NREL's Cyber-Energy Emulation Platform (CEEP)

Energy Security and Resilience (ESR) Initiative

Central to achieving reduced carbon emissions and sustained economic recovery from the COVID pandemic is a national energy system based on low-carbon technologies and resistant to disruption from severe weather events and human attacks. NREL's Energy Security and Resilience (ESR) Initiative applies NREL's expertise in the design and operation of clean, highly distributed energy systems to the most pressing security and resilience challenges.

Advances in energy and information technologies, together with operational strategies and business models, are changing the way energy is produced, delivered, and used. As a prominent example, the electric power system—with the market-driven deployment of increasing amounts of renewable energy—is an increasingly complex "cyber-physical" system that integrates a vast power grid with smart buildings, electric vehicles, and numerous consumer devices that are changing the grid edge. Additionally, the power grid is evolving to leverage technologies and support other infrastructures for the benefit of the consumer. For example, 5G telecommunications promises to enhance control of the increasing number of grid-connected devices, and electrification of transportation can lead to significantly reduced carbon emissions.

These trends promise great benefit to consumers in the forms of choice, cost savings, business opportunities, and emissions reduction. At the same time, new possibilities arise for energy disruption from natural phenomena such as severe weather or human actions such as cyberattacks. The vulnerabilities of increasingly complex and interdependent energy systems are not yet well understood. Failure to develop and deploy technological and operational mitigations will decrease the pace of transition to a low-carbon energy system, and increase the risk of severe consequences such as disruption of critical infrastructure or compromised national security. NREL's ESR Initiative addresses these challenges.

The Opportunity

NREL's ESR Initiative is leveraging and developing capabilities that enable research at the scales needed to advance the security and resilience of the rapidly transforming national energy system. Complementing capabilities of other U.S. Department of Energy (DOE) laboratories, NREL is focusing on:

- Research and evaluation of emerging clean energy materials, components, and systems—domestic and foreign— applying NREL strengths in renewables, smart buildings, connected transportation, energy storage, advanced grid controls, and operation.

- Cybersecurity of highly distributed clean energy networks: A major NREL focus. Leveraging a unique cyber-energy emulation platform, NREL's cybersecurity research applies analysis, modeling, emulation, evaluation, and visualization capabilities to bolster the cybersecurity and cyber-resilience of complex clean energy networks.

- NREL's Advanced Research on Integrated Energy Systems (ARIES) Initiative is integrating experimental and computational capabilities at NREL's Flatirons Campus and the Energy Systems Integration Facility on the main campus; cybersecurity is a primary ARIES research area. The ARIES evaluation capabilities will also provide a first-of-kind environment for evaluating the resilience of clean energy systems.

- Hardware-in-the-loop (HIL) emulation capability: high-fidelity grid simulation and controls with support equipment interconnects with at least a 10-MW power capacity.

- Digital communication simulation and emulation, including wired and wireless HIL and software-defined networks for legacy and future telecom standards.

- High-performance computing (HPC) and large-scale data systems required for detailed cyber-physical system simulations, advanced visualization, artificial intelligence (AI)/machine learning tools, and agent-based modeling for multi-domain (technical/economic/ human factors) scenario attack studies and impact assessments.

- Test bed for at-power equipment vulnerability verification. Capabilities to address a range of threats and hazards—cyberattacks, physical attacks, and extreme weather—alone or in combination.

- Interconnections with other government and academic organizations to facilitate collaborative research and risk mitigation.

The ESR Initiative is leveraging NREL's research and development in new technologies, control methodologies, advanced sensing and data analytics, and sophisticated models and validation techniques—leading to near real-time situational awareness and system control at the fidelity necessary to optimize performance and resilience. It will support the study of cyber-physical systems within the U.S. and international electric grids, serving as a new national asset to leverage research at the interface between distribution and bulk power systems and at the dynamic grid edge. New research in the emerging area of science of signatures will lead to rapid detection, isolation, and mitigation of disruptions to critical infrastructure. Combined with NREL emulation environments, this work will provide a laboratory environment for developing AI approaches for intrusion detection, attack recognition, and forensics—all reflecting real-world attack scenarios.

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ESR Initiative research will also help the United States address disruptions and impacts from natural and human threats to U.S. critical infrastructure: defense and security, energy, water, food, manufacturing, supply chain, communications, and emergency services. This will include capability to develop resilience planning that incorporates the interdependencies among these critical infrastructures. This work is planned to support training, exercises, and gaming scenarios in contexts including continuity of operations and government, disaster response and recovery, sensitive U.S. Department of Defense operational energy planning and evaluation, and sustainment of mission-critical facilities.

In real-world scenarios, it will be increasingly important to explore the effective balance of automation and human intervention in crisis management involving highly distributed, unprecedentedly complex control systems. New control theory, decision science, and agent-based game theoretic experimental platforms can help reduce risk by accounting for the inherent uncertainty of human actions.

Research will also include exploring the security and resilience implications of potential game-changing evolutions of the U.S. grid, including decarbonization, shifting use patterns catalyzed by acute events such as the COVID-19 pandemic, decentralization of generation assets, migration to DC power systems, environmental change, demographic change, or highly autonomous systems. This research will inform policy and investments, minimizing unintended consequences and contributing to greater economic prosperity.

NREL Capabilities

NREL has deep expertise in science and technologies essential to improving the security and resilience of the energy and interrelated infrastructure systems our country depends on, both domestically and in other countries. This expertise includes discovery and development of innovative energy materials and chemicals; component design and system evaluation; analysis, modeling, emulation, and visualization of energy systems; AI and machine learning; and computational science.

NREL's long-standing commitment to energy security and resilience has been expressed across the laboratory's research portfolio, with examples including solar conversion technologies for space applications, microgrids for campuses and military installations, remote energy systems for science and military outposts, and resilient electricity system assessment and design criteria for communities recovering from natural disasters.

The primary research areas in NREL's long-term vision—Integrated Energy Pathways, Electrons to Molecules, and Circular Economy for Energy Materials—all aim toward a more secure and resilient U.S. energy system and economy. The Advanced Research on Integrated Energy Systems (ARIES) research platform is networking high-power research and evaluation capabilities across the laboratory expressly to support advancing strategic priorities such as energy security and resilience.

In concert with NREL's established energy capabilities, a focus on security and resilience will ensure that the next-generation energy infrastructure will meet the challenges of evolving natural and malicious threats. Continued investment in staff expertise, analysis and evaluation capabilities, and facilities supporting this work will enable NREL's maximum contributions to securing our national energy infrastructure.

Contact NREL Associate Laboratory Director Juan Torres at Juan.Torres@nrel.gov to learn more.
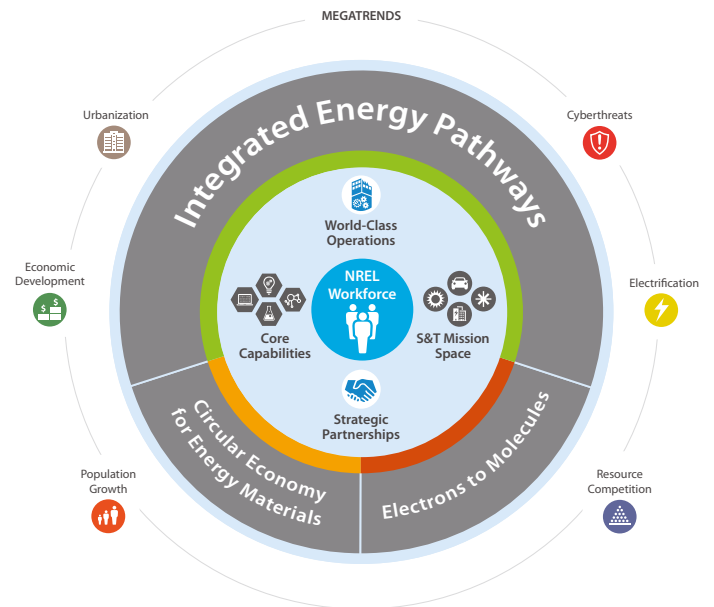
NREL's 10-Year Plan: A Vision for the Future