**There’s always a huge temptation in videos about Nuclear Fusion to quote the hackneyed old cliché that it’s a technology that’s only twenty years away, and always will be. (use your own quote from your fusion video?)**

**So, I promise you this time, I definitely will not be using the cliché that nuclear fusion is only twenty years away, and always will be.**

**Because to be completely honest, I’m not actually sure the picture is even quite as optimistic as that.**

**There’s been a lot of press interest in apparently major breakthroughs in nuclear fusion recently, and just to be clear, no one would be more delighted than me to see commercially viable electricity generation from fusion power become a reality, because it would pretty much solve the world’s energy and resource scarcity problems in one fell swoop.**

**So, you know, I do see the appeal, don’t get me wrong.**

**The slight wrinkle is that the whole structure for gauging how well the various research centres are progressing appears to be built on what a cynical person might describe as wilful mass delusion.**

**So, what’s going on?**

**Hello and welcome to Just Have a Think,**

**It’s a very compelling story isn’t it, the whole Nuclear Fusion thing…**

**The dream is to reproduce the reaction that happens in our own sun, where lighter elements like hydrogen and its isotopes of deuterium and tritium, are converted into heavier elements like helium. As the nuclei of these lighter elements are fused together, they emit neutrons, and very large quantities of energy. We’re talking about energy levels about ten million times greater than we currently achieve by burning fossil fuels. Nuclear fusion is, in fact, the process by which all elements in the Universe were created in the first place, which is why that nice man Mr Moby says we’re all made of stars.**

**Lovely.**

**In theory, by replicating that process in a controlled environment here on earth, you could get a relatively cheap and essentially unlimited amount of energy without any greenhouse gas emissions and with only a tiny fraction of the radioactive nuclear waste produced by the global nuclear fission industry. And all of this coming from good old H2O.**

**According to the Dutch high energy physicist L.J. Reinders, who produced this mammoth, nine-hundred page tome, there’s an awful lot of hydrogen’s heavier isotope, deuterium, in our oceans. To be more precise, one in every six thousand four hundred and twenty atoms of hydrogen is deuterium. And it can literally be scooped up, isolated and utilised. As Reinders points out, no mines are needed, no transport of fuel to power stations will be required, because you’ll just build a power plant close to every coastline, where your water supply will be effectively infinite. And the fact that the fusion process itself produces no greenhouse gas emissions, means it could be the perfect solution to our present-day climate emergency.**

**Almost sounds too good to be true doesn’t it. And that’s because it quite probably is.**

**The best funded experimental fusion reactors in operation today use designs known as tokamak and stellarator. They're both examples of what's called magnetic confinement technology. The International thermonuclear experimental reactor or ITER has been in development since 1985. When construction work is finally completed in the latter half of this decade, it’ll be the biggest tokamak machine on the planet. It originally had a budget of five billion Euros but it’s now looking like it’ll burn its way through more like twenty billion with no guarantee at all of a successful outcome. It's basically a bunch of incredibly strong magnets that contain a huge donut-shaped stream of super-heated plasma. The plasma is contained and compressed by the magnets, until the nuclei fuse together and release their energy as heat. That heat gets trapped in a specially created blanket that sits around the reaction chamber. Then, theoretically, it’s just a matter of piping that heat into water to create steam that goes across a turbine and drives a generator that makes electricity.**

**Sounds quite straightforward in principle but applying those principles to the real world has proven to be anything but easy. First of all, getting plasma up to a temperature that’s many times hotter than the surface of the sun and keeping those streams of plasma in place long enough for the fusion reactions to take place is extremely challenging. China holds the current temperature record with their Experimental Advanced Superconducting Tokamak, or EAST, which, in twenty-twenty one reached a hundred and sixty million degrees Celsius. That’s more than ten times hotter than the sun’s core. So, you know, pretty impressive. But they only managed it for twenty seconds and the power required to achieve it was enormous, which is something we’ll come back to in a moment.**

**In late December twenty-twenty one another experimental tokamak device called the Joint European Torus, or JET near Oxford in the UK, achieved what they claimed to be the highest sustained energy pulse ever created. Using a fuel made of equal parts deuterium and tritium, the JET tokomak produced fifty-nine megajoules of energy over a five second fusion pulse. That’s about enough energy to boil sixty kettles and it’s twice the amount they achieved in their last record-breaking attempt. But that previous record was set way back in nineteen-ninety seven, so it’s taken twenty five years to achieve this level of progress. The experiment achieved a ratio of energy out to energy in, which the fusion community call Q, of zero point three-three over the five second interval. And to be clear, that means the energy they got out was only one third of the energy they put in. And the Q they were referring to was specifically Q plasma, which in Nuclear Fusion speak means the ratio of energy going into plasma to energy coming out of plasma. It doesn’t account for any other energy requirements for the overall system, which is something else we’ll come back to later.**

**You may well also have seen an announcement in twenty-twenty one from the US Department of Energy’s National Ignition Facility who used a different technique called Inertial Confinement, using laser energy, instead of the magnetic confinement technique used in tokomaks. They achieved a Q plasma of zero point seven. It was big news at the time and the fusion community was very excited by what they saw as a significant breakthrough. It meant that seventy percent of the energy that went into the plasma came out again as a result of the fusion reaction. OK, so that’s getting another step closer to 1 for 1 right? Well, not really, because we’re still only talking about the energy in the plasma here, not the entire system, and the pulse lasted for less than four billionths of a second, so I wouldn’t go trying to switch your energy supplier to Fusions R Us just yet!**

**Part of the problem is that, as well as keeping them incredibly hot, you also need to keep your plasma particles moving in the right direction. The magnetic field in a tokomak’s donut shape is stronger in the middle and weaker at the edges, so there’s a tendency for particles to drift off course and hit the containment walls. And once that happens the reaction is over.**

**Stellarator reactors are an attempt to overcome this problem. Open up one of these devices and you’ll find the weirdly contorted twists of its vacuum chamber and containment magnets. It’s a shape so complicated that it had to be designed on a supercomputer at the Max Planck Institute in Germany and welded together by precision computer guided robots. There are 50 magnet coils in here, each containing over a kilometre of superconducting cable weighing six tons, designed specifically to force particles through regions of high and low magnetic fields so that, in theory, the effects of the two cancel each other out and keep the plasma away from the containment walls.**

**But whichever design you look at, the fact is that firing up and running all the components of these systems requires a massive amount of auxiliary power, which is not reflected in that Q plasma number we just looked at. So, to truly consider how close the fusion bods are getting to a machine that can actually produce useful electricity that you and I can use to make a cup of tea, you have to look at what’s called Q total. Sabine Hossenfelder is a physics PhD and Research Fellow at the Frankfurt Institute for Advanced Studies in Germany. She also runs a YouTube channel called Science Without the Gobbledygook, which no doubt many of you are already subscribed to. Sabine made a brilliant video back in October twenty-twenty one explaining the whole Q thing, so if you want the deep dive then I’ll leave a link to that video in the description box below.**

**In very basic terms though, if you’re an investor looking to build a commercially profitable power plant then you obviously need to know the total amount of energy required by the entire system compared to the total amount of useable electricity your system will send into the grid. That’s where Q total comes in . It takes into account all the power required to run, cool and maintain the enormous magnets and all the other electrical and control systems that keep the reaction going. It also factors in the efficiency of converting heat into steam and driving the electrical generator, which is likely to be somewhere around fifty percent.**

**The ITER reactor is designed to have a power generation capacity of five hundred megawatts when it’s completed and the team claim to be aiming for a Qplasma of 10, which is more than fourteen times greater than anything anyone has so far achieved. But, according to ITER Head of Electrical Engineering, the whole system would actually require four hundred and forty megawatts of input power to achieve a fusion generation capacity of five hundred megawatts, so the Q total in that case would be five hundred over four hundred and forty, which is about one point one four. Now that’s not earth shattering but it’s still better than break even, right?**

**Well, no, because we still have to apply that heat to electricty conversion efficiency of fifty percent. So, now we’re down to a Q total of zero point five seven. So even assuming that ITER does indeed one day achieve its goals, which by the way it’s not anywhere close to even after thirty-seven years of hard work, then it would still be consuming almost twice as much energy as it produces. And if we apply all those numbers to the headline grabbing Qplasma of zero point seven that the US National Ignition Facility announced, even if their lasers were measurably more efficient than the magnetic containment methods of tokomaks and stellerators, you’re still left with a Q total that’s almost certainly going to be far less than zero point one.**

**And here’s another little reality check that I doubt the fusion bods are keen to trumpet from the rooftops. Just using deuterium to drive the fusion reaction doesn’t cut the mustard. To reach even the modest numbers we’ve looked at today, fusion reactors have to add tritium to the mix, like I mentioned earlier with the European JET facility. The combination of tritium and deuterium results in a far higher production of neutrons from the fusion reaction. But tritium is not abundantly available like deuterium. It’s much rarer and much more expensive. And unlike deuterium, it’s dangerously radioactive. If full scale commercial fusion reactors ever came into existence, then to get enough tritium to make the reaction work they’d need to breed it in the reactor by allowing some of the neutrons created by the fusion reaction to smash into atoms of another element, like lithium, within the walls of the blanket that surrounds the fusion reactor. Then there would have to be some way of extracting that newly created tritium from the blanket and feed it back into the reactor, all without disrupting the magnets or the flow of the plasma. Two small problems with that idea. Firstly, it’s never actually been demonstrated to work in the real world, and secondly, splitting atoms is not a nuclear fusion process, it’s a nuclear fission process. That inevitably means that any prospective new fusion power plant of the future would be subject to all the same tortuous and time-consuming regulatory constraints that tend to cause such costly overruns in todays nuclear fission power plants.**

**I have to say I really admire the tenacity and dedication of the research scientists striving to achieve the ultimate energy solution for our planet, and I really do hope that one day in the future, our descendants will enjoy the fruits of their labour, but it looks very unlikely to happen in my lifetime and right now we’ve got eight years to wean ourselves off fossil fuels, so I can’t help wondering whether the tens of billions of dollars being pumped into fusion research around the world might be better spent on more immediate solutions that are already in place and well proven.**

**Now, I’m quite sure that many of you will have your own very strong views on the subject of nuclear fusion, so if you do then as always, feel free to jump down to the comments section below, and leave your thought there.**

**That’s it for this week, though.**

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**As always, thanks very much for watching, have a great week, and remember to Just Have a Think.
See you next week**