Fusion Finally Coming of Age?

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Harnessing nuclear fusion, the force that powers the sun, has been a pipe dream since the first hydrogen bombs were exploded. Fusion promises unlimited clean energy, but the reality has hovered just out of reach, 20 years away, scientists have said for more than six decades—until now. Researchers at Lawrence Livermore Labs, the University of Washington, and private companies like Lockheed Martin and Canada's General Fusion now foresee the advent of viable, economical fusion energy in as little as 10 years. Powered by new developments in materials, control systems, and other technologies, new reactor designs are testing old theories and finding new ways to create stable, sustainable reactions.

Nuclear power plants create energy by breaking apart uranium and plutonium atoms; by contrast, fusion plants squeeze together atoms (typically hydrogen) at temperatures of 1 to 2 million degrees C to form new, heavier elements, essentially creating a miniature star in a bottle. Achieving fusion requires confining plasma to create astronomical levels of pressure and heat. Two approaches to confining the plasma have dominated: magnetic and inertial confinement. Magnetic confinement uses the electrical conductivity of the plasma to contain it with magnetic fields. Inertial confinement fires an array of powerful lasers or particle beams at the hydrogen atoms to pressurize and superheat them. Both approaches require huge amounts of energy, and they struggle to get more energy back out of the system.

Most efforts to date have relied on some form of magnetic confinement. For instance, the International Thermonuclear Experimental Reactor, or ITER, being built in southern France by a coalition that includes the European Union, China, India, Japan, South Korea, Russia, and the United States, is a tokamak reactor. Tokamak reactors use rings of huge superconducting magnets to form a donut-shaped magnetic field that contains the plasma. But these kinds of reactors are huge and require massive amounts of energy. ITER is expected to cost at least $50 billion by the time it is ready to conduct the first experiments, in 2027.

This kind of magnetic confinement is also inherently unstable. When a less dense fluid pushes on a denser one, the two substances immediately reverse positions—picture pouring water into a jar of oil. The magnetic bottle holding the plasma in place has zero density, which means the plasma constantly wants to move to the outside, escaping confinement. Maintaining the magnetic field under these conditions requires immense energy. Finding a stable confinement mechanism is a key barrier to compact, affordable fusion. However, it appears that scientists are finally making progress on that front, buoyed by renewed funding for research and new technological developments. Lockheed Martin sparked renewed public interest in compact fusion in October 2014, when the company released an announcement predicting its fusion research team would achieve its first milestones in one year. The company has since stopped releasing information on the project, "given the proprietary nature of this work," but Lockheed Martin spokesperson Heather Kelso said in an email that the company "believes nuclear fusion to be an outstanding solution to provide affordable, safe, and climate-friendly base-load power" and is experimenting with a "first generation device."

Other research teams, including two groups at the University of Washington and a number of startups, are also exploring different approaches to affordable fusion power. This recent activity is focused on different mechanisms to confine the plasma. Many of the ideas these teams are exploring have been around for years but have only now become practical due to improvements in materials and control systems, and theoretical breakthroughs. Some of them rely on methods that blend magnetic and inertial containment approaches. The Washington teams are exploring ways to create magnetic containment without the expensive superconducting magnets. One of the teams, led by UW professor of aeronautics and astronautics Thomas Jarboe, is building a spheromak device, in which the magnetic fields are created by driving electrical currents into the plasma itself, rather than by external magnetic coils. "This is a much more elegant solution because the medium in which you generate fusion is the medium in which you're also driving all the current required to confine it," says doctoral student Derek Sutherland, who has been working with Jarboe. This makes the reactor far smaller and less expensive to build and operate.

The US Department of Energy first investigated spheromaks in 1979, before funding cuts stopped federal research in fusion. Even then, Jarboe said, it was clear that if researchers could make the approach work, it would be far more economical than other types of systems. However, the toroids produced by a spheromak are very unstable, making the reaction difficult to sustain; achieving stability in the spheromak has been a key challenge— one the UW team says it has cracked. In fact, the team has a prototype in operation, a reactor about a tenth the scale of a commercial project, which has been able to sustain plasma efficiently. Achieving higher output will require scaling up the project and bringing the plasma to higher temperatures. But, based on 2014 projections, Jarboe believes a power plant based on his design or some like it, could be built and operated for about $2.7 billion, the same cost as a coal-fired plant.

Across the UW campus, Uri Shumlak, also an aeronautics and astronautics professor, is working with electrical engineering professor Brian Nelson on another way to confine plasma that, like the spheromak, eliminates the magnetic coils. Rather than a toroid, the plasma in their reactor forms a column 100 cm long with a 1 cm radius that can persist for as long as it is needed. Known as the Z-pinch concept, this design was first explored in the 1990s; the potential of sheared flow stabilization of the Z-pinch was theorized in 1995 and advanced in experiments published between 2001 and 2009. However, the design fell out of favor because, like spheromaks, instabilities limited confinement time.

Shumlak and Nelson believe they have found a way to make the Z-pinch work, though, using a sheared plasma flow. That sheared flow, Shumlak said, means "we don't have to compress the magnetic field; we can directly compress the plasma itself." They accomplish this by driving a current through the plasma column; the current creates a magnetic field, which encircles the column, providing containment. Shumlak has a $5.3 million grant from the Department of Energy; his team is working with Lawrence Livermore scientists to scale up the device. The goal is to achieve a sustainable fusion reaction capable of powering homes or propelling spaceships. "We're on a timeline of three years," Shumlak said, "to demonstrate that we can scale this concept up to where we can demonstrate that we can generate fusion reactions."

Both UW teams have benefitted from increased interest in alternative approaches to fusion power that might be ready in time to affect climate change. That interest has translated into increased government funding— and the grants the two teams have received from the Department of Energy (DOE). In 2015, DOE announced nine new grants, totaling $30 million, for "developing prototype technologies to explore new pathways for fusion power."

Private investors and startups are also putting down big bets on fusion energy. One Canadian company, General Fusion, has received as much as $100 million in private financing since it formed in 2002. General Fusion's reactor works on magnetized target fusion, a hybrid of magnetic and inertial confinement. The magnetic confinement is essentially the same as Jarboe's, relying on spheromaks to contain the plasma. In the General Fusion device, the toroids are created within a roughly 3-meter sphere containing liquid lead and lithium, which spins around to create a vortex. The spheromak is injected into the center of the vortex, where hundreds of pneumatic pistons hammer the spinning metal to produce precisely timed shock waves that compress the fuel and initiate fusion. The ultra-precise timing required by this approach has only recently become possible with advances in modern control systems.

Other proposals involve fusing protons with atoms of boron 11 in a process known as the pB11 cycle. California-based Tri Alpha Energy is collecting investments from venture capitalists to support the development of a fusion process based on the pB11 cycle. The plan calls for confining and heating a rotating, football-shaped plasma in the vacuum chamber of a cylindrical reactor, speeding its rotation by aiming a particle beam at its edge until it reaches temperatures of 40 to 60 million degrees C, at which point it will fuse.

All these efforts are still in the proof-of-principle stage, years away from achieving ignition—let alone commercial scale. Other technical and engineering challenges remain in the hunt for an efficient and safe fusion power plant. But the work holds out the promise of limitless clean power, a promise that scientists appear to be getting closer to fulfilling.

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