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The Thorium Alternative

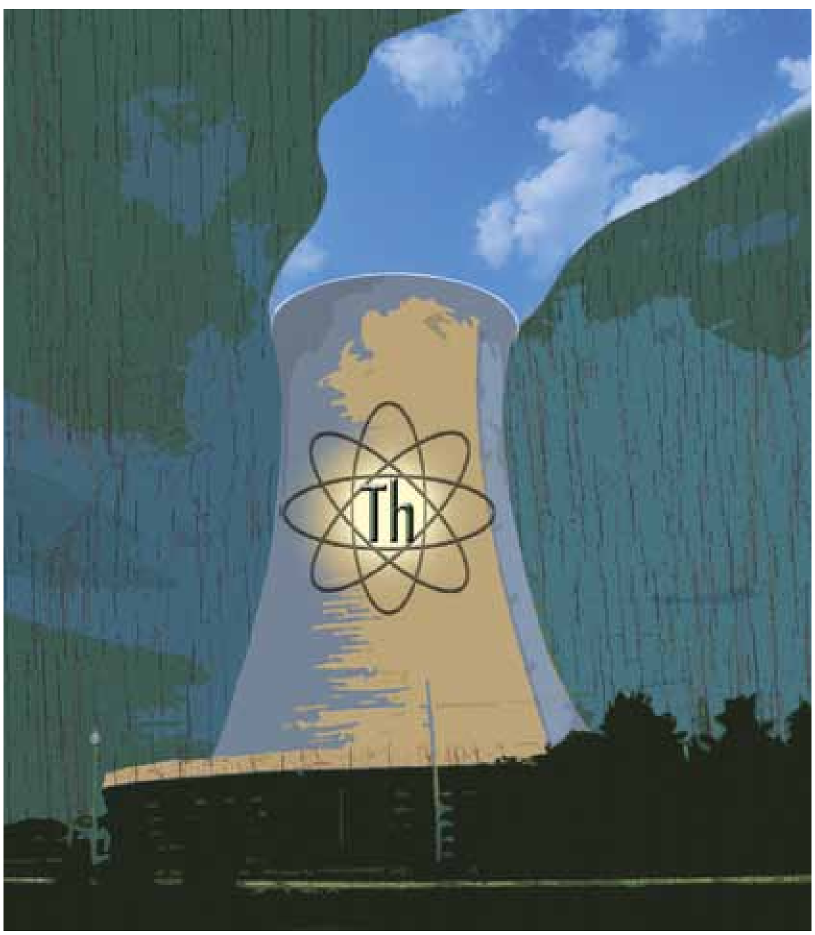
by Ben Daviss

At least one positive result came from Japan's Fukushima nuclear disaster: a renewed curiosity about the vast energy potential of the obscure element called thorium. Corporations and governments from Europe and Scandinavia to Brazil and Asia are now linking their energy futures to this mildly radioactive source of power.

Perhaps even more importantly, thorium holds the promise of tackling three of humanity's most urgent challenges.

China announced in February 2011 that it was launching a massive research and development program to derive energy from thorium to meet the first challenge: to supply commercial electricity to a world chronically short of power.

Second, the reality of global warming becomes less and less deniable every day – and now is made even more urgent by a 2011 study from the U.S. National Snow and Ice Data Center. The report forecasts that the planet's thawing permafrost could release as much carbon into the Earth's atmosphere by 2200 as humanity has put there since the beginning of the industrial revolution.



Anthony Freda / Dan Zollinger

But those who advocate an increased reliance on nuclear energy as the solution to human-caused climate disruption face four obstacles. One is the relative scarcity of the uranium that fuels nuclear reactors. A second is the risk of massive disasters exemplified by Chernobyl, Three Mile Island, and Fukushima only last March. Third is a lethal eternity of nuclear waste.

The fourth – and the third challenge that thorium can play a role in solving – is the issue of survival itself: nuclear waste from atom-powered electricity generators can be reprocessed into plutonium to make the weapons of our nightmares in a fractious world.

Thorium not only has the power to generate electricity through nuclear reactions less dirty than uranium's; its use also tamps down fears of nuclear proliferation because thorium-powered electric generators leave little or no useful fissile material behind. From the 1960s well into the 1980s, Canada, Germany, the US, and the UK tested thorium-based nuclear generation but walked away from the technology – not only because uranium was still cheap and relatively abundant in those days. The developed world also settled on uranium because nations had created a body of military and civilian technologies around it, and also because spent uranium from nuclear power plants could be turned into feedstock for the world's ever-growing arsenal of nuclear bombs. Now China, India, Australia, Czechoslovakia, and Brazil are among the countries investing their energy futures in the thorium alternative.

Thorium is generously scattered around the globe, usually found mixed in among rare earth metals, such as yttrium and cerium, and particularly plentiful in common monazite sands. (White beach sand can be as much as 14% monazite.) China currently has cornered the market in rare earths with most of the world's commercial mines, although Brazil, India, Norway, and the US also are well-endowed.

Until now, thorium has been only a problem – trash to be disposed of by mining operations sifting the rare earths from the geological detritus that envelops them. But mining companies' trash is an energy generator's treasure.

That's because thorium is four times more plentiful worldwide than uranium, can produce more than 100 to as much as 300 times the energy that can be coaxed from an equal volume of uranium, and yields less than one percent of the toxic waste. In an energy-generating reaction, as much as 99% of the thorium can be consumed, compared to typically 2% or less of the uranium that goes into a generating plant. Nobel physicist Carlo Rubbia estimates that a metric ton of thorium – about 2,200 pounds – would surrender as much energy as 200 metric tons of uranium or 3.5 million metric tons of coal. By one estimate, a golf ball-size lump of thorium could, in theory, deliver all the energy one American would use in a lifetime; and the US is thought to have enough thorium to maintain its current levels of energy consumption for 1,000 years. In contrast, cheap and easily accessible deposits of uranium ore are expected to be depleted within 50 years.

Just as important, thorium changes the economics of nuclear power. Because thorium is safer than uranium, a thorium-fired electric plant can be built at about a quarter of the cost per megawatt as a uranium-powered generating station. By various estimates, the annual fuel bill could be 2% or 3% of what it costs to keep a uranium-powered generator going. Based on results from test reactors built in North America and Europe during the 20th century, thorium could cut today's production cost of nuclear-generated electricity by 50% or more. That makes it an ideal fuel for the new generation of modular, portable nuclear reactors now on the drawing boards. (Details in the Spring 2012 *Trends Journal*.)

Country	Estimated reserves in metric tons
Australia	300,000
India	290,000
Norway	170,000
United States	160,000
Canada	100,000
South Africa	35,000
Brazil	16,000
Malaysia	4,500
Other	95,000
World total	1,200,000

To the extent that the word "safe" can apply to a nuclear fuel, it does to thorium. The metal isn't fissile, which means that it can't spontaneously combust when a critical mass of it is piled up together. As a result, a thorium reactor can't melt down like a Chernobyl or Three Mile Island. Because thorium isn't fissile, it needs a nuclear spark to set it off. This usually takes the form of an exterior source of neutrons, which are neutrally-charged atomic particles. The source of neutrons used in some previous thorium experiments: spent uranium from nuclear power plants. "Thorium reactors could be used to burn much of our current stockpile of nuclear waste," according to John Kutsch, executive director of the Chicago-based Thorium Energy Alliance. While uranium's radioactive waste is hot for at least 10,000 years, most ash from a thorium reactor would cool in no more than 300 years.

Perhaps even more important, the waste from a thorium reactor isn't likely to be processed into a weapon. The waste contains the isotope uranium 233, which is as radioactive as plutonium, but far less of it and it's also less desirable as a bomb payload: the 233 is bonded with uranium 232 and the two are fiendishly difficult to separate. In addition, 232 emits clouds of lethal radiation that make it hard to process and also would damage a bomb's internal electronic controls. With a weapons industry already built around plutonium, relatively little development work has been done to weaponize uranium 233 because of the technical challenges involved.

Decades of tests have validated thorium's promise. In the 1960s, the US's Oak Ridge National Laboratory conducted a five-year test of the thorium fuel cycle, in which thorium is bombarded with neutrons, usually from a uranium isotope, plutonium or other fissile material. The thorium absorbs a neutron, becomes unstable, and decays into an unstable byproduct called protactinium that itself decays to become uranium 233 – the fuel that perpetuates the reaction and also is burned to make the heat that boils fluids and spins turbines. The chain of reactions also produces the deadly uranium 232 isotope, which competes with thorium to absorb neutrons; but when an atom of 232 absorbs a neutron, it becomes uranium 233 – the isotope that continues to power the energy-producing reaction. Once begun, the process needs only more thorium to keep going – never additional uranium: the uranium 233 isotope generated by the reaction spews enough neutrons to keep the process going.

In evaluating its thorium test reactor's performance, Oak Ridge reported that:

- the amount of waste fission products was 10 times less than conventional light-water uranium-powered reactors;
- the waste required containment for one one-hundredth of the time until safe for contact with living things, compared to uranium-based waste;
- a thorium reactor can "burn" some radioactive waste that otherwise would have to be sealed and stored for millennia;
- thorium reactors could be made small enough for use on a ship or even an airplane.

The last point is championed by the Thorium Energy Alliance and is a shift that would decentralize electrical generation. Thorium advocates envision a prototypical plant perhaps 180 feet long, 75 feet wide, and 50 feet tall that could produce 50 to 75 megawatts and be built next to a mine or an auto plant. Because the generators could be built simply, without the monstrous cooling towers and ponds that accompany uranium-based generating plants, they could be scaled down to the size of a single megawatt, be built in a factory, and trucked in pieces to a site, much like a modular home. Itinerant generating plants could live on flatbed trucks and be used as a temporary power source at a building site or a military staging area. By 2030, advanced ceramics and other super-tough materials should be available that can guarantee the integrity of these traveling reactors and contain any radioactive waste they produce.

Thorium also can be combined with uranium, or even replace it, to make up the fuel rods in existing nuclear generating stations. "But that's like putting ethanol in your Corvette," says Kutsch. "It can be made to work, but it's not the fuel that the power plant was designed to run most efficiently on."

Instead, China and others are reviving the design tested in the last century: the molten salt reactor or MSR. Many molten salts, such as fluoride, used as a coolant can withstand the temperatures inside a nuclear reactor without building up high pressures, unlike water, and becomes a key safety factor that eliminates much of the plumbing and other design elements that snake through uranium reactors. Thorium can be dissolved in the fluid salt itself, which eliminates the need to fashion fuel rods. Putting thorium into the fluid also burns the fuel more evenly, eliminates much superstructure within the reactor, and allows nuclear by-products – such as isotopes used in nuclear medicine and gases for industrial processes – to be easily siphoned off on the fly. In contrast, uranium-powered reactors periodically need to be shut down and "cleaned": the surfaces of the uranium fuel rods become clogged with waste products and have to be taken out, replaced with new ones, and reprocessed.

It's not only China that's seeing the advantages of thorium. Other countries are now experimenting with thorium technologies to shape their energy futures:

Australia and Czechoslovakia A consortium of private companies from the two countries is investing $300 million to build a 60-megawatt prototype molten salt reactor in Prague. Recognizing that Australia has as much as 18% of the world's thorium reserves, the current prime minister is working to repeal the nation's 30-year ban on building thorium-fueled power plants.

China China's thorium reserves may rival India's and, according to the Thorium Energy Alliance, China may have as much as seven million pounds of thorium already sitting in waste piles from rare earth mining operations. In February 2011, China announced a new program to design a state-of-the-art LFTR reactor. The country already had announced plans to build at least 20 new nuclear generating stations around the country. China will take no partners in the project and has made it plain that it plans to own and control as much intellectual property as possible around thorium-based energy.

India India's newly designed Advanced Heavy Water Reactor uses thorium and a bit of uranium as fuel, minimizing the danger of accidents and offers "enhanced proliferation resistant characteristics". India's Atomic Energy Commission foresees hundreds of these small-scale plants dotting the countryside – powering localized industrial development, cooling and lighting rural homes, and desalinating and purifying water. India has been in discussions with many of the world's leading companies doing business in nuclear technology, including General Electric, Westinghouse, and the NASDAQ-traded, Virginia-based Lightbridge Corp. India expects to offer thorium technology for export "in the near future."

Israel In May 2010, researchers at Ben-Gurion University and the Brookhaven National Laboratory in New York received a three-year Energy Independence Partnership Grant from the United States-Israel Binational Science Foundation. The team is using the funds to create a self-sustainable thorium-fired nuclear fuel cycle – one that will produce as much fuel as it consumes, which isn't possible with uranium.

Norway is estimated to have the third largest thorium deposit in the world. The country has been lulled by its wealth of hydroelectric power and offshore oil. But with its North Sea oil fields running low, it may gradually turn to thorium energy after other countries have proven and commercialized a new generation of reactors.

Sweden Vattenfall, a Swedish utility, has partnered with Norwegian start-up Thor Energy to conduct a series of tests to assess development of thorium reactors. Thor Energy is the latest creation of Alf Bjorseth, Norway's leading entrepreneur in green power.

Even the US is taking steps. Congress is now considering bills to lift the ban on domestic mining of rare earths – a ban originally imposed because the mining operations created radioactive waste in the form of thorium. "The nation would gain the rare earth minerals it needs to manufacture electronic components and the world would have more thorium – which is now becoming a valuable by-product instead of a waste problem," Kutsch says.

In addition to major firms and national energy agencies, entrepreneurs are hoping to turn thorium into energy – and profits. Thorium One is a Vancouver R&D venture with offices in Johannesburg, South Africa, creating a process to mix thorium with uranium waste for use as reactor fuel. Thorenco LLC in San Francisco is looking for backers to help make a prototype of its portable, factory-built thorium reactor that could be shipped to remote locations to supply heat and electricity. Every six to ten years when the fuel needs replacing, the core can be shipped back to the factory to be cleaned out and reloaded.

But, despite its allure, thorium's road ahead isn't entirely free of bumps. The promise of relatively cheap uranium – around $20 a pound at current prices – could lull many countries or companies to procrastinate about making investments in basic R&D for another few decades.

Also, the thorium fuel cycle does produce radioactive waste in the form of isotopes. Most of thorium's isotopes decay in a matter of minutes or days, although one form lingers for 7,300 years and another for 14 billion – roughly the estimated age of the universe. The good news is that thorium's isotopes produce only alpha radiation, which is so weak that it can't penetrate human skin; it causes harm only if ingested or inhaled. In contrast, an array of uranium's isotopes endure for eons and produce gamma rays, which cause radiation sickness, a panoply of cancers, and other illnesses.

However, the thorium fuel cycle also produces an isotope of the radioactive element thallium, which emits cancer-causing beta radiation. Even though the isotope becomes harmless after about five years, the waste still must be contained and guarded. The presence of radioactive waste in any form will fuel ongoing political contention over nuclear power in western countries, slowing commercialization of thorium plants there. And, of course, any new nuclear technology requires a period of cautious research, trials, and evaluation.

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Still, some believe that two or three years of computer-based design and simulation, followed by another two or three years of prototype testing, will yield commercial, thorium-fueled electricity before 2020.

Trendpost: *Even after Fukushima, nuclear power development continues in Asia, driven largely by the relative advantages of thorium as fuel, improved design and technology, and the growing urgency of the need to replace dwindling petroleum reserves and mitigate climate disruption. Countries with central decision-making authority over their energy industries will design and test the first generation of commercial thorium nuclear reactors before 2020, causing uranium as a fuel for power plants to gradually be abandoned by new designers. In the West, where organized opposition to nuclear energy is as old and entrenched as the nuclear industry itself, resistance will fade – gradually at first, then at a growing pace as key thought leaders change their stance. (Stephen Tindale, the former UK director of Greenpeace, has become a public, though reluctant, advocate of nuclear power, influenced in part by the growing interest in thorium as a fuel.) The intellectual property surrounding thorium energy technology will be owned largely by governments and government-owned utility agencies, although private companies in the West will hold key patents and interests.* ■