In a binary black-hole system, the black holes spiral inward and eventually merge into one, emitting gravitational waves in the process. Observations of this process were reported for the first time earlier this year.
CREDIT: Simulating eXtreme Spacetimes (SXS) project

However, according to recent computer simulations, those elements would be ejected en masse during neutron-star mergers. New research even suggests that a nearby neutron-star merger that took place shortly before the formation of our solar system may have gifted our future planet with a modest excess of these valuable elements. Then the two neutron stars combined into a single black hole that has since wandered away across the galaxy.

Fryer believes there is much to learn from neutron-star mergers and their gravitational-wave emissions in terms of the evolving population of black holes, production of heavy metals, and extreme physics. He is currently working to identify observable events that would sharpen human understanding of the unobservable structure and dynamics of neutron-star interiors. He is also preparing to use merger statistics, as they roll in, to help resolve a longstanding ambiguity concerning the cutoff mass above which stars are destined to become black holes instead of neutron stars. His recent publications lay the groundwork for these advances.

But beyond pure science, Fryer's research is a matter of national security. In addition to neutron-star collisions likely being the ultimate supplier of key national-security materials, including uranium, their explosive nuclear dynamics are applicable to nuclear-weapons research. And many of the Los Alamos scientists who work with Fryer on astrophysical problems subsequently join him and others on essential national-security computations as well. LDRD

— Craig Tyler

Small Fusion Could Be Huge

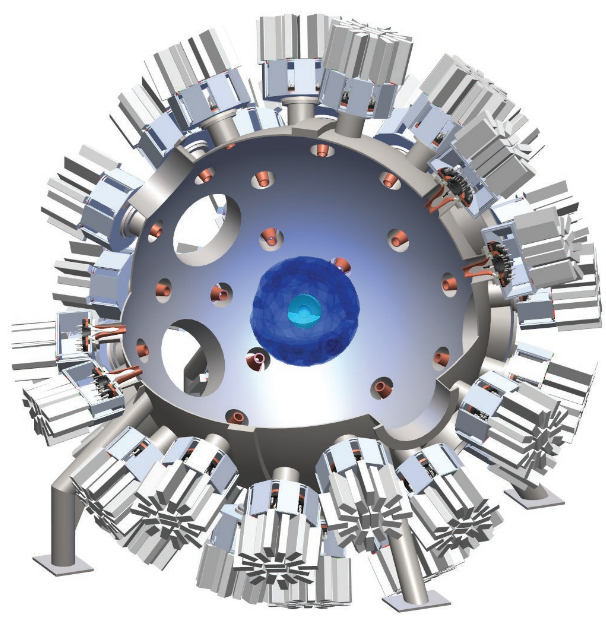
COMMERCIAL POWER FROM NUCLEAR FUSION is 30 years away. We know this because the fusion-energy research community has been saying so for 50 years.

If fusion energy ultimately works, its benefit to humankind is virtually impossible to overstate. The nuclear energy release is about four million times greater than the chemical energy released by burning coal, oil, or natural gas, and for that reason it requires very little fuel. Sixty kilograms of fusion fuel—which one strong person could physically carry into the power plant—would power a city of a million for a year. It would take 400,000 metric tons of coal to do the same. On top of that, the fusion reaction produces no carbon emissions, nor any other pollutant.

The reaction works by joining, or fusing, nuclei of hydrogen-2 (or deuterium) and hydrogen-3 (tritium) together to make helium-4 (a harmless and useful gas) plus a neutron, which then interacts with lithium in a way that "breeds" tritium for subsequent fusion reactions. The inputs, deuterium and lithium, are both present in seawater in quantities that would last millions of years at least.

The world's grandest fusion project to date is an international collaboration called ITER that comprises a massive reactor under construction in France. Once finished, it will be an experimental platform for demonstrating a sustained fusion reaction that generates more power than it consumes, similar to what goes on at the core of the sun. It was originally scheduled to come online this year at a cost of \$12 billion, but its director-general recently stated that it would not be finished before 2025—and for no less than \$20 billion—producing a net energy gain no earlier than 2035. The U.S. share alone is now expected to grow from \$1.1 billion to closer to \$5 billion. And that's just for a fusion *experiment*—the precursor to an actual power plant.

While ITER is a major step toward proving the feasibility of fusion, many scientists and energy-policy experts believe it is important to



Cutaway view of an imploding plasma liner (blue), formed by 60 inward-directed plasma jets, as it engages a magnetized plasma fuel target. (Plasma is hot, ionized gas.)

work in parallel on other aspects of fusion power. In addition to the U.S. Department of Energy's earlier commitment to ITER, its Advanced Research Projects Agency-Energy (ARPA-E) last year announced nine research grants "to create… new, lower-cost pathways to fusion power and to enable more rapid progress in fusion research and development." The largest of these grants, awarded jointly to Los Alamos National Laboratory and HyperV Technologies Corp., comes in at about one thousandth the projected cost of the U.S. contribution to ITER.

The project leader, Los Alamos physicist Scott Hsu, explains that their work is one embodiment of an approach called magneto-inertial fusion (MIF), which combines the benefits of two large-scale fusion paradigms, magnetic confinement and inertial confinement. ITER, for instance, is a magnetic-confinement device, using ultra-powerful magnetic fields to contain the 150-million-degree plasma undergoing nuclear fusion. (Such high temperatures are necessary for fusion because only at high temperatures can positively charged atomic nuclei slam into each other with sufficient speed to overcome their mutual electrical repulsion and fuse into larger nuclei.) By contrast, the National Ignition Facility at Lawrence Livermore National Laboratory in California is an inertial-confinement device, using inward-directed lasers to implode a nuclear-fuel pellet.

In an exploratory experiment of Hsu's approach to MIF, 60 electromagnetic plasma guns, designed and built by HyperV and mounted all around a spherical vacuum chamber, simultaneously fire supersonic jets of plasma. (A full-scale reactor would employ hundreds of plasma guns.) The jets converge at the center of the chamber for the purpose of compressing another plasma of laser-magnetized nuclear fuel, injected moments earlier.

Such plasma-jet driven MIF builds upon success obtained recently at Sandia National Laboratories. There, researchers obtained conditions suitable for fusion by compressing a solid liner surrounding the hot, magnetized fuel. However, the Sandia experiment was not designed for the repetitive pulsing required for fusion energy, as each compression, or "shot," severely damages the liner and other components. Hsu's plasma-jet compression is designed to overcome this by effectively constructing a plasma liner, instead of a solid one, that's reestablished with each shot.

"We will be able to fire one shot every second, continuously restoring fusion conditions without damaging the hardware," says Hsu. In theory, that could be sufficient to achieve ignition—the all-important and maddeningly elusive state of getting significantly more power out than what is put in. Initial simulations suggest that, in principle, the fusion energy output could be quite large, possibly reaching up to 30 times the energy supplied to the plasma jets. Of course, actually achieving such a large gain, or really any gain at all, will not be so straightforward.

"Remember, the closer you come to ignition, the more unforeseen problems arise," says Hsu. "The history of fusion-energy research has shown that time and time again." With each snag encountered, studied, and overcome along the way, he plans to progressively improve simulations of the system's performance for ever-more realistic predictions. "But if we do achieve ignition, then our technology should scale well for commercial power applications. In fact, that's one of the key reasons for taking this approach."

—Craig Tyler

Cathedral of Santa Maria del Fiore in Florence, Italy

Can Free Particles Save a Priceless Treasure?

SADNESS COULD HAVE OVERWHELMED LOS ALAMOS particle physicist Elena Guardincerri last summer when she saw the ever-expanding cracks threatening the dome of the Cathedral of Santa Maria del Fiore (better known as the Duomo), a Renaissance icon in Florence, Italy. Engineered by famed master builder Filippo Brunelleschi, it was completed in 1436, and the secrets of what hidden supports or unidentified vulnerabilities might lie behind its walls have been lost to the ages. But Guardincerri was in Florence on a mission to aid restoration: to meet with the president of the Opera del Duomo, the corporation that has managed the cathedral since its construction, and present an innovative imaging solution sourced from the cosmos with which to peer inside.

Though widely renowned for his skill at solving engineering problems, Brunelleschi was considered foolish by some for abandoning flying buttresses and other conventional supports in favor of his own unorthodox ideas for constructing the dome. He deliberately left no drawings behind, and his design still poses a few riddles: Does the double-shell dome have an inner support system of iron chains inside the masonry, as alluded to in historical documents? Is the inner wall made of rubble masonry as well as bricks? Such information is essential as architects and engineers enhance their models of the dome and decide how to protect this world treasure from further damage—or outright collapse.

Instead of metal detectors, x-rays, or ultrasonic inspection, Guardincerri's team will use cosmic-ray muon trackers to create vivid images of hidden reinforcement elements inside the dome's masonry and exam-