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. Research is guided by multidisciplinary innovation and collaboration with academia, industry partners, and government agencies.

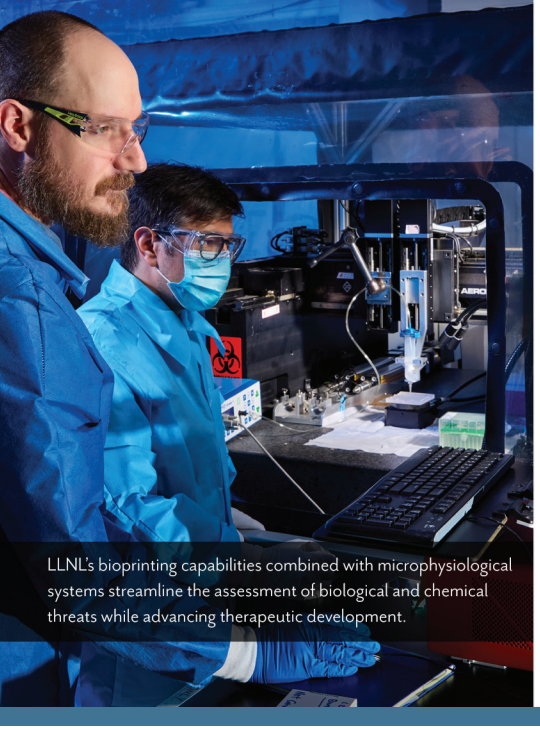
By combining capabilities and forging partnerships in quantitative biology, computing, engineering, and precision measurement, LLNL assesses, designs, and tests medical countermeasures against biological and chemical threats while finding new approaches for low-carbon materials. By expanding biological models, researchers are pioneering solutions for biofuels, carbon sequestration in soils, and eco-friendly extraction of critical minerals.

Bioengineering advances include implementating the polymerase chain reaction (PCR) technique on new platforms. By integrating analytical tools, systems biology techniques, human-on-a-chip models, and high-performance computing, staff explore the mechanisms of disease, develop novel diagnostics and therapeutics, and engineer microbial communities to counter emerging threats in biosecurity, health, and the environment.

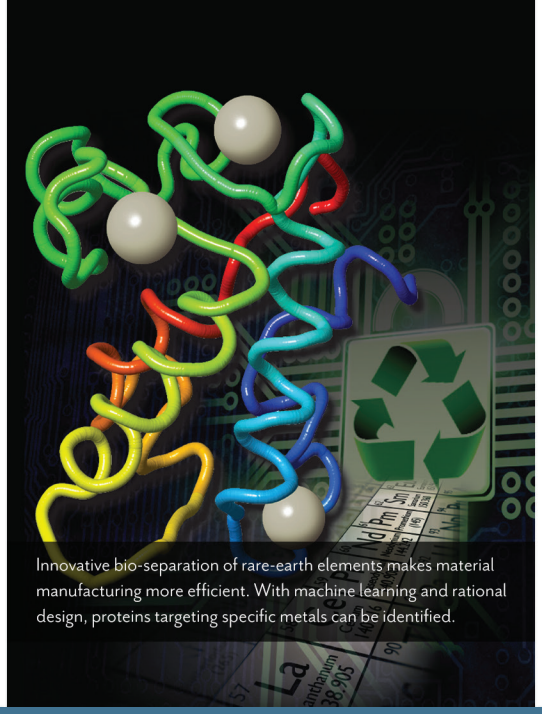
Applications

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, LLNL teams apply the design–build–test–learn cycle to tailor biological molecules and systems to achieve new functionalities. 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 only U.S. facility that offers ultra-high-sensitive isotopic analysis for biomedical researchers measuring extremely low radioisotope concentrations.
- A Biomedical Foundry within our microfabrication facility (ISO 13485 compliant) for manufacturing medical prototypes and developing human-on-a-chip models.
- A Rapid Response Laboratory (RRL) with a high-throughput automated pipeline to rapidly produce and evaluate computationally designed antibodies.
- Experimental multiphysiological systems and computational platforms for biological and chemical threat analysis and therapeutic evaluation.
- A combination of stable isotope probing, advanced imaging, genomic profiling, and computational modeling to investigate microbial communities within ecological frameworks.
- 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.
- LLNL's Bio Resilience Mission Focus Area integrates biology with high-performance computing to enable innovative threat analysis and therapeutic development.



LLNL's bioprinting capabilities combined with microphysiological systems streamline the assessment of biological and chemical threats while advancing therapeutic development.



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.

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

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 biological and chemical threat detection, assessment, and impact predictions, accelerated development of therapeutics and countermeasures, and engineering of microbiomes for health, energy, and environmental sustainability. 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 miniaturized fieldable PCR 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. This platform 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. The invention led to high-density, microfabricated, and fully implantable neural prosthetics. Implantable/wearable interfaces now expand beyond the brain including spinal cord electrode arrays.
- Microphysiological systems including an instrumental 3D brain model and neurovascular unit provide understanding to mitigate neurological threats.
- High-performance computing enabled 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 wound microbial signatures that inform the treatment of soldiers' combat-related injuries using microbial metagenomic DNA sequencing and advanced machine learning (ML) techniques.
- Acceleration of drug discovery by coupling physics-based modeling with ML algorithms. A first-in-class medication targeting cancer-related genetic mutations is in clinical trials.

The Future

Laboratory bioresearchers integrate experimental and computational models with unique laboratory capabilities to accelerate diagnostics, therapeutics, and sustainable biomanufacturing. A multifaceted approach includes early biological threat assessment, broad-target antibodies, and novel therapeutics and vaccines. Additionally, there is a strong commitment to bioeconomy and sustainability, driving advancement in biomanufacturing, biofuels, and ecosystem management.

Integration of big-data analytics and computational and biological 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 via computational and experimental integration focuses on engineering of microbial systems and biomolecules—from proteins to small molecules—with applications in healthcare, energy, climate solutions, and supply chain resiliency. Through innovation and collaboration, the future holds proactive solutions to national security challenges.

LLNL-MI-2001237
This work performed under the auspices of the U.S. Department of Energy by
Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
December 4, 2024