with agencies responsible for protecting the United States from threats from hostile powers, terrorists, and terrorist organizations; educating employees about such threats; and conducting these activities in a professional manner, sensitive to the needs of employees.

The IA Field Intelligence Element (FIE) provides programmatic support in the areas of physical, personnel, cyber security, and requisite training for all intelligence-related work. This effort includes Intelligence Work-for-Others (IWFO); human subjects work; all related computing; secure destruction of sensitive components at the laboratory; and the Technical Assessment Translation Services that provides technical translations for other government agencies. The FIE also manages all IA secure facilities and interfaces with DOE-IN, various national laboratories, other government agencies, universities, and divisions at Argonne.

Overview of the Division's Strategy. The CI program will continue raising the awareness of all Argonne personnel to counterintelligence and counterterrorism issues without impeding Argonne's pursuit of its program goals and the meeting of its requirements. It will do so by conducting briefings and debriefings of personnel who travel abroad or host foreign visitors and assignees. In addition, new employee orientation briefings and presentations for management and staff will be conducted, pursuant to DOE directives.

IA will continue to provide a world-class, secure, and compartmented facility. This helps ensure that Argonne scientists have the capability to provide DOE-IN, other U.S. government policymakers, and the intelligence community with timely, accurate, and high-impact intelligence analyses in infrastructure protection, nonproliferation, safe nuclear systems, advanced detection, and emergency preparedness and response. Expansion of facilities, including a build-out of secure laboratory space, is required to support future growth of this function. Funding of $5.6 million has been requested from DOE-IN.

CENTERS

Risk and Infrastructure Science Center (RISC)

The interconnectedness of infrastructure systems—both physical and cyber—coupled with factors including climate change, population shifts, and aging infrastructure amplify the risk to infrastructure and community resilience. The United States must make informed decisions to prevent, protect against, mitigate, respond to, and recover from system failure. RISC researches, designs, and delivers scientific capabilities to inform decision-making regarding the most challenging security, risk, and resilience problems. Throughout the last two decades, RISC has completed major research efforts and developed unique tools to support federal sponsors in protecting the nation's critical infrastructure. RISC experts have developed methods to understand dependencies, build resilience among infrastructure sectors and assets, and respond to emergencies. RISC's unique research programs protect the nation's cyber-based infrastructure systems and serve as a distinctive resource to U.S. communities for addressing emergency response, transportation security, and crisis management issues.

RISC currently focuses on the following four core research areas:

- **Infrastructure Science.** Conducts research and analysis to enhance infrastructure resilience and reduce the risk of damage or destruction from climate change, natural hazards, accidents, or terrorist threats. Informs the resilient design of future infrastructure to build assets, systems, and networks that are capable of withstanding the threats of tomorrow.
- **Cyber Operations, Analysis, and Research.** Provides operations, subject matter expert, and research support to developing and implementing advanced cyber security solutions. Conducts focused analysis of the intersection of cyber and physical risks.
- **Threat Analysis.** Conducts near-real-time, all-source analysis by fusing intelligence with complex data sets and multidisciplinary expertise. Delivers highly sophisticated analysis through actionable products, portals, and tools.
- **Emergency and Disaster Analysis.** Develops and applies methodologies and technologies to assist emergency managers, planners, and responders in preparing for, responding to, and recovering from manmade or natural disasters.

The RISC vision is to be a recognized global leader in providing innovative solutions to the most challenging security, risk, and resilience problems. RISC, guided by the following strategic goals, seeks to:

- Build an expert, elite workforce and empower them to succeed;
- Employ business strategies that enable the center to provide innovative capabilities to a variety of sponsors;
- Provide state-of-the-art cyber and physical analytic methodologies and products to address climate change, natural hazards, accidents, and terrorist threats;
- Inform the planning, preparedness, and resilient design of infrastructure to build or adapt assets, systems, and networks that are capable of withstanding future threats;
- Conduct near-real-time, all-source analysis in support of the intelligence community; and
- Integrate emergency preparedness methodologies and technologies into full-spectrum resilience analysis in an all-hazards threat environment.

Inside the Advanced Powertrain Research Facility's Environmental Test Cell (ETC), vehicle researchers are able to simulate a range of external temperatures—from frigid cold to blistering heat—in order to study the impact of temperature on the performance of electrified vehicles. Seen here, Argonne engineer Henning Lohse-Busch uses a thermal camera to check temperatures during "hot" testing.

Center for Transportation Research (CTR)

CTR supports DOE's Vehicle Technologies Office to develop and assess advanced transportation solutions. For more than 20 years, Argonne's CTR has been at the forefront of research and development for a wide range of advanced vehicle technologies, a variety of alternative fuels, and more efficient engine operations. CTR also works with industry on proprietary technology and assessments. We apply our tools and expertise to bring various fuel-efficient products to market. The breadth of research within CTR is extensive, and the multidisciplinary team of researchers is a differentiator for Argonne. CTR's research includes the following:

- Engine combustion, fuels, and after treatment
- Vehicle systems testing and analysis
- Tribology and thermal/mechanical systems
- Systems modeling and controls strategies
- EV-smart grid interoperability
- Advanced Vehicle Technology Competition management.

The mission of CTR is to perform transportation research to reduce petroleum consumption, including:

- Demonstrating fuel efficiency gains at the component, system, and vehicle level via testing and analysis with assessments and proof-of-concept demonstrations of technology;
- Developing new tools and functionality for model-based system engineering in product development to accelerate speed-to-market using multidisciplinary research teams;
- Identifying novel concepts in materials, fuels, additives, and exhaust after-treatment systems for environmental and efficiency gains;

- Performing analysis to evaluate promising advanced transportation technologies and inform decision makers;
- Promoting electric drive technologies with focused efforts on system cost reductions and EV-smart grid interoperable operation;
- Leading efforts for codes and standards development with unbiased data and a technology-neutral position;
- Assisting in development of the DOE research agenda and target setting;
- Providing access to data and research findings via conference presentations, publications, website information, and material dissemination;
- Educating students in automotive engineering fields with curriculum development and hands-on experiences with advanced technology achieved through student vehicle competitions;
- Transferring knowledge, technology, and tools for commercialization and industry application; and
- Developing partnerships to confirm research relevance and value.

Center for Integrated Resiliency Analyses (CIRA)

A community's ability to recover from disruptive events results in large part from its capability to anticipate and respond to challenges posed by the event to its physical and socioeconomic infrastructure assets. As such, Argonne's CIRA develops tools and strategies that local, regional, state, and federal decision makers can use to improve the resilience of communities and regions and to develop robust mitigation strategies that can speed recovery times after disruptive events.

CIRA is a virtual center that resides within Argonne's Global Security Sciences (GSS) division and is built on decades of national security, emergency management, and climate change research performed at Argonne. For more than 30 years, local, regional, national, and international governments and private sector organizations have sought Argonne when developing complex national security analysis tools and conducting strategic resilience studies. Argonne's very broad expertise crosses many relevant domains, including:

- Decision science and analysis
- Infrastructure vulnerability assessment
- Geospatial analysis
- Environmental integrated assessment modeling
- Integrated physical/social/cultural behavior modeling
- High-performance computing.

Being a virtual center, CIRA will collaborate and integrate staff across the laboratory to develop and promote integrated, system-of-systems solutions and tools in support of addressing national security issues.

A community's ability to recover from disruptive events results in large part from its capability to anticipate and respond to challenges. Successful emergency response is no accident; it takes a great deal of careful and coordinated planning, orchestrated effort and regular testing to ensure that everything works as intended under stress. The Center for Integrated Resiliency Analyses applies the knowledge Argonne gained from over 35 years of research and consultation to develop tools and plans that improve community responsiveness and resiliency in the face of threats and disasters, be they man-made or naturally occurring.

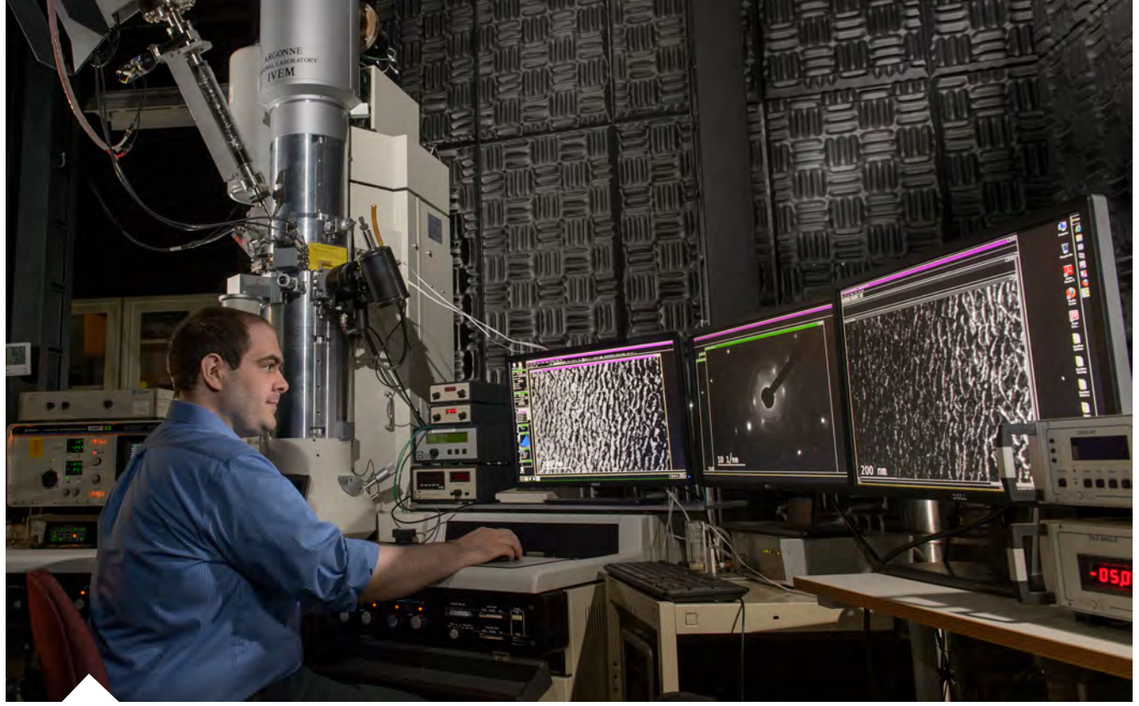
USER FACILITIES

Transportation Research and Analysis Computing Center (TRACC)

TRACC is a national user facility that provides high-performance computing resources to address priority national transportation issues. Federal and non-federal sponsors use TRACC to take advantage of its state-of-the-art, high-performance computing resources as well as the scientific expertise of its staff in the areas of:

- Traffic modeling and simulation
- Emergency transportation planning
- Computational fluid dynamics for infrastructure analysis
- Computational structural mechanics for transportation applications.

TRACC was established in 2006 at Argonne through a congressional grant to acquire and operate DOT's largest high-performance computer systems as a platform that was provided free of charge to DOT's transportation research projects across the nation. The facility is co-located with the Argonne Leadership Computing Facility (ALCF), which provides leadership-class computing resources to the scientific community. The TRACC high-performance computing cluster is a production platform that is being used by more than 100 remote users across the United States. The TRACC system administrators support these users with services such as software installation, adaptation of software applications, management of resources, backups, system security, data transfer, and remote access and effective resource sharing.



The Intermediate Voltage Electron Microscope (IVEM)-Tandem User Facility images the changes in atomic structure and defect formation during irradiation at high magnification. IVEM resumed operation this year within the Nuclear Engineering division.

Intermediate Voltage Electron Microscopy (IVEM)-Tandem Facility

The IVEM-Tandem Facility at Argonne is a user facility supported by DOE-NE for *in situ* studies of defect structures in materials and fuels under controlled irradiation conditions. IVEM is unique in its ability to image the changes in atomic structure and defect deformation during irradiation at high magnification. Key facility capabilities/features include the following:

- Real-time observation of defect formation and evolution during irradiation; access to the full kinetics of damage accumulation in the same specimen location;
- Well-controlled experimental conditions (constant specimen orientation and area, specimen temperature, ion type, ion energy, dose rate, dose, and applied strain), with no activation of samples;
- Provision of measurements/data for refinement and validation of computer model simulations of irradiation defect states; and
- Capability to create high-dose damage in hours, rather than the years such damage would require in a nuclear reactor, supporting accelerated studies of material response to high doses of particle (ion and neutron) irradiation.

The IVEM-Tandem facility is unique in the United States (and one of only five worldwide). In addition to serving as a user facility for national and international research projects, it fulfills a key role in materials advances targeted as part of the EGS core initiative on Safe, Secure, and Sustainable Nuclear Energy Systems and the emerging initiative on Applied Materials and Advanced Manufacturing.

National Security Facility (NSF)

The NSF is a flexible, state-of-the-art user resource that has multi-network workspaces, a data center, a conference room, and sound-rated rooms for secure discussion and special work. It has the capability for multi-secure network computing, as well as developmental local area networks that can be used for creating cutting edge computer applications. The data center can hold up to nine fully loaded racks of computer equipment. The conference room has multiple secure purposes: conferences and meetings, video teleconferences (VTCs), and computer application training. In addition to the conference room, the facility can host multiple VTCs simultaneously. The conference room may also be set up as a watch floor as needed.

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water
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nuclear
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preparedness
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leadership
growth
frontier
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transportation
sustainable
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CONTACT

Mark Peters
Associate Laboratory Director
Energy & Global Security
Argonne National Laboratory
630.252.4534

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