Advanced Materials and Manufacturing

Designing tailored materials and fostering innovation in advanced manufacturing to fabricate structures with the properties and performance needed to address national security missions.

Mission Impact

Lawrence Livermore National Laboratory (LLNL) brings a multidisciplinary approach to address our nation's need for rapid development of advanced materials and manufacturing processes. Our scientists and engineers develop innovative materials with tailored properties that can be used across a broad range of mission applications, including energy storage; advanced optical materials used in high-intensity laser systems; quantum materials; and components that can function effectively in extreme environments.

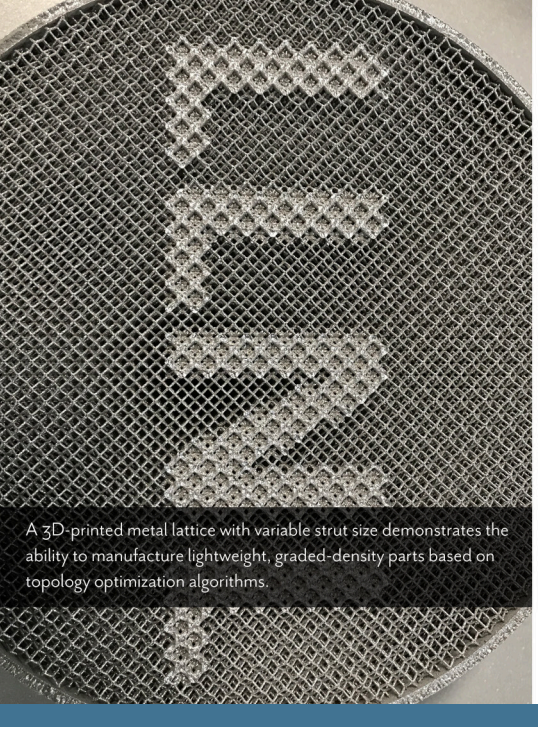
We continue to advance manufacturing technology, enabling us to develop customized feedstocks and unique fabrication techniques. We also develop novel diagnostic methods so we can accelerate testing and evaluation cycles—and deliver timely solutions.

Our overall aim is to create an advanced material development and manufacturing ecosystem that is more agile and more responsive to the needs of national security stakeholders. We explore ways to reduce manufacturing costs, reduce material and energy waste, and accelerate discovery and development timelines. In addition, we use multiscale predictive modeling and machine learning to reduce uncertainties regarding how a material will perform at scale, in relevant conditions, over its service lifetime.

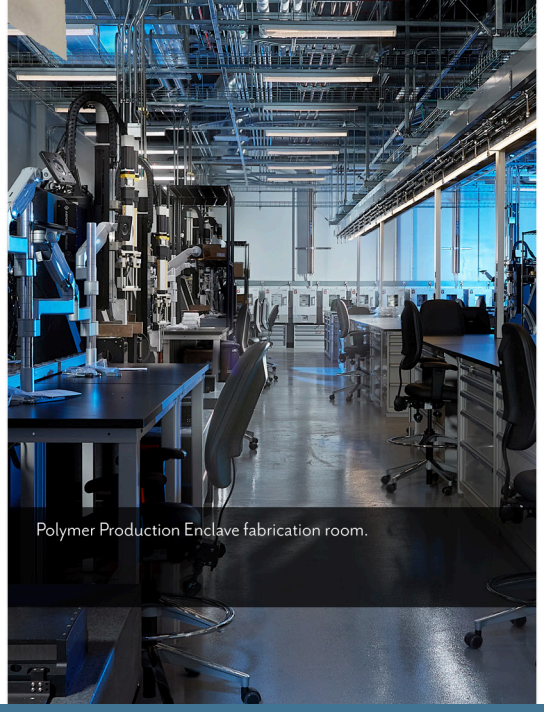
Accomplishments

At LLNL, today's research builds on decades of experience studying a broad spectrum of materials and mission-relevant applications. Our research spans the entire design-development-deployment cycle, including discovery and optimization of materials that can meet emerging mission needs, and manufacturing capabilities that can produce materials at scale, with structures that are tailored to meet specific performance requirements. Examples of our accomplishments include development of:

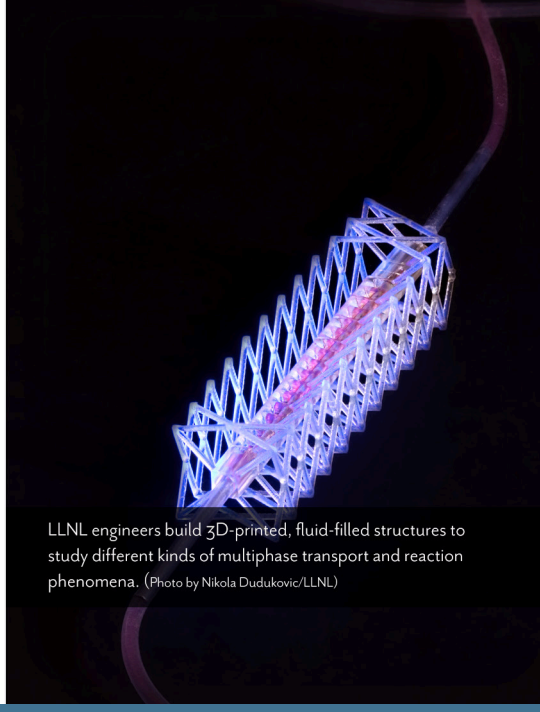
- Customized alloys for extreme environments, with thermally stable microstructures that are lightweight, corrosion-resistant, and radiation-tolerant, and use of predictive models to identify aging-resistant designs—with applications such as hypersonic vehicles, space science, high-power lasers, and nuclear reactors.
- Highly permeable polymer microcapsules filled with sorbents that can capture carbon dioxide from our atmosphere and facilitate long-term sequestration.
- A method to 3D-print microbes in controlled patterns, expanding the potential for using engineered bacteria to recover rare-earth metals, clean wastewater, and detect actinides.
- A laser-based volumetric additive manufacturing (AM) technique, known as computed axial lithography, which can be used to fabricate layer-less micro-optics with complex architectures and extremely smooth surfaces in only seconds.
- A groundbreaking method to control the flow of liquids and gases using 3D-printed, micro-architected structures—a novel approach to cellular fluidics with applications such as conversion of carbon dioxide to fuel, desalination, air filtration, heat transfer, and delivery of fluids in zero-gravity environments.
- Composite materials with the ionic conductivity needed to increase voltage, storage capacity, and thermal stability—providing new options for fast-charging, lightweight batteries.
- Additively manufactured transparent ceramics with customized composition and structure, optimized for use as laser-amplification media.



A 3D-printed metal lattice with variable strut size demonstrates the ability to manufacture lightweight, graded-density parts based on topology optimization algorithms.



Polymer Production Enclave fabrication room.



LLNL engineers build 3D-printed, fluid-filled structures to study different kinds of multiphase transport and reaction phenomena. (Photo by Nikola Dudukovic/LLNL)

Scientific Underpinnings

LLNL integrates expertise in engineering, materials science, physics, chemistry, data science, and manufacturing science to create innovative solutions. For example, we study the chemical, electronic, structural, and kinetic properties of materials—including polymers, alloys, ceramics, foams, and biomimetic materials. We explore ways to enhance feedstock development, fabrication techniques, and characterization methods, and we study material aging and degradation that can impact long-term performance. We use LLNL's high-performance computers to conduct predictive simulations of material properties, performance, and degradation, enabling us to optimize designs. The following LLNL resources accelerate development of innovative solutions:

- **The Advanced Manufacturing Laboratory** and the **Center for Engineered Materials and Manufacturing** develop new AM capabilities, including laser systems, advanced optics, and multi-material solutions, which are used to fabricate architected materials with unique properties, while also fostering partnerships with industry and academia.
- **The Polymer Production Enclave** enables rapid design and development of polymer parts for stockpile modernization programs, offering a unique space where design activities and production enhancements can be rapidly tested and evaluated.
- A suite of **advanced, in-situ, non-destructive characterization capabilities**, including 3D imaging, spectroscopy, x-ray computed tomography, and ultra-fast electron microscopy—enables researchers to rapidly assess a material's properties and identify defects introduced through the manufacturing process.
- **World-class supercomputing resources,** which data scientists use to conduct high-fidelity multiscale models of material synthesis and manufacturing processes—enabling rapid design, scale-up, and optimization of new, tunable materials and feedstocks.
- **The Laboratory for Energy Applications for the Future** (LEAF) fosters cross-cutting research aimed at accelerating development of scalable, optimized structures for energy production, storage, and transmission, such as batteries, supercapacitors, hydrogen energy systems, desalination, and carbon capture and conversion.
- **The Superblock facility** and other spaces designed to handle advanced radiological materials, where we develop and deploy customized actinide processing techniques and deliver high-purity, actinide-based materials for mission-critical experiments.

The Future

Our long-term vision involves leveraging LLNL's newest resources to expand collaborative research space. We will explore new partnerships with industry and research institutions at the Advanced Manufacturing Lab and the Polymer Production Enclave, boosting our ability to rapidly deliver solutions.

We will continue to take leadership roles in DOE-sponsored research collaborations to enable efficient hydrogen production, storage, and delivery solutions. We will continue participating in the DOE Energy Materials Network and related multilab consortia, while planning and executing DOE's long-term strategy aimed at addressing critical materials challenges.

Innovative solutions will be adapted for new environments, including applications in biosecurity, water security, space science and security, and materials for environmental remediation. LLNL ensures the long-term performance of energy production and delivery infrastructure as it faces climate-caused risks to material used in pipelines, turbines, and nuclear power plants. The Laboratory retains a continued focus on accelerating delivery of solutions that support the safety and reliability of our nuclear deterrent.

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