Bioscience and Bioengineering

Protecting the nation by countering current and future biological and environmental threats.

Health, Environment, and Energy Security

Bioscience and Bioengineering research at Lawrence Livermore National Laboratory (LLNL) delivers transformative biological solutions for national health, environment, and energy security needs. This research capitalizes on LLNL's capabilities in high performance computing, experimental biology, and automation platforms.

Our expertise in low-dose radiological effects and genomics led to a founding role in the Human Genome Project. Bioengineering advances include the invention of PCR-on-a-chip and droplet PCR. Combining capabilities and partnerships in quantitative biology, computing, and precision measurement, we excel in assessing biological threats, accelerating medical countermeasure design and testing, and innovating approaches to low-carbon material development. Researchers expanded biological models to encompass climate and ecology research and are pioneering solutions for biofuels, carbon sequestration in soils, and eco-friendly extraction of critical minerals.

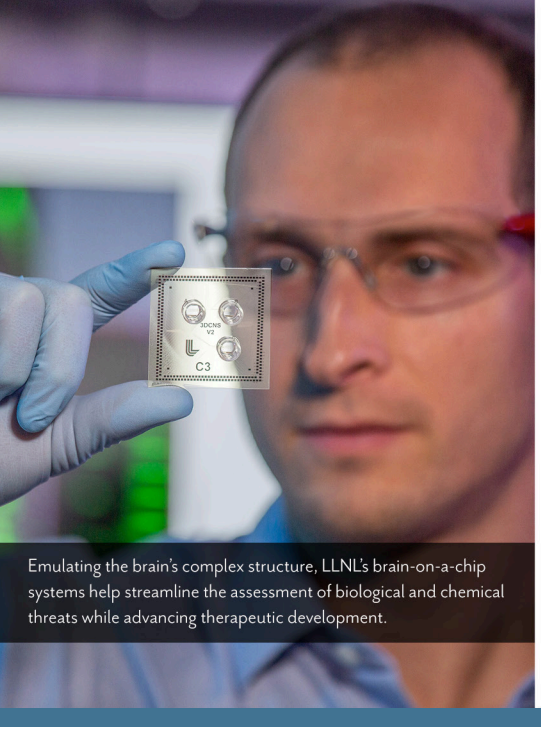
By integrating analytical tools, systems biology techniques, human models on a chip, and high performance computing, our dedicated staff dissect the underlying mechanisms of disease, develop novel diagnostics and therapeutics, and engineer microbial communities to counter biosecurity, health, and ecological threats.

Applications

Teams of scientists and engineers converge their expertise in biological science, high-performance computing, precision measurement, and engineering to understand, predict, and engineer the behaviors of complex biological systems. By coupling world-class computational resources with targeted experiments, bioscientists apply the design–build–test–learn cycle to tailor biological molecules and systems to achieve desired functionality.

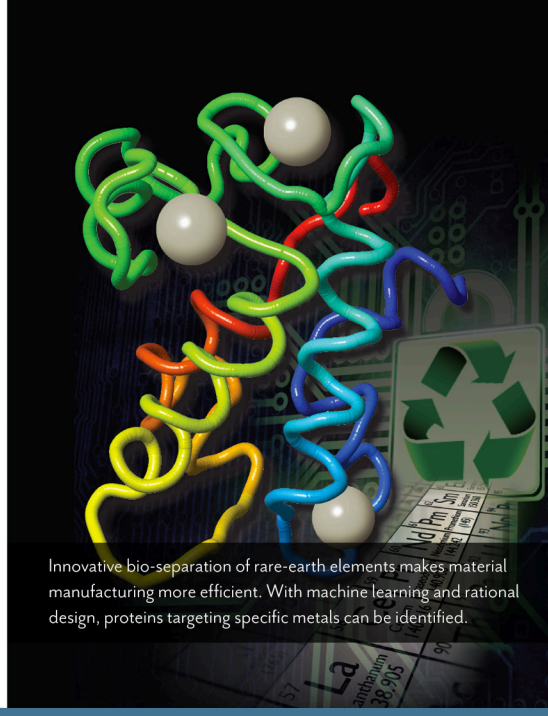
Applications of cutting-edge capabilities in bioscience and bioengineering include:

- High-performance computing to simulate biological systems across scales, including atomistic and coarse-grained molecular dynamics, quantum simulations, constraint-based genome-scale simulations, reaction–transport dynamic simulations, as well as agent-based, whole-organ, and pharmacokinetic and pharmacodynamic models.
- The National User Resource for Biological Accelerator Mass Spectrometry, the sole facility of its kind in the United States, which offers ultra-high-sensitivity quantitative isotopic analysis for biomedical researchers measuring extremely low concentrations of radioisotopes.
- A Biomedical Foundry (microfabrication facility, ISO 13485 compliant) for manufacturing medical prototypes and developing human-on-a-chip models.
- Experimental and computational platforms for the blood–brain barrier and central nervous system that can be broadly used for biological and chemical threat analysis and therapeutic development.
- A combination of stable isotope probing, advanced imaging, proteogenomic profiling, and computational modeling, which is used to investigate microbial communities within their ecological framework.
- Synthetic biology techniques and secure biosystems design for engineering safe and effective microorganisms and microbial communities for environmental applications and medical countermeasures.
- A BSL-3 Select Agent Center and Animal Care Facility; additive manufacturing with a focus on bioprinting and biomaterials; and bio-forensic science capabilities at the Laboratory's Forensic Science Center.
- Our Bio Resilience Mission Focus Area integrates biology with high-performance computing to enable innovative threat analysis and therapeutic development.



Emulating the brain's complex structure, LLNL's brain-on-a-chip systems help streamline the assessment of biological and chemical threats while advancing therapeutic development.

Research by Lawrence Livermore National Laboratory scientists suggests that immune responses could be bolstered by drugs to aid recovery from brain infections caused by emerging pathogens.



Innovative bio-separation of rare-earth elements makes material manufacturing more efficient. With machine learning and rational design, proteins targeting specific metals can be identified.

Accomplishments

LLNL brings together multidisciplinary biological expertise with world-class resources in high-performance computing and unique experimental facilities to tackle pressing national health and environmental challenges. LLNL's expanding areas of research include early bio threat analysis, assessment, and impact predictions, accelerated development of therapeutics and countermeasures, engineering of microbiomes for health, energy, and environmental sustainability, as well as the rapid detection and response to emerging novel pathogens. Furthermore, the Laboratory is at the forefront of developing innovative diagnostics and treatment approaches for cognitive impairment. Examples of LLNL bioscience and bioengineering accomplishments include:

- Development of PCR-on-a-chip and droplet PCR. These inventions have led to multiple FDA-approved commercial medical diagnostic products for detecting diseases such as tuberculosis, AIDS, and COVID-19.
- Development of the Lawrence Livermore Microbial Detection Array, a pangenomic platform capable of rapid detection of over 12,000 microorganisms within a single day. It is now used for applications in diverse fields such as biodefense, drug and food safety, and space biology.
- LLNL played a critical role in developing the world's first artificial retina. Also known as the "bionic eye," this retinal prosthesis was developed for people blinded by retinitis pigmentosa or macular degeneration. The invention led to first FDA-approved high-density, microfabricated, and fully implantable neural prosthetic ever produced.
- High-performance computing enabled the development of the LLNL therapeutic antibody design platform capable of designing antibodies in weeks compared to months-to-years using conventional methods.
- Novel nanoparticle-based vaccine delivery formulations are undergoing animal testing to evaluate efficacy against infections caused by chlamydia and other pathogens.
- Identification of microbial signatures that inform the treatment of wounds from combat-related injuries in soldiers using a combination of microbial metagenomic DNA sequencing and advanced machine learning techniques.
- Development of sustainable biomining approaches for extracting and purifying rare-earth elements to safeguard the domestic supply of critical minerals for clean energy transition.

The Future

Laboratory bioresearchers employ machine learning, omics, and unique laboratory capabilities to accelerate diagnostics, therapeutics, and sustainable biomanufacturing. Their multifaceted approach includes early biological threat assessment, broad-target antibodies, and novel therapeutics and vaccines. Additionally, there is a strong commitment to sustainability and driving advancement in biomanufacturing and ecosystem management.

Integration of big-data analytics and computational modeling enhances genotype-to-phenotype predictions, improving our understanding of pathogens, host factors, and infectious disease outcomes. This involves a meticulous dissection of the intricate relationship between pathogen genotype, exposure conditions, and host fitness, offering revolutionary insights for disease anticipation and management.

Predictive design, through computational and experimental integration, focuses on engineering of microbial systems and biomolecules, from proteins to small molecules. Its applications range from healthcare to energy, climate solutions, and supply chain resiliency. Through innovation and collaboration, the future holds proactive solutions to pressing national security challenges.

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