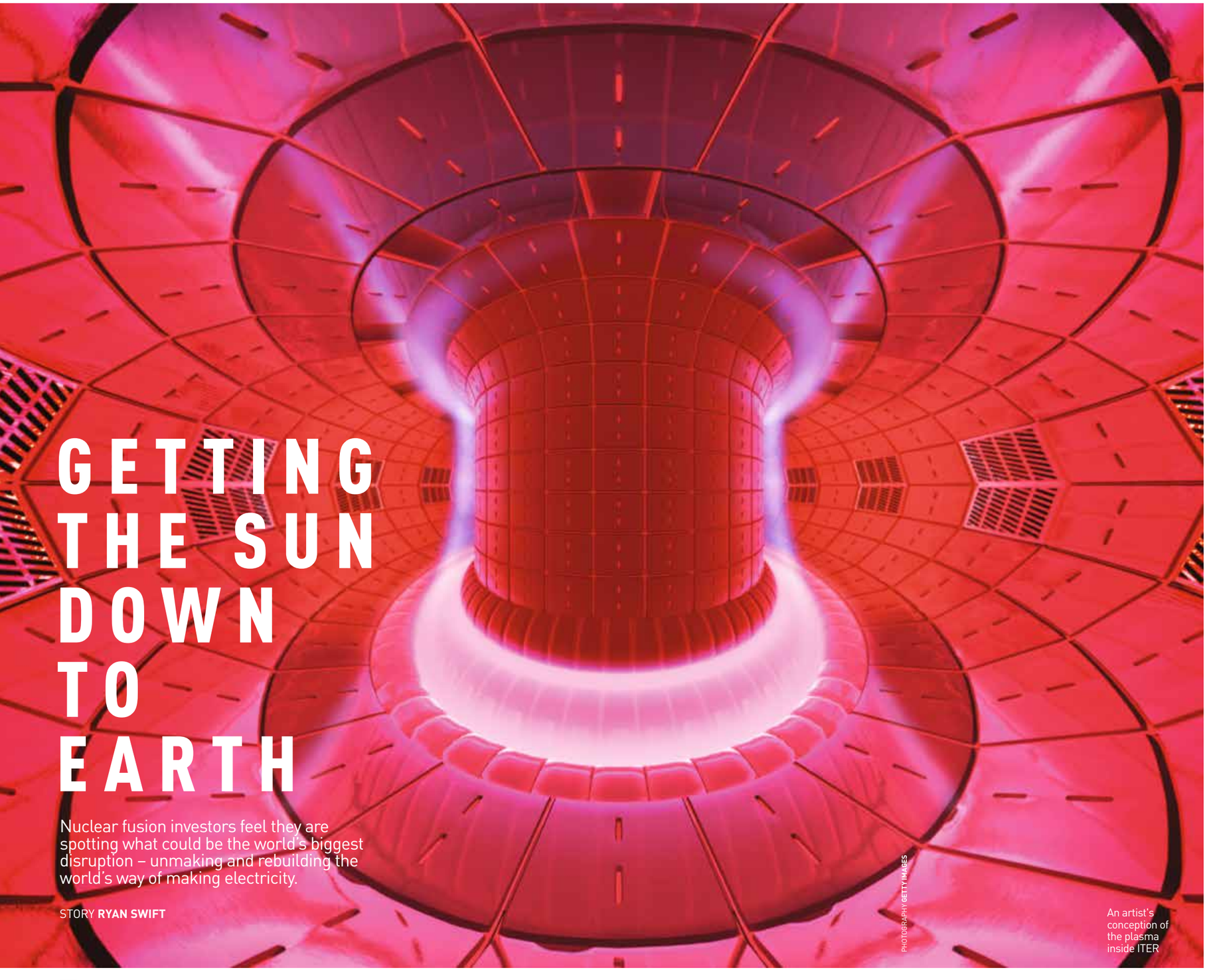


GETTING THE SUN DOWN TO EARTH

Nuclear fusion investors feel they are spotting what could be the world's biggest disruption – unmaking and rebuilding the world's way of making electricity.

STORY **RYAN SWIFT**

PHOTOGRAPHY **GETTY IMAGES**

An artist's conception of the plasma inside ITER

By and large, the electricity business is dirty. Generating electricity still involves burning a lot of coal. Burning natural gas is cleaner, but still causes harmful emissions. Despite years of heavy investment in renewable energy sources such as wind, solar and geothermal, these still constitute a distinct minority of total electricity generation. Add to that the almost certain increase in electricity demand and generation in the years to come, as Asia and Africa continue to industrialise and urbanise. The pressure for green sources of electricity will only increase.

Nuclear fission, the process of splitting heavy uranium atoms to create heat and therefore electricity, has fallen from favor because of the horrible risks associated with the radioactive waste that results from the fission process. Chernobyl and Fukishima are testaments to that. Yet, nuclear fission is one of the biggest sources of emissions-free electricity the world has.

To fix this dilemma, a global band of scientists and engineers have been on a quest to crack the riddle of nuclear fusion power, a potential source of clean, limitless electricity. For over 50 years, major governments and research labs have committed resources to trying to make nuclear fusion power work, in the hope that pollution-free, readily available electricity can be had, everywhere in the world. Nuclear fusion relies on isotopes of hydrogen, readily found in seawater.

Nuclear fusion power is made by fusing together two hydrogen atoms to create a heavier helium atom, which releases a tremendous amount of heat energy. The process is the same, that powers the Sun, and therein lies the problem. Creating and containing a nuclear fusion reaction is essentially trying to create and control a small piece of the Sun, on Earth. It's really hard to do. Generating the temperatures necessary to induce fusion of hydrogen requires enormous inputs of energy. Moreover, the Sun relies on pressure from its gravity to induce fusion of hydrogen atoms. To get a hydrogen gas to a state hot enough to create fusion (known as a plasma) requires that gas to reach temperatures of about 100 million degrees Celsius. The temperature of the core of the Sun is estimated to be about 15 million degrees by comparison. But the big question is, how do you harness something that's 100 million degrees? And that has been the question that's stopped fusion from joining and probably taking over the world's energy mix.

A common refrain among fusion enthusiasts and engineers is that nuclear fusion is just 30 years away – and has been so for at least 40 years. Every so often, the prospects of nuclear fusion as a common power source seem to brighten, only to dim again as engineering challenges refuse solutions. Until now, almost all research and progress in nuclear fusion technology has come from major inter-governmental programmes or national fusion laboratories working with leading universities.

Yet, in the past few years, a small band of scientists and engineers, some demoralised by slow progress in existing labs, have begun to work on small-scale projects, taking start-up approach to the engineering problems, which could finally yield the long awaited solution of how to commercialise nuclear fusion power. Along the way, they have opened up opportunities for early stage investors, keen to see fusion power become reality – and possibly become the world's first trillionaires in the process.

FROM THE COLD WAR TO THE HOT STUFF

In 1985, as the Cold War was about to enter its last phase, then USSR Secretary General Mikhail Gorbachev and US President Ronald Reagan met in Geneva, Switzerland, to discuss a range of issues. At that meeting, they set in motion an enormous project now called ITER (International Thermonuclear Experimental Reactor), whose aim was to solve the engineering riddles of creating a stable and contained nuclear fusion reaction, drawing from it the heat required to generate electricity. ITER has since been the main focus of intra-government funding and attention for decades. The Soviets and the Americans had both been working on the possibilities of nuclear fusion power up to that point. The communiqué released by the US and USSR emphasised the importance of nuclear arms reduction and peaceful cooperation. The last item on the communiqué said that the nations of the world should be brought together to develop and widely distribute the "essentially inexhaustible" energy from fusion power.

Today, the massive ITER reactor is currently under construction in Cadarache, in the South of France, and it could easily be the most complex engineering endeavor on Earth. There are now 35 nations directly involved with the ITER project, while many of these nations harbour their own national and university laboratories doing research work on nuclear fusion, and on building reactors with the aim of better understanding the physics and the engineering.

The website for ITER touts its size, with an array of overwhelming statistics, almost as if to justify the many billions that have been spent so far. Over 4000 workers are or will be required on a site covering 180 hectares. At the heart of it all is the main reactor building (one of 39 buildings on site), which is a seven-storey structure in reinforced concrete. The reactor core will weigh three times as much as the Eiffel Tower, and the central magnet at the core will generate a force twice that of the rocket power of a space shuttle. So far, the cost of building the ITER reactor is estimated at US$20 billion (HK$ 155 billion), four times the original estimate 10 years ago.

But for the small ventures now setting out on their own, it is ITER's gargantuan size that is the biggest problem. Bureaucracy is widely blamed for delays and cost overruns, and that's frustrating to the scientists and engineers desperate to see fusion become a reality. Worse, ITER takes up much of government funding, leaving university based research labs and projects searching for money. And ITER itself is not immune to funding interruptions – the United States Congress has repeatedly questioned the prospects of continued funding.

Compared to the colossal effort at Cadarache, Canadian fusion company General Fusion's operation is tiny. It is tucked into a large warehouse at the end of a nondescript cul-de-sac on the outskirts of Vancouver, and employs less than 70 people. Yet, it is this operation that several private investors are betting will win the race to commercialise nuclear fusion power. Should General Fusion (or another of the contestant companies) win that race, then it and its investors could overturn the global electricity industry, a business measured in trillions of dollars.

IN THE PAST FEW YEARS, A SMALL BAND OF SCIENTISTS AND ENGINEERS, SOME DEMORALISED BY SLOW PROGRESS IN EXISTING LABS, HAVE BEGUN TO WORK ON SMALL-SCALE PROJECTS, TAKING A START-UP APPROACH TO THE ENGINEERING PROBLEMS, WHICH COULD FINALLY YIELD THE LONG AWAITED SOLUTION OF HOW TO COMMERCIALISE NUCLEAR FUSION POWER

PHOTOGRAPHY **GETTY IMAGES**

ABOVE
The International Thermonuclear Experimental Reactor in Saint-Paul-les-Durance, southern France.

OPPOSITE
German Chancellor Angela Merkel at the Wendelstein 7-x nuclear fusion reactor of the Max-Planck-Institut für Plasmaphysik in Greifswald, northern Germany on February 3, 2016.

For Christofer Mowry, newly-installed CEO of General Fusion, the last decade has seen a "paradigm shift" in the way fusion research and development is being done, from large government programmes to smaller, faster ventures. It is a development inspired in part by the growth of start-up ventures in rocketry and space exploration – if start-up ventures can do that, why not nuclear fusion?

Given that current investments in such nuclear fusion programmes are often measured in the millions or tens of millions of dollars, it's a captivating idea, particularly if you're a far-sighted tech guru. Billionaires such as Jeff Bezos, Microsoft's Paul Allen, Peter Thiel and others have decided to stake their claim on the potential of nuclear fusion.

THE CHALLENGES AND THE REMEDIES

The technical challenges to fusion are immense. A 100-million degree plasma has to be created, sustained and controlled. It has to be held in a vacuum using magnetic forces, as nothing can touch it. Yet, heat needs to be captured to ultimately generate the electricity. At the same time, generating temperatures that run to the millions of degrees also requires an enormous energy input. So far, nobody has achieved net energy gain from a fusion reaction.

Various fusion programmes at university and government labs have made progress and developed a number of possible approaches to the challenges. In fact, a number of the ideas that start-up ventures are looking at are based on older designs that may have become viable thanks to new materials, technology and faster computing power. General Fusion's Mowry cites the onset of high speed computing as a major reason that his company is moving forward. "A lot of the fundamental work and technical platforms have been created or developed by governments in national laboratories," Mowry says. "In the last 10 to 15 years, the computing power and data analytics have gone up enough to allow insights into the data that General Fusion generates."

It's the high speed computing power that also allows for General Fusion's preferred approach to generating fusion – precisely timed "pistons" that rapidly compress a plasma to create a fusion burst. For David Kingham, CEO of Tokamak Energy in the UK, a key technology has been the development of high temperature super conductors, which only started to be manufactured

COMPARED TO THE COLOSSAL EFFORT AT CADARACHE, CANADIAN FUSION COMPANY GENERAL FUSION'S OPERATION IS TINY... YET, IT IS THIS OPERATION THAT SEVERAL PRIVATE INVESTORS ARE BETTING WILL WIN THE RACE TO COMMERCIALISE NUCLEAR FUSION POWER

around 2011. These super conductors are needed to make the magnetic fields needed to contain a plasma, and do so in a relatively small space.

The ITER design, Kingham says, was developed before these conductors were available, and he suggests that ITER is wedded to a design that should have been abandoned long ago. It is for this reason, he says, that some scientists and engineers have drifted away from the big projects like ITER, in search of faster moving projects. Last year, ITER chief Bernard Bigot said the reactor will not see the first plasma test before 2025, while fusion won't happen before 2035.

While ITER celebrates its size, for the investors and CEOs of the small ventures, being small affords a flexibility required to overcome the immense technical challenges. By being small, numerous changes and iterations to a reactor design can be made at each step, rather than being committed to a gargantuan – but flawed design. New technology can be quickly incorporated and changes can be quickly made.

OPPOSITE
General Fusion is investing heavily in finding a solution to creating effective fusion technology.

RIGHT
Christofer Mowry, CEO of General Fusion.

COURTESY **GENERAL FUSION**

MOTIVATIONS FOR INVESTORS

The growth of a handful of companies led by scientists and engineers trying to build a commercial fusion reactor has opened the way for numerous investors to get involved. But it's not an easy field to deal with. How does an investor tell the difference between one approach to nuclear fusion from another, especially when both methods may have top-level scientists and engineers on staff?

Both Kingham and Mowry point to a staged model of funding as providing a means of assurance for investors. "We set out a plan to raise money in order to hit (technical) milestones. We first tackle a tough challenge, then raise more money," says Kingham. Such an approach allows investors to feel that their money is not just going into a science project with no determined outcome, or just into a research black hole with no bottom. It also potentially helps to get investors that are used to looking at much shorter, more defined timelines, to get onboard.

Venture capital funds SET Ventures and Chrysalix were both early stage investors in General Fusion, around 2009 and 2010. Both found out about the work of General Fusion through partners and decided to press forward. "We were compelled by the story (of General Fusion), using fusion technology in a cost effective manner. They look at it like it's not just a science experiment. We looked around, and there were not many other fusion ventures at that time," says Rene Savelsberg, CEO of SET Ventures.

Both SET Ventures and Chrysalix had to rely on third party experts to guide them on their prospective investment in fusion. In SET's case, Savelsberg says they went to an institute in the Netherlands linked to the ITER project for advice, holding a number of sessions with them before finally signing on. Chrysalix did something similar in Canada. "I don't think anyone can invest without outside experts," says Mike Sherman, managing partner of Chrysalix and now a board member of General Fusion.

That said, both CEOs and investors say that the pool of investors can now widen, as several ventures move from an early stage of development towards a more commercial stage. General Fusion has managed to attract investors ranging from private individuals (Jeff Bezos, billionaire founder of Amazon) to the sovereign wealth fund Khazanah Nasional.

Tokamak Energy in the UK counts tech investors such as UK billionaire and hedge fund founder David Harding, who famously brought scientific and mathematical rigour to the world of investing in the 1980s, making his fortune along the way. Also on board is Sir Martin Wood, founder of Oxford Instruments and a pioneer in superconductors. Kingham says that Tokamak Energy is up to 25 investors now, half of which are individuals and the other are institutional investors, and that a number of shareholders have invested on several rounds. "Ultimately, we need to raise more than €200 million to make the progress we want," Kingham says.

There are less than half a dozen serious, private nuclear fusion ventures worldwide that have received any investment. Though these companies will not publicly provide investment information, Dr Stephen Dean, president of Fusion Power Associates, a non-profit research and education foundation, estimates that about US$500 million has been invested in such ventures so far. He puts annual expenditures at about US$100 million. These are relatively small figures, but given the technical complexity and the high risk, high reward nature of fusion power, it could also be viewed as the right moment to plant a flag.

One big thing that has changed is the nature of the industry, says Chryslix's Mike Sherman. He points to two major shifts since Chrysalix put money down on General Fusion – an increase in the number of private fusion power ventures, and an increase in the urgency in the discussion about climate change. Fusion power was the subject of a recent documentary screened at the SXSW festival (a gathering of the Technorati) called *Let There Be Light*, which highlights both the difficulties with the ITER project, and the hopeful challenge mounted by General Fusion.

The discussion around solving the climate crisis has also brought on board impact investors. Canadian billionaire Jeff Skoll, who was the first investor in eBay and later financed a number of socially-oriented films, including Al Gore's 2006 documentary, *An Inconvenient*

Truth, has invested in Helion Energy, alongside Peter Thiel.

It may also be that some of the tech billionaires behind such daring ventures are also simply interested in making sure that progress on nuclear fusion is made, regardless of who wins the race. That may yield results for investors, even if they back the losing horse. "The intellectual property sitting with General Fusion is pretty valuable already," says Savelsberg of SET Ventures. "Every time we look, we see progress."

The end goal for all these ventures is a commercialised reactor, compact enough to be manufactured on industrial land and shipped anywhere in the world. Nuclear fusion relies on isotopes of hydrogen, readily found in seawater. Both Mowry and Kingham expect to be able to mass-produce their patented reactors for buyers globally. Kingham envisions manufacturing will take place on old docklands near London. By 2019, Tokamak Energy aims to get its newest reactor, the ST40 to nearly fusion gain
– meaning that almost as much energy is coming out as going in. From there, Kingham reckons the next step will be a reactor that could be a prototype for a commercial reactor – along with the funding to make it happen.

Both CEOs see their companies getting to commercialised fusion power by the 2030s. But optimism, however helpful, doesn't change the fact that fusion is hard to do. Nuclear physicists seem divided on whether the start-up approach to something so technically difficult can actually succeed. The fundamental question remains: can a small, investor driven start-up beat the juggernaut that is ITER?

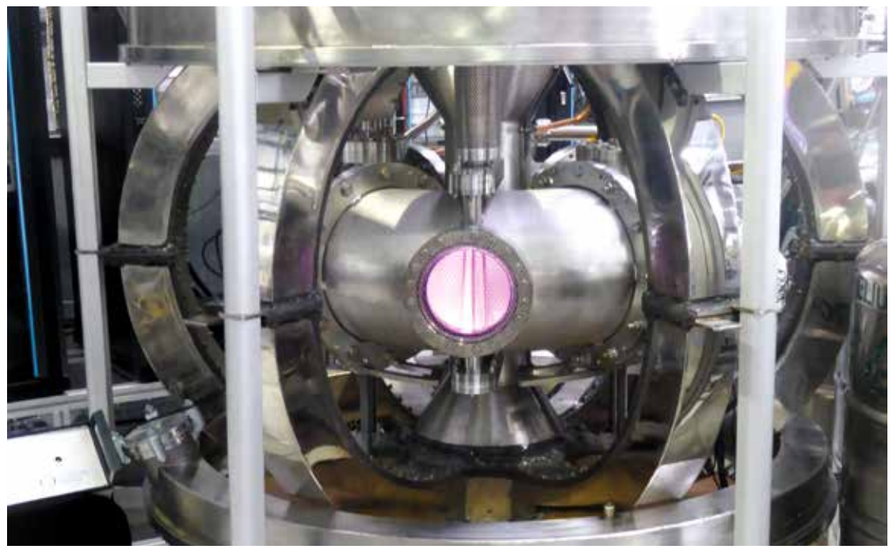
Then, there is the fact that fellow tech billionaires aren't all convinced of fusion's promise. Elon Musk has said that fusion power would be great, but that with solar, you have "indirect access to fusion power" already. And a new generation of nuclear fission scientists is also employing the start-up approach to the question of making nuclear fission, with its radioactive issues, better and more robust.

POWER PLUGS COMING TO ASIA

Should nuclear fusion power become a reality, one of the biggest beneficiaries would be Asia. China still gets the overwhelming majority of its electricity from burning coal and India is struggling to add power generation capacity. Renewables are part of the mix, but are still far behind overall requirements. Compact nuclear fusion reactors could also provide power to cities regardless of location. Mowry even speculates that compact nuclear fusion reactors could be located inside a city, which he says is perfect for densely populated Asia, though such a huge reordering of power distribution would be a challenge.

SHOULD NUCLEAR FUSION POWER BECOME A REALITY, ONE OF THE BIGGEST BENEFICIARIES WOULD BE ASIA

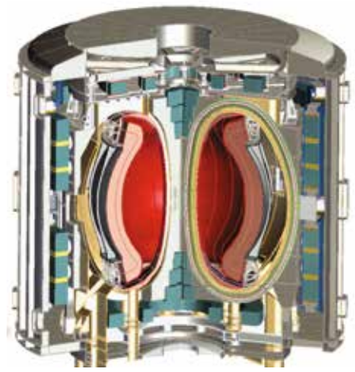
ABOVE AND BELOW
General Fusion's laboratory in British Columbia, Canada;Tokamak Energy's power module concept developed with Princeton University.



COURTESY **GENERAL FUSION**

General Fusion's Mowry indicates that, as of this fall, he will be touring Asia, looking for the next round of funding to take General Fusion through its next engineering challenge. Hong Kong is on his list of very probable destinations. David Kingham of Tokamak Energy UK is also interested in Asian sources of funding. So far, Tokamak Energy hasn't received any investment from Asia, but Kingham says he is in talks now with several potential investors in Asia.

For Hong Kong based investors, the opportunity to change the world, and get a piece of the action, is coming soon. If, by 2030, a couple of compact nuclear fusion reactors are powering Hong Kong, the investment will have been worth it. The only thing standing in the way is the question of how to keep a 100-million-degree gas contained and productive.



BETTING ON THE LONG SHOT

The world's biggest names in technology and innovation are seeing the light in fusion. For some, it may be a long shot bet on something really big, for others, it's the right thing to do. And for some, it's a bit of both.

GENERAL FUSION

Jeff Bezos Founder, Amazon
Net worth: US$80 billion

Khazanah Nasional Sovereign Wealth Fund, Malaysia
AUM: US$33 billion

HELION

Jeffery Skoll Co-Founder, eBay
Net Worth: US$4.2 billion

Peter Thiel Co-Founder, PayPal
Net Worth: US$2.2 billion

TOKAMAK ENERGY

David Harding, Founder, Winton Capital
Net worth: US$1.5 billion

Sir Martin Wood Founder, Oxford Instruments
Net Worth: Unknown

TRI ALPHA

Paul Allen Co-Founder, Microsoft
Net Worth: US$20 billion

Venrock Rockefeller Family Venture Fund
AUM (2014): US$2.6 billion