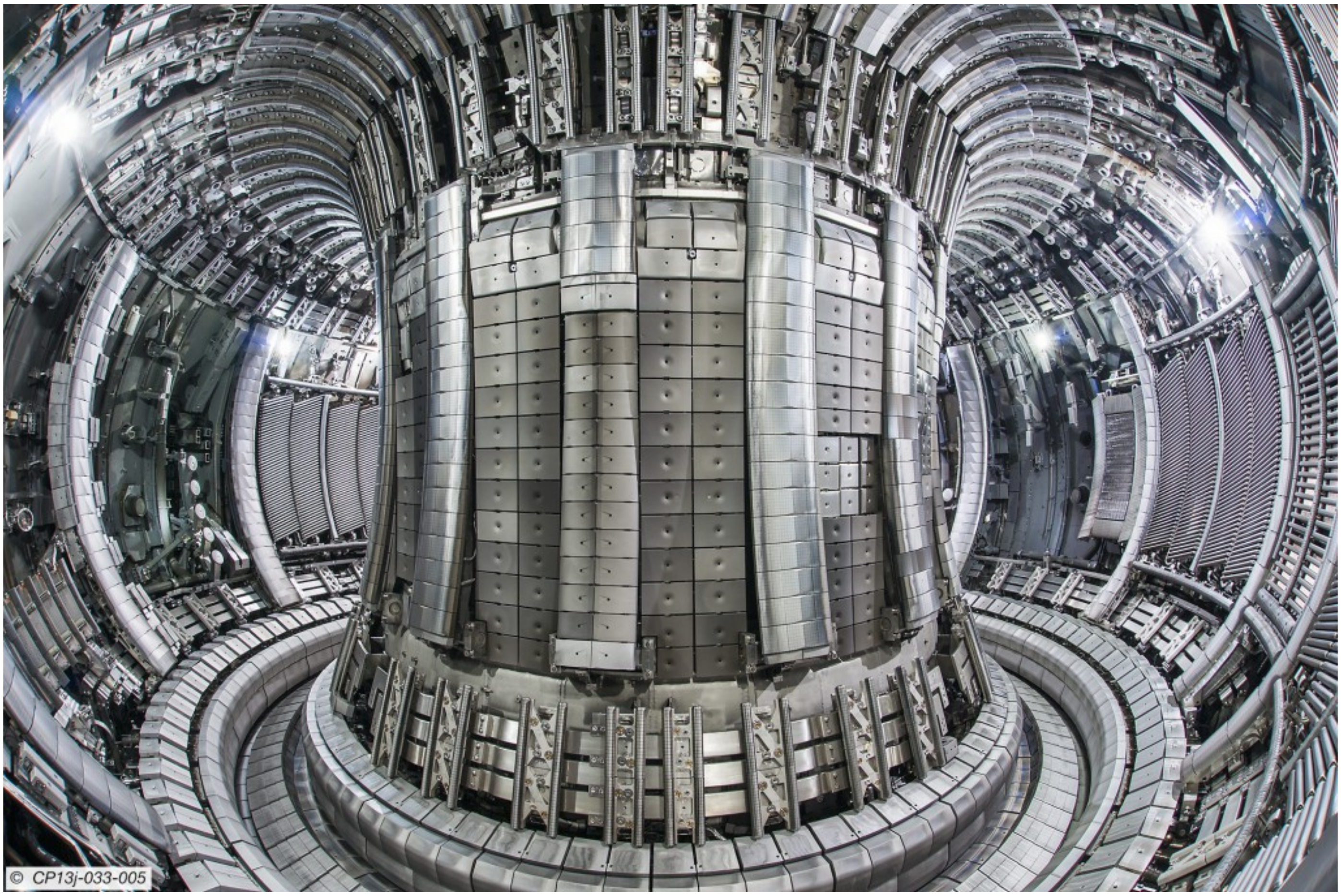
Why Nuclear Fusion Is Always 30 Years Away



The Joint European Torus tokamak generator, as seen from the inside. (*Credit: EUROfusion)*

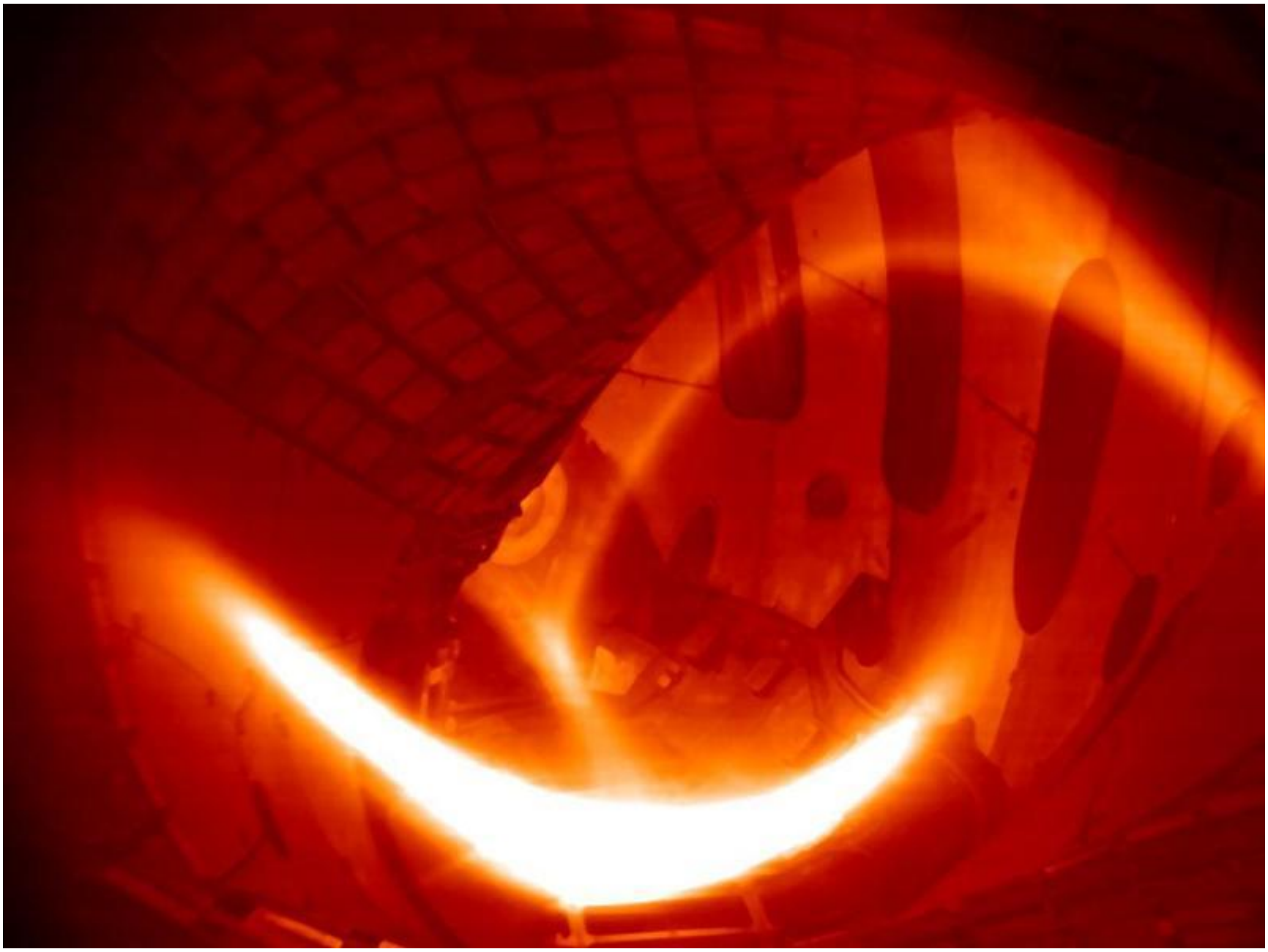
Nuclear fusion has long been considered the “holy grail” of energy research. It represents a nearly limitless source of energy that is clean, safe and self-sustaining. Ever since its existence was first theorized in the 1920s by English physicist Arthur Eddington, nuclear fusion has captured the imaginations of scientists and science-fiction writers alike.

Fusion, at its core, is a simple concept. Take two hydrogen isotopes and smash them together with overwhelming force. The two atoms overcome their natural repulsion and fuse, yielding a reaction that produces an enormous amount of energy.

But a big payoff requires an equally large investment, and for decades we have wrestled with the problem of energizing and holding on to the hydrogen fuel as it reaches temperatures in excess of 150 million degrees Fahrenheit. To date, the most successful fusion experiments have succeeded in heating plasma to over 900 million degrees Fahrenheit, and held onto a plasma for three and a half minutes, although not at the same time, and with different reactors.

The most recent advancements have come from Germany, where the Wendelstein 7-X reactor recently came online with a successful test run reaching almost 180 million degrees, and China, where the EAST reactor sustained a fusion plasma for 102 seconds, although at lower temperatures.

Still, even with these steps forward, researchers have said for decades that we’re still 30 years away from a working fusion reactor. Even as scientists take steps toward their holy grail, it becomes ever more clear that we don’t even yet know what we don’t know.



The first plasma achieved with hydrogen at the Wendelstein 7-X reactor. Temperatures in the reactor were in excess of 170 million degrees Fahrenheit. (*Credit: IPP)*

For Every Answer, More Questions

The Wendelstein 7-X and EAST reactor experiments were dubbed "breakthroughs," which is an adjective commonly applied to fusion experiments. Exciting as these examples may be, when considered within the scale of the problem, they are only baby steps. It is clear that it will take more than one, or a dozen, such "breakthroughs" to achieve fusion.

"I don't think we're at that place where we know what we need to do in order to get over the threshold," says Mark Herrmann, director of the National Ignition Facility in California. "We're still learning what the science is. We may have eliminated some perturbations, but if we eliminate those, is there another thing hiding behind them? And there almost certainly is, and we don't know how hard that will be to tackle."

We will almost certainly get a better perspective on the unknown problems facing fusion sometime in the next decade when an internationally-backed reactor, intended to be the largest in the world, comes to fruition. Called ITER, the facility would combine all we have learned about fusion into one reactor.

It represents our current best hope for reliably reaching the break-even point, or the critical temperature and density where fusion reactions produce more power than is used to create them. At the break-even point, the energy given off when two atoms fuse is enough to cause other atoms to fuse together, creating a self-sustaining cycle, making a fusion power plant possible.

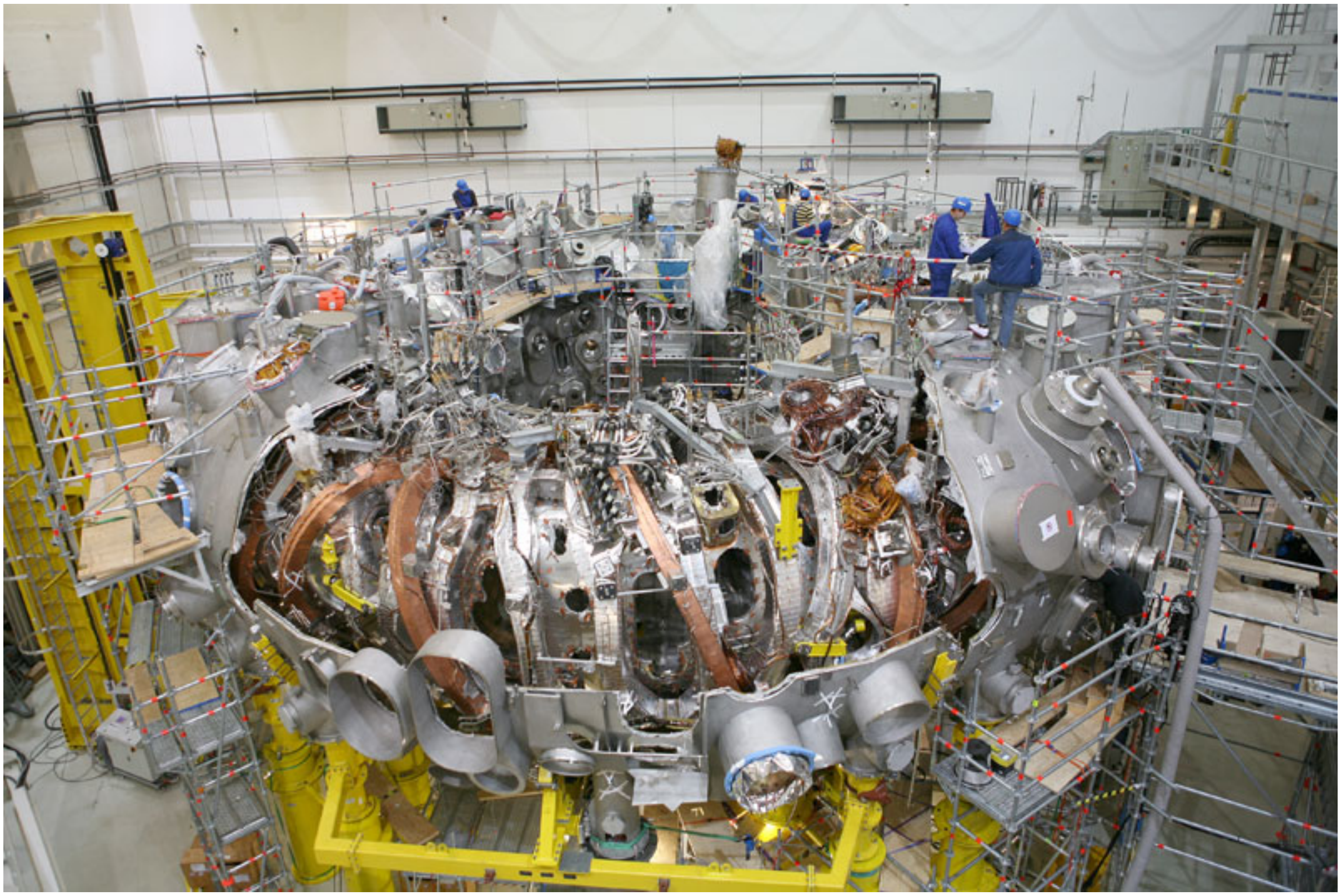
Perhaps inevitably, however, ITER has fallen prey to setbacks and design disputes that have slowed construction. The U.S. has even threatened to cut its funding for the project. It is these sorts of budgetary and policy hesitations that could ensure we continue saying fusion is 30 years away, for the next three decades.

In the face of more immediate challenges, from health epidemics to terrorism, securing funding for a scientific long bet is a hard sell. A decades-long series of "breakthroughs" that lead only to more challenges, compounded by pervasive setbacks, have diluted the fantastic promise of a working fusion reactor.

What Exactly Is Fusion?

Reliably reaching the break-even point is a twofold problem: getting the reaction started and keeping it going. In order to generate power from a fusion reaction, you must first inject it with sufficient energy to catalyze nuclear fusion at a meaningful rate. Once you have crossed this line, the burning plasma must then be contained securely lest it become unstable, causing the reaction to fizzle.

To solve the issue of containment, most devices use powerful magnetic fields to suspend the plasma in midair to prevent the scorching temperatures from melting the reactor walls. Looking something like a giant doughnut, these "magnetic containment devices" house a ring of plasma bound by magnetism where fusion will begin to occur if a high enough temperature is achieved. Russian physicists first proposed the design in the 1950s, although it would be decades before they actually achieved fusion with them.



A magnetic confinement fusion device, the Wendelstein 7-X, under construction. (*Credit: IPP)*

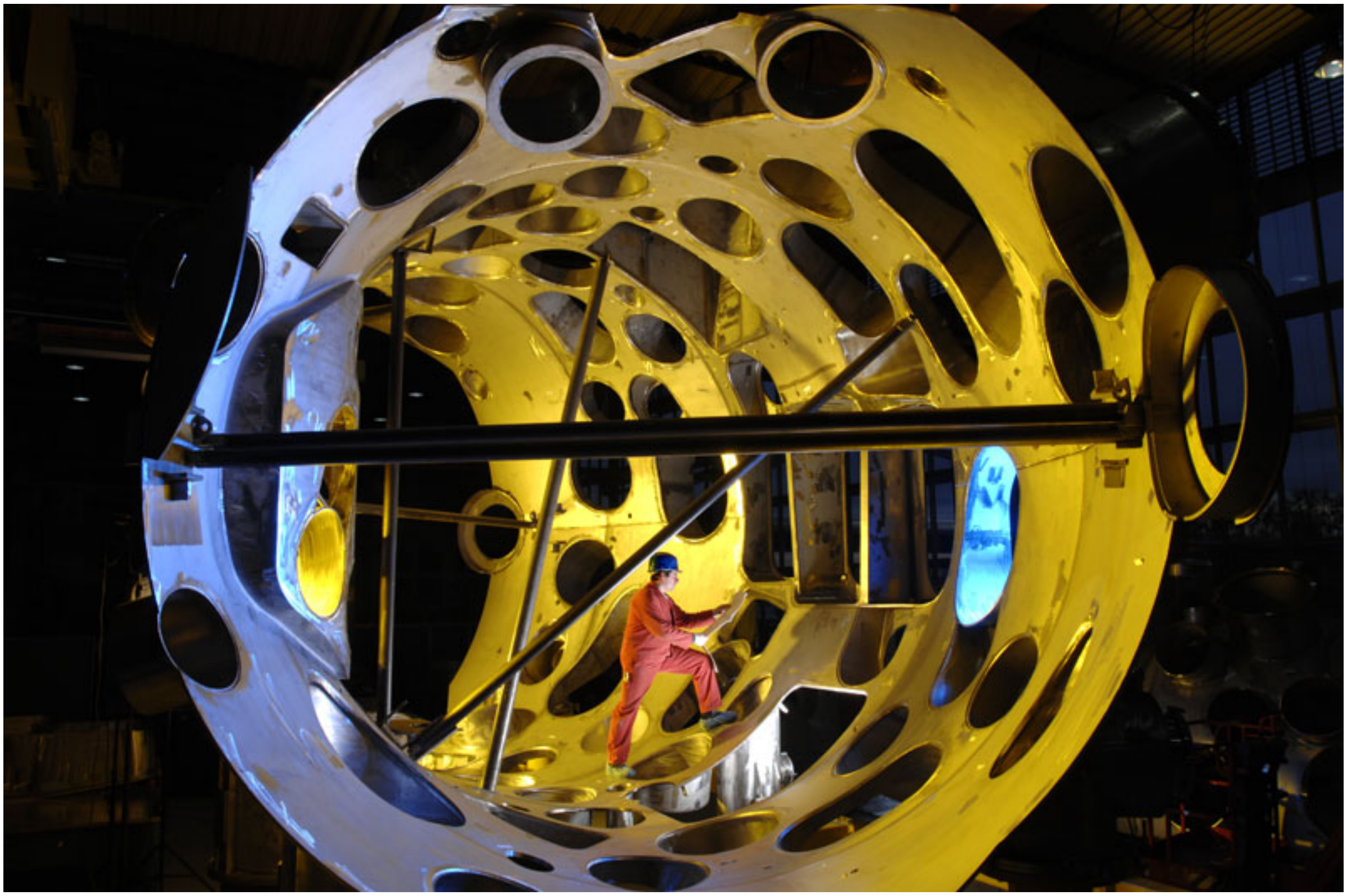
To create a truly stable plasma with such a device, two magnetic fields are required: one that wraps around the plasma and one that follows it in the direction of the ring. There are currently two types of magnetic confinement devices in use: the tokamak and the stellarator.

The differences between the two are relatively small, but they could be instrumental in determining their future success. The main disparity in their design arises from how they generate the poloidal magnetic field — the one that wraps around the plasma. Tokamaks generate the field by running a current through the plasma itself, while stellarators use magnets on the outside of the device to create a helix-shaped field that wraps around the plasma.

According to Hutch Neilson of the Princeton Plasma Physics Laboratory, stellarators are considered more stable overall, but are more difficult to build and suffer from a lack of research. Tokamaks, on the other hand, are much better understood and easier to build, although they have some inherent instability issues.

At the moment, there is no clear winner in the race between the two, as neither appears to be close to the "holy grail." So, due to lack of a victor, researchers are building both.

"There is a lack of a solution at this time, so looking at two very realistic and promising configurations for closing that gap is the responsible thing to do," says Neilson.



One of five sections that comprise the outer vessel of Wendelstein 7-X, photographed during production. *(Credit: Wolfgang Filser/IPP)*

Currently, the largest fusion reactor in the world is the Joint European Torus (JET), a tokamak based in England and supported by the European Union. JET was commissioned in the 1970s and first came online in 1983 and successfully produced plasma, the first step in achieving fusion.

With a series of upgrades beginning in the late 1980s, JET became the world's largest fusion generator, and currently holds the record for the most energy produced in a fusion reaction at 16 megawatts. Even so, it has not yet reached the break-even point.

ITER Offers a Way

To reach this all-important milestone, we will likely have to wait for ITER. Latin for “the way,” ITER will be the largest and most powerful fusion generator in the world, and is expected to to cross the break-even point. ITER is projected to produce 500 MW of power with an input of 50 MW, and be able to hold plasma for half an hour or more. That’s enough energy to power roughly 50,000 households.

Based on the tokamak design, the project is the result of a collaboration between the European Union and six other countries, including the U.S., that have pooled resources and expertise to build a reactor that is expected to be the gateway to useable fusion energy.

One of the cables used to create the toroidal magnetic field within ITER. (*Credit: ITER Organization)*

One of the main issues facing current generators is one of size, says Duarte Borba, a researcher at EUROfusion, and ITER will attempt to overcome this shortfall. As reactors get larger, they become more stable and can achieve higher temperatures, the two key factors in creating fusion.

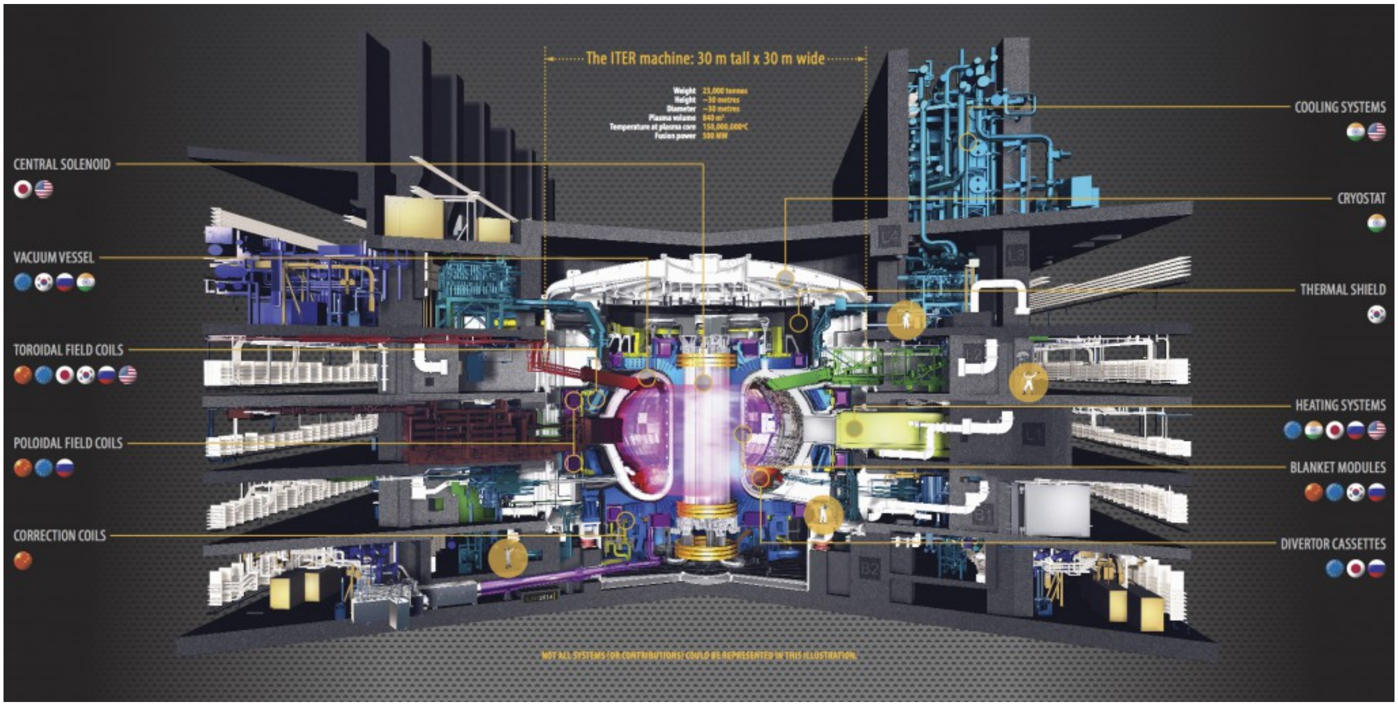
ITER is meant to be the successor to JET, and will take the technology developed there and apply it on a much larger scale. This includes JET's tungsten and beryllium divertors, which capture energy in the reactor, as well as the capability to fully control the system remotely. ITER will also use superconducting magnets to create its magnetic field, as opposed to ones made of copper, according to Borba.

Such magnets will reduce the amount of energy consumed by the device and will allow for longer, more sustained plasma production. JET can currently only produce plasma in bursts, as it cannot sustain the high levels of energy use for very long.

Collaboration Is Key

The most important development made by JET and implemented with ITER may not even be scientific, but rather bureaucratic in nature, says Borba. As a project supported by multiple nations, JET forged the path for organizing and implementing a large-scale, decades-long project.

With a projected price tag of $15 billion and a daunting shopping list of complex components, ITER could only exist today as a collaborative effort. Each of the member nations contributes researchers and components, with the hope that the potential benefits will be shared by all.



An illustration showing which countries are responsible for manufacturing various parts of the ITER reactor. (*Credit: ITER Organization)*

However, the democratic nature of ITER has significantly slowed down its construction. The goal is to have all of the parts arrive at the same time, but allocating each part to a different country brings in political and economic variables that throw the timing off. When ITER first received formal approval in 2006, it was slated to first achieve fusion in 2016, a date which has since been pushed back at least 10 years. Issues with component construction and design disagreements have been blamed for the delays.

A Worldwide Effort

To achieve a fusion power plant capable of addressing our energy needs, ITER alone is still not enough, according to Neilson. Even though it represents a significant advancement in reactor design, ITER isn't the end game for fusion research.

If everything goes to plan, ITER will pave the way for another reactor, called

DEMO, which will expand the technologies perfected by ITER to an industrial scale, and hopefully prove that nuclear fusion is a viable source of energy.

In the meantime, the new crop of fusion reactors appearing around the world will continue to play crucial roles in the chase for fusion. Far from being redundant, their supplemental research will attack the problem from different angles.

While ITER addresses the issue of scale, fusion projects in Asia are attempting to hold on to plasmas for longer and longer as they probe the benefits of superconducting magnets, Neilson said. Meanwhile, in Germany, the Wendelstein 7-X is pushing the boundaries of the stellarator design, possibly sidestepping issues of stability entirely. Nuclear fusion research has been a mild success in terms of international cooperation, with a growing number of countries determined to contribute their own piece of the puzzle.

Today, there are nuclear fusion experiments operating in the U.S., Germany, United Kingdom, India, France, Japan and several other countries. More reactors are being planned or are currently under construction. Even with the surge of interest, it’s still not enough, says Neilson.

“For a problem as dense and challenging as fusion, you want to have many more experiments trying out different parts of the problem than we actually have,” says Neilson.

More Than a Scientific Problem

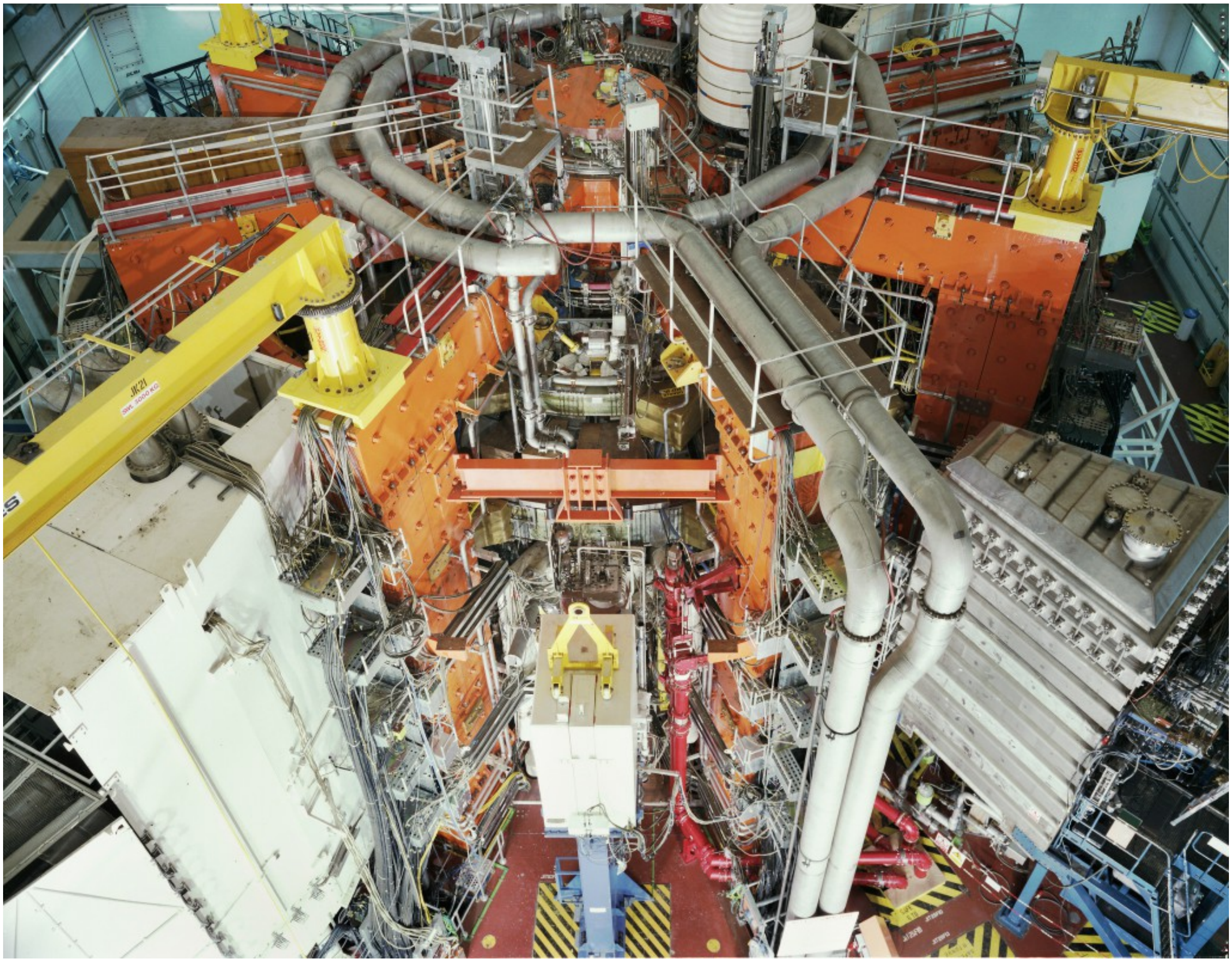
Ultimately, the question may be one of funding. Multiple sources said they were confident that their research could progress faster if they received more support. Funding challenges certainly aren’t new in scientific research, but nuclear fusion is particularly difficult due to its near-generational timescale. Although the potential benefits are apparent, and would indeed address issues of energy scarcity and environmental change that are relevant today, the day when we see a payoff from fusion research is still far in the future.

Our desire for an immediate return on our investments dampens our enthusiasm for fusion research, says Laban Coblentz, the head of Communication at ITER.

“We want our football coaches to perform in two years or they’re out, our politicians have two or four or six years and they’re out — there’s very little time to return on investment,” he said. “So when somebody says we’ll have this ready for you in 10 years, that’s a tough narrative to tell.”

In the U.S., fusion research receives less than $600 million in funding a year, including our contributions to ITER. This is a relatively small sum when compared to the $3 billion the Department of Energy requested for energy research in 2013. Overall, energy research represented 8 percent of the total funding the U.S. gave out for research that year.

“If you look at it in terms of energy budgets, or what’s spent on military development, it’s not really a lot of money that’s going to this,” says Thomas Pedersen, division head at the Max-Planck Institut für Plasmaphysik. “If you compare us to other research projects, it seems very expensive, but if you compare it to what goes into oil production or windmills or subsidies for renewables, its much, much less than that.”



The JET reactor, as seen from above. (*Credit: EUROfusion)*

Pedersen looks at fusion research in terms of expected inputs and gains. Research into solar and wind power may be relatively cheap, but the payoff pales in comparison to a working nuclear fusion generator.

Always 30 Years Away

However, the finish line has been visible for some time now, a mountaintop that seems to recede with every step forward. It is the path that is obscured, blocked by obstacles that are not only technological, but also political and economic in nature. Coblentz, Neilson and Borba expressed no doubts that fusion is an achievable goal. When we reach it however, may be largely dependent on how much we want it.

Soviet physicist, Lev Artsimovich, the “Father of the Tokamak” may have summed it up best:

“Fusion will be ready when society needs it.”