TECHNOLOGY

Labs Take Aim at Rapid-Fire Lasers for Fusion Power

LIVERMORE, CALIFORNIA—Some time early in the next century, researchers here hope to bring a piece of the sun down to Earth. They intend to ignite a miniature fusion reaction—the power source for the sun and stars—by blasting a hydrogen pellet with a battery of lasers. If it works, the feat might help show the way to harnessing fusion in a practical power plant. But the massive lasers used to spark this fusion pulse have a big drawback: They can't fire at the rapid pace needed for an inertial-confinement fusion (ICF) power plant. Fusion researchers have long assumed that they will have to switch to new, untested fusion drivers—probably beams of ions—for that task. That conventional view is, however, about to be challenged.

Researchers at the Lawrence Livermore National Laboratory and the Naval Research Laboratory (NRL) in Washington, D.C., are preparing to build lasers capable of both high power and machine gun–fast pulses. Last fall, the Livermore team launched a 3-year, $7 million program to construct a prototype benchtop laser called Mercury, which would unleash a 100-billion-watt pulse every tenth of a second. That's well short of the power needed for fusion, but Mercury would have more potent successors. Not yet funded, but hoping to pursue the same goal, is the NRL, Livermore's archrival in laser fusion research.

Each lab has its own approach to preventing the heat buildup that slows the firing of today's most powerful lasers, with Livermore relying on new, more efficient ways of pumping energy into a solid-state laser and NRL counting on systems for cooling a gas laser. "There will be a competition, I think, between Livermore and NRL on the two types of laser technologies," says Stephen Bodner, a former Livermore researcher at the naval lab. But if either one succeeds, a future power plant would be able to draw directly on the know-how coming from the giant glass lasers that have long been the mainstay of ICF research.

Construction is set to begin next month on the latest and most formidable of these facilities, a billion-dollar, 500-terawatt laser at Livermore known as the National Ignition Facility, or NIF (*Science*, 28 February, p. 1252). NIF is meant to achieve "ignition"—heating and compressing a fuel pellet enough to kindle a self-sustaining thermonuclear burn that produces more energy than it consumes.

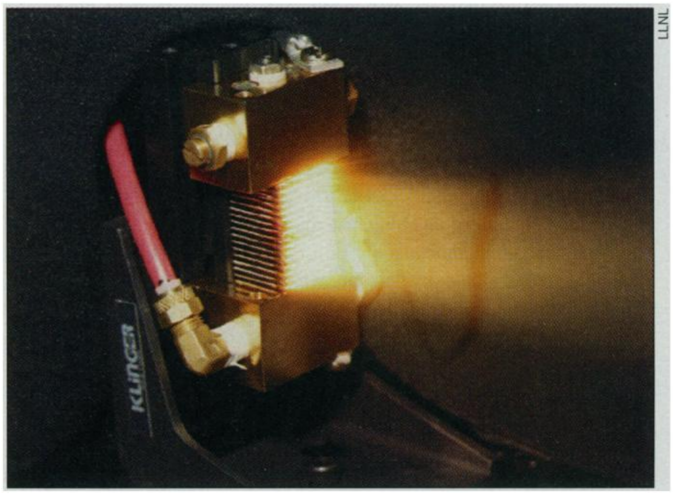
Like all its predecessors since the early 1970s, NIF will generate light by using flash lamps to pump energy into pink slabs of glass infused with the element neodymium. The laser beam then extracts energy from the glass. But the glass heats up in each shot, wasting energy and preventing the laser from firing again until it cools off, which can take hours.

To boost the repetition rate of its new lasers, the Livermore team is replacing the glass with a helium gas–cooled crystal known as ytterbium-doped strontium-fluorapatite, which can shed heat faster than neodymium glass while storing four times as much energy. The team also plans to pump this laser not with flash lamps but with other lasers: much larger and more powerful relatives of the laser diodes used in CD players. Laser diodes produce light in a narrower band of frequencies, more closely matching that of the beam they would feed. The closer match means less wasted energy and hence less heat.

Livermore hopes to complete the bench top–size Mercury by 1999, says Christopher Marshall, the project leader. Beyond Mercury would be Venus, at 10 times the power—if funding permits. And, by 2020 or 2030, a laser called Terra would reach the 10-terawatt range. "Beyond that size, you're adding multiple beam lines" to reach powers comparable with NIF's, Marshall says.

NRL's Bodner is hoping to build a five-pulse-per-second prototype laser in the Mercury power range, based on a laser technology that generates light in an excited gas of krypton-fluoride. Unlike a solid, a gas can be circulated through a cooler to tame heat buildup. Bodner believes that krypton-fluoride lasers enjoy an advantage because they have an extraordinarily uniform beam, which should help to ensure symmetric implosion of the fuel capsule. Beams from solid-state lasers, in contrast, lose some of that uniformity when their natural infrared light is converted to a shorter wavelength for fusion, he says, although Livermore researchers believe they can smooth their beam further if needed.

Proving the promise of his gas-laser technology would take about 5 years, Bodner says. But his plan suffered a setback in January. Budget pressure forced the U.S. Department of Energy (DOE) to back off from a plan to spend about $2 million in fiscal 1998 funding for the project.



Kindling a laser flame. High-powered laser diode arrays like this one could "pump" a rapid repetition fusion laser.

Ion-beam researchers eye both upstart lasers with some skepticism. Last summer, a DOE-sponsored review panel reiterated that heavy-ion beams remain the most promising candidate for fusion-energy drivers. Heavy-ion beams benefit from 60 years of experience with particle accelerators, which routinely fire at least as rapidly as needed for fusion power, says fusion physicist Roger Bangerter, who heads a heavy-ion–driver program at Lawrence Berkeley National Laboratory, in which Livermore is also taking part. And because ion accelerators focus their beams with magnetic fields rather than glass lenses, they don't suffer from the so-called final-optic problem, in which the onslaught of radiation from exploding fuel pellets darkens the lenses. On the downside, say researchers, it will take years of basic physics research just to determine whether floods of like-charged ions—which naturally repel each other—can be forced to converge precisely on a fusion fuel target.

While ICF scientists all argue passionately for their preferred approach—and against rival plans—few are ready to venture which option will win out decades from now. Says Livermore's Marshall: "These different options all have something to offer that the other doesn't. But all have a little bit of an Achilles' heel associated with them as well."

–Peter Weiss

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