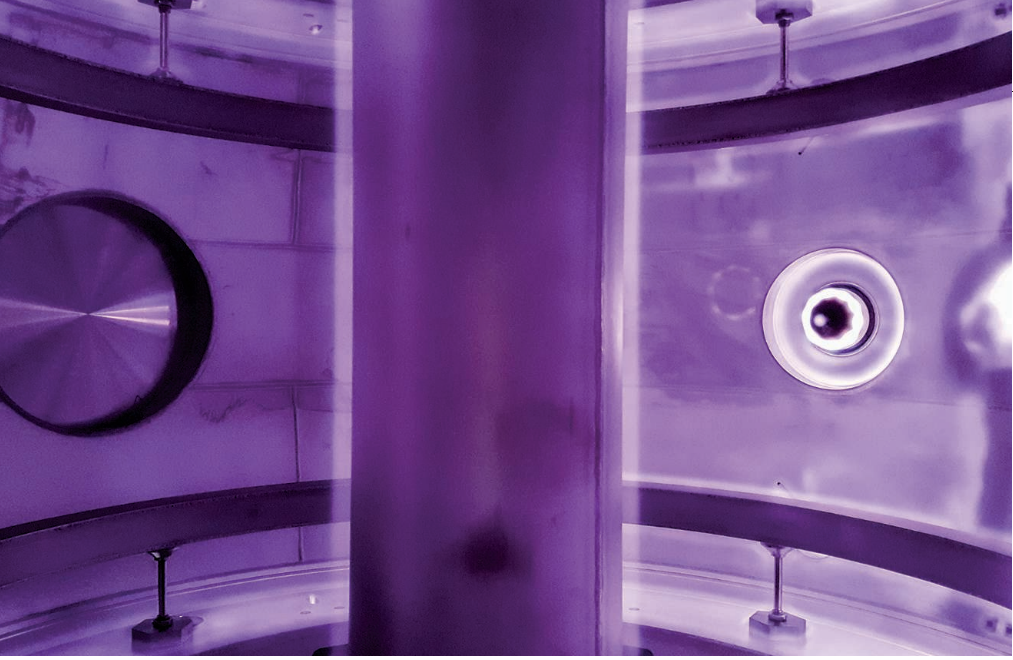

Plasma inside Tokamak Energy's spherical ST40 reactor could reach 100 million degrees Celsius.

ENERGY

Private fusion machines aim to beat massive global effort

Startups avoid ITER's path with new prototype reactors

By **Daniel Clery**

When finally complete in 2025, the $20 billion fusion reactor called ITER, rising near Cadarache in France, will be seven stories tall. Even then, nothing guarantees that it can hold nuclei together at temperatures of 150 million degrees Celsius, inducing them to fuse and release energy. Now, a small U.K. company has unveiled a 2-meter-tall chamber that looks like an oversized beer keg and cost about £10 million to develop. Using a different reactor shape than ITER and, eventually, superconducting magnets, the company says it has a cheaper and faster path to an energy-producing fusion reaction.

"Fusion hasn't been exciting enough in recent years," says David Kingham, CEO of Tokamak Energy near Oxford, U.K. "Someone has to inject some excitement and can-do attitude."

Tokamak Energy is not alone. A few other privately financed startups are challenging the publicly funded, slow-moving ITER behemoth (*Science*, 25 July 2014, p. 370). Two of the startups, Tri Alpha Energy of Foothill Ranch, California, and General Fusion of Burnaby, Canada, are also building new machines in the next few years that aim to get close to the break-even point, where the energy generated equals the energy put into the system. Mainstream fusion researchers say the approaches are technically plausible and welcome the competition. "Fusion is too important for one approach or one device," says Dennis Whyte, director of the Plasma Science and Fusion Center at the Massachusetts Institute of Technology in Cambridge.

Since the 1960s, one shape has dominated fusion: the tokamak, a ring-shaped vessel for containing plasma, the ionized gas that must be heated to more than 100 million degrees Celsius to achieve fusion. Powerful magnets around the tokamak create fields that not only keep the plasma from damaging the interior surfaces, but also compress and heat it. Yet scientists have struggled to keep the plasma stable and hot enough for a fusion reaction that produces excess energy. Because theory and experiment suggest that large tokamaks retain heat better, they have tended to get ever bigger—and more expensive.

In the 1980s, however, theorists predicted that changing the shape of the tokamak from a doughnut to a cored apple would improve plasma stability (*Science*, 22 May 2015, p. 854). Tokamak Energy is betting on that shape, called a spherical tokamak. It also aims to crank up the strength of the confining magnetic fields with superconducting magnets. Conventional superconductors must be cooled to liquid helium temperatures—a great expense. Tokamak Energy is experimenting with layered tapes that contain high-temperature superconductors (HTS) sandwiched between other materials and only need cooling with far cheaper liquid nitrogen. "I'm very convinced that this material will make the difference in fusion over the next few years," Kingham says.

In 2015, Tokamak Energy built a spherical tokamak just over a meter across and showed it could confine plasma at a million degrees. Now, it says its 2-meter device, called ST40, will be able to heat a plasma to 100 million degrees within a magnetic field of 3 tesla—as strong as the field in a medical MRI machine. *Science* was given an exclusive look at the new machine before it begins operation in a few months' time. It will use conventional copper-wire magnets while researchers develop HTS magnets for a successor machine. Even without HTS magnets, ST40 could reach 100 million degrees by 2019, enough "to validate this concept of spherical tokamaks for fusion power," Kingham says.

Tokamak Energy, with £20 million in funding, "has achieved a huge amount with a relatively small amount of money," says Mark White of the Rainbow Seed Fund, a U.K.-backed venture capital fund for commercializing science from government labs that has invested in Tokamak Energy. In contrast, its competitor Tri Alpha has amassed more than $500 million from a mix of investors including the Wellcome Trust and Kuwait's sovereign wealth fund.

Tri Alpha exploits a phenomenon called a

Great balls of fire

Three startup fusion companies are challenging ITER, an over-budget and overdue public project.

NAME	LOCATION	TECHNOLOGY	STAFF	FUNDING	STATUS	TARGET TEMPERATURE
Tokamak Energy	Milton, U.K.	Spherical tokamak	35	$25 million	New ST40 device in 2017	100 million degrees Celsius
Tri Alpha Energy	Foothill Ranch, California	Beam-driven plasma rings	160	>$500 million	New C-2W device in 2017	30 million degrees Celsius
General Fusion	Burnaby, Canada	Target implosion	65	>$75 million	Prototype in 3–5 years	100 million degrees Celsius
ITER	Cadarache, France	Tokamak	2300	$20 billion	Under construction. First plasma in 2025	150 million degrees Celsius

PHOTO: TOKAMAK ENERGY LTD 2017

field-reversed configuration (FRC), a spinning smoke ring of plasma that produces its own confining magnetic field because of the currents of electrons and ions within it. Known since the 1960s, FRCs could be coaxed to last only for a fraction of a millisecond before fizzling out. In 2015, Tri Alpha revealed it could make an FRC last 5 milliseconds and confine plasma at 10 million degrees Celsius (*Science*, 28 August 2015, p. 912). In its 25-meter-long device, plasma guns at both ends fired FRCs at high speed toward the center, where they merged and converted kinetic energy into heat, boosting the temperature. The machine further heated and stabilized the merged FRC by bombarding it with particles.

Over the past year, Tri Alpha has dismantled its machine and built a new one, 30 meters long, with more particle beams and better control of the heat loss from the plasma. When the researchers fire it up in a few months, they hope to achieve 30-million-degree plasmas lasting up to 40 milliseconds. Chief Technology Officer Michl Binderbauer says they should learn enough physics from this machine to move on to much higher temperatures. That path may be long: Tri Alpha wants to use a different fuel that does not create hazardous high-energy neutrons, but requires billion-degree plasmas to fuse.

Across the border in Canada, General Fusion is taking another radical approach. The company also relies on self-confining plasma rings but will inject them into a spherical reaction chamber whose walls are coated with liquid lithium metal. Dozens of pneumatic pistons, sticking out from the chamber like porcupine quills, will then hammer down on the lithium in unison, generating a shock wave that converges on the plasma and crushes it, creating high temperature and pressure.

With more than CA$100 million from government and private sources, General Fusion since 2002 has been working separately on the three components of the system—plasma injector, lithium vortex, and pneumatic pistons. "Now we have to put it all together," says CEO Chris Mowry. The final device may have as many as 400 pistons, and will take between 3 and 5 years to build, he says. The aim is to heat plasma to 100 million degrees, close to energy-producing conditions. Mowry says the device will rely on well-understood mechanical systems, which will produce "an affordable and practical power plant."

Despite such bold claims, plasma physicist Glen Wurden of the Los Alamos National Laboratory in New Mexico says he and others are impressed with the results that the fusion startups are now reporting. But, he adds, that respect is "tempered by what are perceived as overly optimistic schedules." ■

ARCHAEOLOGY

Claim of very early humans in Americas shocks researchers

Skepticism greets report of smashed mastodon bones

By **Lizzie Wade**

What broke the 130,000-year-old mastodon bones in California? Most archaeologists would tell you it couldn't have been humans, who didn't leave conclusive evidence of their presence in the Americas until about 14,000 years ago. But a small group of experts now says that the fracture patterns on the bones, found during highway construction near San Diego, California, must have been left by humans pounding them with stones found nearby. If correct, the paper, published this week in *Nature*, would push back the presence of people in the Americas by more than 100,000 years—to a time when modern humans supposedly had not even expanded out of Africa to Europe or Asia.

"The claims made are extraordinary and the potential implications staggering," says Jon Erlandson, an archaeologist at the University of Oregon in Eugene who studies the peopling of the Americas. "But broken bones and stones alone do not make a credible archaeological site in my view." He and many other archaeologists say it will take much stronger evidence to convince them that the bones were fractured by ancient people.

> *"The claims made are extraordinary and the potential implications staggering."*
> **Jon Erlandson**, University of Oregon

Archaeologists first excavated the Cerutti Mastodon site in 1992, after the construction exposed bones. Over time they found more splintered bones and a smattering of large round rocks embedded in otherwise fine-grained sediment. More recently, Daniel Fisher, a respected paleontologist at the University of Michigan in Ann Arbor, took a close look at the fractures and found patterns he says are consistent with blows from a rounded stone, which leave a characteristic notch at the point of impact. Other chips of bone show what he calls unmistakable signs of being popped off by the impact. "Nobody has ever explained those [characteristic bone flakes] satisfactorily in any way not involving human activity," Fisher says. He says humans were probably breaking the bones to reach the marrow, or to turn the bone itself into a sharper tool. The nearby stones, hefty and round, show wear patterns consistent with being smashed against bone, the authors say. In experiments, they used that method to break elephant bones and produced identical fracture patterns.

The bones' collagen, a protein that can be used for radiocarbon dating, was long gone. Instead, the team relied on a dating technique based on the radioactive decay of uranium in minerals within the bone. Several dating experts said the methods were sound and found the 130,000-year date trustworthy. "At face value, these results are *about* as good as you can get," says Alistair Pike, a uranium dating expert at the University of Southampton in the United Kingdom.

But that still leaves the question of what splintered the bones. "It is one thing to show that broken bones and modified rocks could have been produced by people, which [this paper does]," says Don Grayson, an archaeologist at the University of Washington in Seattle. "It is quite another to show that people alone could have produced those modifications." And Gary Haynes, an archaeologist at the University of Nevada in Reno, notes that "the features of the broken bones … are also produced when heavy construction equipment crushes buried bones."

Author and site excavator Thomas Deméré, a paleontologist at the San Diego Natural History Museum, says the team carefully excavated 50 square meters beginning in 1992, and the bones described in the paper were "deeply buried. … There was no equipment damage to the heart of the site."

The lack of actual shaped stone tools, a "universal" at Old World sites, troubles archaeologist John Shea of the State University of New York in Stony Brook. Even the archaic humans that might have been present then, like *Homo erectus* or the mysterious Denisovans, left such flakes. "This evidence is well documented, but it's not sufficient to close the case," Shea says. ■

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Editor's Summary