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THE ADVANCED MANUFACTURING LABORATORY IS OPEN FOR BUSINESS

ADVANCED technology is reshaping and transforming manufacturing the world over. Signs of this transformation are everywhere: factory automation, machine learning, additive manufacturing, robotics, and cloud-based process management, to name only a few trends. Livermore contributes to this renaissance through its research and development (R&D) in fields such as advanced manufacturing, partnerships that use the Laboratory's high-performance computing to improve industrial processes, and commercializing new manufacturing technologies.

Now, the Laboratory has opened the Advanced Manufacturing Laboratory (AML), a 1,300-square-meter facility where Livermore scientists and engineers are working side by side with partners in the private sector and academia to create new materials and technologies. R&D at AML aims to further Livermore's national security missions while enabling partners to release new products and services into the marketplace, a process called spin-in/spin-out technology development.

"U.S. industry is becoming highly innovative in manufacturing technology," says Patrick Dempsey, director of strategic partnerships in the Laboratory's Engineering Directorate. "AML will help us take advantage of industry's innovation by partnering our R&D efforts with theirs, accelerating the progress of both." Livermore's growing research efforts in additive manufacturing, along with development of an open space for research collaboration, planted the seeds that germinated into the new facility. From planning to opening, creating AML took approximately three years.

Outside the Fence for Easier Access

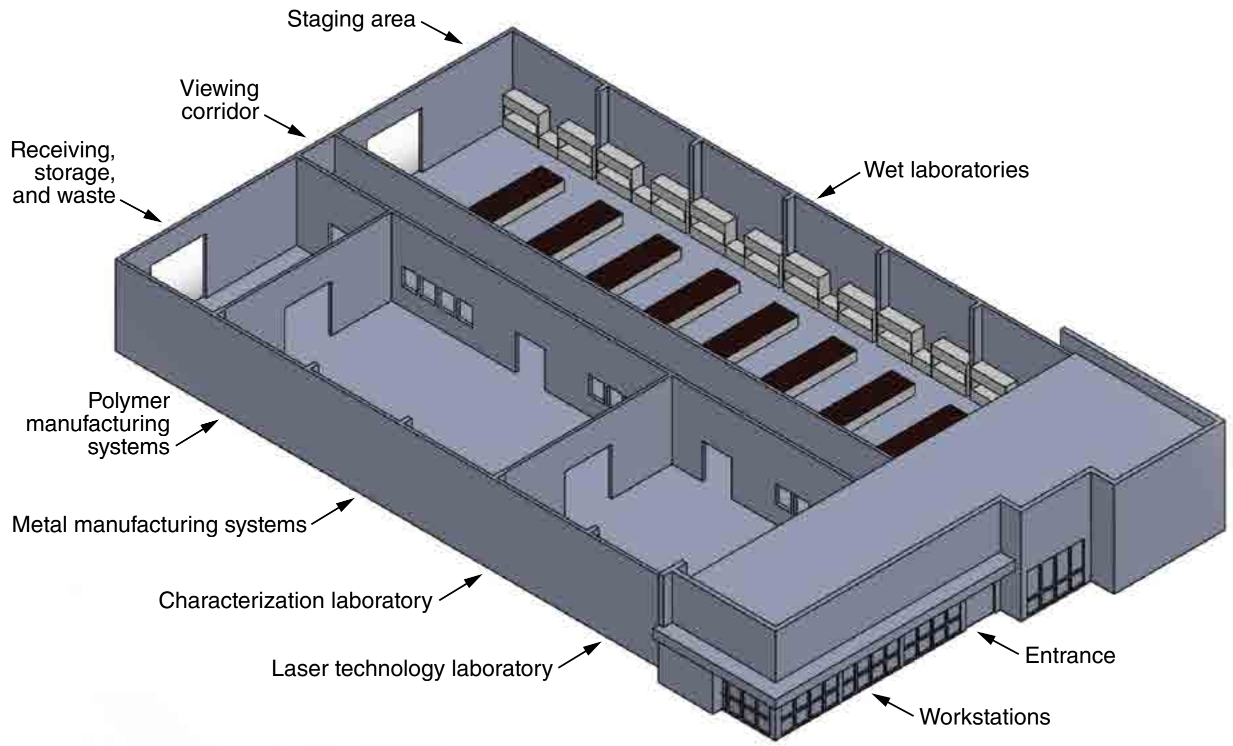
AML is located "outside the fence"—on the Livermore Valley Open Campus (LVOC), which is sited beyond the security fence. The LVOC location facilitates collaboration and communication by freeing partner personnel from the strict security requirements that must be followed when working within Laboratory boundaries. At the same time, AML's partnership model provides mechanisms to address the partners' concerns, including intellectual property and confidentiality.

"We are looking for partnerships with industry in areas of research and development that we both care about," states Chris Spadaccini, director of the Center for Engineered Materials and Manufacturing and head of Livermore's Additive Manufacturing Initiative. "We expect that both sides will contribute actively to efforts that advance technologies useful to our partners' needs and the Laboratory's missions. We are also pursuing partnerships with academic institutions, because AML could serve as a hub to support student and faculty interactions with Livermore and the commercial sector." In developing AML, the Laboratory took active steps to fully understand industry's needs, such as holding an "industrial partnerships day" to hear from potential partners in person and using the Federal Business Opportunities channel to solicit partnership ideas from companies. Anantha Krishnan, the Laboratory's associate director for Engineering, says, "AML is enabling a new business model for Livermore to team with industrial and academic partners, and the success of these collaborations could provide a template for public–private partnerships in the future."

The Laboratory, industry, and academia are working side by side to develop advanced materials and manufacturing processes at the Advanced Manufacturing Laboratory (AML), located on the Livermore Valley Open Campus. Partnerships at AML are designed to further Livermore's missions and benefit partners developing commercial products and processes. (Photo by Randy Wong.)

Five Tracks to Cover the Possibilities

The result of this consultative development is a flexible facility with a strategic plan that offers five tracks for partnerships: design, materials, processes, applications, and qualification and certification. Each track focuses on a particular area of manufacturing relevant to a party's interests. In the design track, for example, partners can leverage Livermore's design optimization capabilities and high-performance computing resources to improve complex, multifunctional designs for their products. The materials track applies Livermore's expertise in developing new manufacturing materials, such as metallic particles, nanomaterials, glass, and liquid photo resins.



The 1,300-square-meter AML has some of the world's most sophisticated capabilities for developing new advanced manufacturing technologies, including wet and dry laboratories, laser-based technologies, and a characterization laboratory.

In each area of AML, advanced manufacturing equipment is being moved in and set up. Here, Laboratory researchers will collaborate closely with partners in industry and academia in nearly any sector, including defense, transportation, energy, and biomedicine. (Photo by Randy Wong.)

AML's facilities reflect Livermore's process expertise across a broad spectrum of materials and scales, including direct ink writing, powder bed fusion, electrophoretic deposition, projection microstereolithography, and laser-based processes such as two-photon lithography and selective laser melting. With these capabilities, partners on the applications track can develop new materials and components for nearly any sector—transportation, defense, energy, or biomedicine, for example. With some advanced manufacturing processes promising shorter development times, the qualification and certification track is tailored to accelerate the commercial acceptance of new materials, processes, and components. AML is currently home to more than half a dozen partnerships, and more are in the pipeline. Three examples demonstrate how the private sector is taking advantage of AML's full potential.

Locating Accurately in Time and Space

The Global Positioning System's (GPS's) network of satellites has revolutionized navigation, allowing even ordinary consumers with a GPS-enabled device to accurately determine their location almost anywhere on Earth. However, in a critical application such as aeronautical or marine navigation, failure of a GPS receiver could be disastrous. Vector Atomic, a startup in Oakland, California, is developing quantum sensors for inertial navigation and timing that do not rely on GPS. Instead, the devices will determine the position and orientation of a vehicle by precisely measuring its linear and rotational acceleration through the quantum interference of atomic wave functions. To achieve small size and low power usage in these devices, Vector Atomic is using AML's facilities and staff to incorporate Livermore-developed micromirror array technology, which controls and directs light using microscale structures to manipulate arrays of tiny mirrors. (See *S&TR*, September 2017, pp. 16–19.) In addition, the partnership will rely on AML's unique micro- and nano-additive manufacturing processes and precision microassembly capabilities.

Livermore is pursuing the Vector Atomic partnership through a cooperative research and development agreement (CRADA). Engineer Robert Panas, the Livermore lead for the partnership, explains, "The CRADA will allow us to merge these two technologies. Our micromirror technology can modulate and tune the laser power for the atomic sensors more accurately than any other available technology. The result will be a device that can operate in demanding environments with substantial jostling and shaking. We expect the combined product to represent an improvement of more than an order of magnitude over current inertial navigation systems."

Optics Polished to a Fine Shine

Large fluxes of energy pass through the optics of the 192 beams comprising the world's highest energy laser, Livermore's National Ignition Facility (NIF). With repeated shots, tiny pits in NIF's optical glass can enlarge to become damage sites that compromise performance. "The Laboratory has made a substantial effort to mitigate damage precursors and initiated damage sites on NIF's large optics," says Ibo Matthews, a group leader in Livermore's Materials Science Division. "The damage mitigation process we developed uses carbon dioxide lasers to repair damage on the surfaces of silica optics, smoothing their imperfections. We realized that this process could be used for the laser polishing of glass, even the localized repair of NIF optics." The enabling research was funded primarily by the Laboratory Directed Research and Development Program. (See *S&TR*, April/May 2017, pp. 17–20.)

At a conference in 2014, a presentation about the technology by Matthews, Materials Science Division staff scientist Nan Shen, and their team attracted the attention of Edmund Optics, which quickly entered into talks with Livermore. The U.S.-based company eventually established a CRADA to work with the Laboratory at AML. The partnership's goal is to extend Livermore's technology into a commercial system capable of polishing industrial lenses and mirrors to the same high surface quality demanded by NIF.

Perfecting a Manufacturing Control Method

An industrial manufacturing process must be carefully controlled to ensure that the final product conforms exactly to specifications. Livermore researchers have teamed with General Electric (GE) to explore a method called feedforward control in the additive manufacturing of three-dimensional (3D) parts. "In feedforward control, a computer model simulates a part and its manufacturing process," explains Wayne King, the partnership's Livermore lead and overall lead of the Accelerated Certification of Additively Manufactured Metals Project. "The simulation actually trains the manufacturing tool in building the part, so the quality of the final product depends on the fidelity of the simulation."

At AML, the partners are developing the prototype for a feedforward control–based machine capable of 3D printing high-quality metal parts. "We aim to get feedforward control into an additive manufacturing system within two years. The key to success is incorporating this control approach into a commercial machine, something that would not be possible without GE," says King. (See *S&TR*, January 2015, pp. 13–18.) The Department of Energy's Technology Commercialization Fund is supporting the Livermore–GE partnership. In addition, the Laboratory, GE Global Research, and several other partners are developing feedforward methods to speed up the qualification and certification of 3D-printed metal replacement parts for the U.S. Navy, an effort funded by the Office of Naval Research.

These three examples represent the many partnerships that are active or under development at AML—and the Laboratory is seeking to establish more. When Livermore's talented researchers partner with their industrial and academic counterparts in a space containing some of the world's most advanced manufacturing capabilities, the expected result is not merely accelerated innovation, but innovation that benefits U.S. industry and advances the Laboratory's missions in the face of rapid transformation in these arenas.

—Allan Chen

Key Words: additive manufacturing, advanced manufacturing, cooperative research and development agreement (CRADA), Edmund Optics, feedforward control, General Electric (GE), inertial navigation, Laboratory Directed Research and Development Program, Livermore Valley Open Campus (LVOC), micromirrors, quantum sensors, two-photon lithography, Vector Atomic.

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