FRONTIERS

Watts New in Fusion Power?

By SPENCER SHORKEY

MILLERS FALLS – Nuclear fusion research and development has been gaining a lot of steam (or should I say plasma?) in the past year, with significant milestones achieved by projects in four countries: the US, China, England, and France.

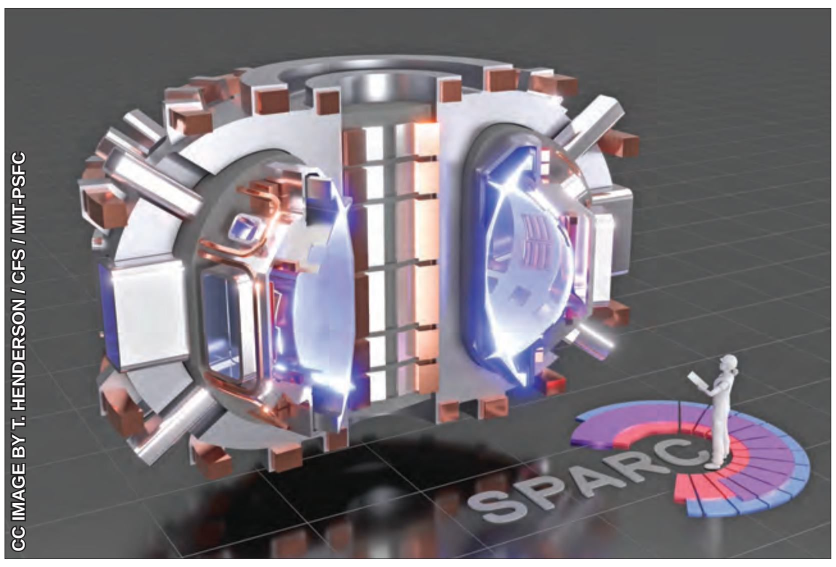
The sun, as you may know, is the gigantic faraway nuclear fusion reactor that continually bombards the solar system with light. Our planet receives about one-billionth of all the sun's light output, with about 100,000 terawatts (TW) of power reaching Earth's surface at any given moment. About 1% of this is transformed into wind currents in our atmosphere, and may be feasible in theory to harvest at least 2% of this wind power, amounting to 72 TW. The green things that cover our planet absorb less than 0.1% of sunlight, amounting to about 60 TW of power harnessed by the biosphere.

Mankind's total power utilization comes in at about 20 TW, though this comes largely from fossil fuels.

There is plenty of solar and wind power yet to be harnessed by mankind as we transition to clean energy, but a longstanding goal of advanced nations has been to directly harness nuclear fusion energy on Earth in manmade reactors. Governments and international research teams have labored for numerous decades engineering reactors capable of recreating conditions similar to in the sun, where insanely high pressures – up to 250 billion times Earth's atmosphere – and temperatures (15 million °C) create a special state of matter, called *plasma*, which is necessary to fuse small atoms into bigger atoms.

A related technology, nuclear fission, works in the opposite manner, splitting larger atoms into smaller ones. Atoms are categorized by their number of protons: hydrogen has one proton; carbon has six, aluminum has 13, gold has 79, and uranium has 92 protons. Physics works out such that atoms smaller than iron (26 protons) can generate energy by being fused *together* (nuclear fusion); atoms larger than iron yield energy when split *apart* (nuclear fission).

One kilogram (kg) of refined uranium yields 24 gigawatt-hours (GWh) of heat energy if fully reacted by nuclear fission; however, only about 45 MWh can be recovered by conventional fission reactors as electricity. Nuclear fusion of 1 kg of the hydrogen isotopes deuterium and tritium could theoretically yield up to 94 GWh, but net energy recovery of controlled fusion has not yet been achieved.



An artist's rendering of the SPARC reactor at MIT.

Fission reactors have been in commercial operation since the 1950s, while commercial fusion, according to conventional wisdom, has always been 30 years away. Conventional wisdom also tells us that it's easier to break things rather than to make things, which pretty much applies to atoms too. It is extremely challenging to generate controlled fusion conditions to begin with.

The most widely used fusion reactor design is a ringlike assembly of circular magnets designed to heat and pressurize hydrogen plasma as it traverses the loop at high speeds. These magnets require huge amounts of power to run. China's Experimental Advanced Superconducting Tokamak (EAST) reactor uses up to 7.5 MW of heating power to generate 100 million °C plasma in a 3.5-tesla (T) magnetic field.

EAST has been operational for nearly two decades, during which time significant advancements were made in the capacity of its cooling system, enabling it to hold a 70 million °C plasma for nearly 20 minutes this January. In future designs, EAST will continue to improve its cooling system, enabling it to create larger and more efficient plasmas. Though reports on how exactly EAST aims to harness the heat energy from the system are limited, its advancements in high-performance fusion thermal management bode well for that end goal.

The Joint European Torus (JET), housed in England, and the under-construction International Thermonuclear Experimental Reactor (ITER) in France are closely related international fusion projects. JET has run short plasma experiments, a few seconds a time, for the past few decades, and holds the record since 1997 for closest-to-breakeven power output, having produced 16 MW of peak power using an input of 24 MW of heating power, a "Q" ratio of 0.67. Q higher than 1, a net power gain, is yet to be achieved. This year JET sustained a Q of 0.33 for five seconds, validating the fuel composition planned for the ITER reactor.

ITER is a scaled-up version of JET, increasing the magnetic field 11.8 T and heating power to 370 MW. ITER aims to reach 150 million °C, and achieve a Q of 10, meaning a tenfold higher power output than input. ITER is slated to finish construction and begin experiments around 2025, and will cost about $50 billion. Reactor hardware is being installed, and the reactor segments will be welded together this summer.

Though the ITER system will not be capable of turning excess heat into electricity, ITER's planned successor, the EU-DEMO, is planned to achieve a Q of 25, yielding 2,000 MW of heat energy, and would be coupled to a 790 MW steam turbine to fully realize fusion electricity generation. EU-DEMO is planned for operation in 2051, and its price tag will definitely be higher than ITER's, though cost is expected to decrease for production-scale versions.

In our own backyard is SPARC, a fusion reactor collaboration between the Massachusetts Institute of Technology (MIT) and Commonwealth Fusion Systems (CFS). SPARC leverages a new magnet design that is both more powerful and more efficient than that used by ITER. Using a 12.2 T magnetic field, the project plans to hit Q = 11, comparable to ITER. However, it will require much less heating power (25 MW), generate hotter plasmas (200 million °C), and be 65 times smaller in size.

SPARC plans to generate its first plasma around 2025, with plans for next-generation 200 MW reactors actually putting power on the grid by 2033. The cost of these reactors is unclear, though it would likely be less than ITER, given SPARC's high-efficiency magnets.

Nuclear fusion may be capable of gigawatt-scale power outputs, but the reactor costs may be in the tens of billions of dollars, translating to well over $10 per watt of capacity. Comparatively, covering less than 2% of the Sahara desert with solar panels could yield around 20 TW of power – mankind's annual consumption. The cost of such a deployment would in theory amount to about 30 cents per watt of power capacity. And while Massachusetts has a limited supply of solar, plans to harness offshore wind supplies, estimated to cost about $30 to $50 million for each 13 MW-rated turbine, come out to about $2 to $4 per watt.

Though fusion may prove a viable technology in coming years, its full-scale implementation is likely much further out, as many known and unknown engineering challenges remain, particularly on the side of continuous operation and harnessing of the energy. It is not safe at all to bet on fusion technology to help substantially in clean energy transitions of the coming decades, given the uncertain timeline. Reactor costs would also have to come down at least an order of magnitude to be competitive with wind and solar.

Still, fusion is probably finally less than 30 years out, and the first Q > 1 plasmas may well be achieved in our own state. It will be exciting to see how these major projects advance in the coming decade.

MEDICINE

It's Maple Syrup Time!

By CATHERINE DODDS, MD

TURNERS FALLS – As a native of Wisconsin and a relatively recent transplant to western Massachusetts, I am delighted by the yearly cycle of maple sugaring season. Indeed, what we lack in quantity compared to, say, Quebec or Vermont, we make up in local passion about our maple products.

This got me thinking about the medical side of maple.

My next statement may seem odd to anyone not in the medical field, but for most doctors, the words "maple syrup" are as likely to make us think of a rare genetic disease as we are to think of pancakes. In medical school, we are all taught about maple syrup urine disease, even though we're unlikely to actually see it, since only around 1 in 100,000 people has this disease. Maple syrup urine disease is so named because specific genetic defects in how the body processes amino acids (the building blocks of protein) cause the urine to smell distinctively like maple syrup. An unusual and memorable symptom, indeed!

Back to the good stuff. Fundamentally, maple syrup is sugar: the raw sap less so, the hardened candies or granulated sugar more so, and syrup in the middle. But I don't want this maple-themed commentary to be a total downer about diabetes and the risks of high sugar consumption. That is common sense to everyone, and moreover would be unfair to the glory of our local maple trees and the hard work of those who tap them each winter.

The internet at large has been more interested in the potential health benefits of maple syrup than the medical community. The few scientific or medical studies that have been published about maple syrup are more to do with chemical composition analysis than medical uses. So there's a big caveat in that my comments here are opinion, not medical evidence.

In contrast to regular table sugar, maple syrup contains varying – though generally small – amounts of several essential nutrients including manganese, potassium, calcium, zinc, magnesium, copper, thiamine (vitamin B1), riboflavin (vitamin B2), iron, and phosphorus. It also contains antioxidants, chemicals that help reduce cellular damage which have been linked to cancer prevention and immune function. Darker maple syrup is richer in antioxidants than lighter hues.

In the ongoing controversy about which sweeteners are best – or at a minimum the lesser of evils – an argument could be made that maple syrup is healthier than many of the alternatives. It has nutrients that regular white or brown sugar, generally derived from sugar cane or sugar beets, does not. It has fewer calories per volume and a lower glycemic index than both table sugar and honey.

So how best to enjoy our local maple syrup? Personally, I recently enjoyed the extra dark variety from Bergeron Sugar House, drizzling a few drops into some Vermont cheddar that was part of the sourdough bread, egg, and cheese sandwich I made for a lovely Saturday breakfast.

The key health lesson about maple syrup is that a very small amount goes a long way.

Naturally-derived sugar from maple sap is still sugar, and smothering foods in gallons of maple syrup is not going to be healthy for any of us. Those with diabetes or tooth decay would do best to avoid any added sugars, whether table sugar, honey, or maple syrup. But for the rest of us, that tiny pour of maple syrup or sprinkle of maple sugar can brighten up just about anything on our table, particularly this time of year.

Catherine Dodds, M.D. lives in Turners Falls.