**If you have even a passing acquaintance with this channel, you’ll know that I’m constantly banging on about the next ‘exciting battery breakthrough’.** **They’re coming at us thick and fast these days, aren’t they?**

**According to this recent article, having started at virtually zero in 2017, global battery energy storage capacity has grown so exponentially that by 2025 it's projected to surpass the mighty pumped hydro as the largest energy storage medium in the world.**

**Now, of course, just like all the other so-called ‘green’ technologies, batteries are not a silver bullet that’ll solve the climate emergency. I’m often accused of believing that technology alone can drag humanity out of its current existential predicament, which always makes me wonder whether those critics have watched any of the dozens and dozens of videos I’ve made explaining quite specifically why technology alone CANNOT drag humanity out of its current existential predicament. There are myriad other problems and challenges that we’ll need to overcome in the coming decades. But batteries ARE definitely a thing. And they‘re a thing that’s not going away. The tricky challenge with so many new developments popping out of labs all over the world right now, is to work out which ones are legitimate contenders and which ones are no more than delusional hopium on the part of their inventors.**

**Fortunately, a group of proper grown-ups with impressive credentials and doctorates, and all that lovely stuff, recently conducted a study of what they see as the most likely challengers to the lithium-ion overlord.**

 **So, I thought I’d spend a bit of time having a look at their findings.**

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

**The study in question comes from the world-renowned Fraunhofer Institute for Systems and Innovation Research in Germany.**

**It’s called ‘Alternative Battery Technologies – Roadmap 2030+” and it’s been developed as part of a project called BEMA 2, funded by the German Federal Ministry of Education and Research, or BMBF.**

**I won’t attempt to read out what the acronym BEMA stands for in German because I have a pathological aversion to making a complete tit of myself, but I’ve written it out on screen here so you can see what I mean.**

**Anyhow… the clever boffins at Fraunhofer highlighted four distinct technology families for their study, and then drilled down into each category to look at the different flavours available within them. Obviously the grand-daddy of the metal-ion category is lithium-ion.**

**We’ve looked at it and its close relative sodium-ion on several occasions, including the recent video about Natron in the USA, which you can jump back to by clicking up there.**

**Both those technologies are already on the market, so if we consider them in terms of the industry standard Technology Readiness Level ladder, they both sit right up there on the top rung.**

**But there are a couple of other options in this family that the Fraunhofer team say are worth considering. First up is Magnesium-ion.**

**Magnesium is a highly abundant material, and its chemical composition gives it a relatively high theoretical energy capacity. The challenge that developers are currently grappling with is finding the optimum combination for the cathode and anode materials.**

**The exciting bit, if you’re a battery chemist, is that magnesium-ion cells are intrinsically safe, partly because they don’t tend to promote the growth of the dreaded dendrites that can afflict lithium-ion batteries.**

**And partly because magnesium itself has a high auto-ignition temperature of four-hundred and seventy-three degrees Celsius compared to lithium’s one-hundred and seventy-nine Celsius.**

**That means ultra-fast charging times are a very real possibility. Magnesium is also less reactive to air than lithium because of its self-passivating behaviour.**

**Even more encouraging is the fact that metal oxideconfigurations are achieving good operating voltages between two-point-four and three-point-nine volts, and they look like they’ve got the potential to reach energy densities of around six-hundred and fifty Watt-hours per kilogram, which is almost three times higher than the best current lithium-ion technology.**

**The less exciting bit, if you’re a battery salesman, is that Magnesium-ion batteries are still at the fundamental research stage, which means they only reach rung number three on our Technology Readiness Level ladder**

**Zinc is another interesting option in the metal-ion family. Zinc is an already well-established raw material in global supply chains with an availability about ten times higher than lithium.**

**There’s also a very good recycling industry in place for Zinc, which ticks an important sustainability box.**

**And Zinc is pretty stable in water too, which means battery chemists can use benign aqueous electrolytes instead of the slightly nasty organic solutions used in lithium-ion.**

**The trouble is, they only currently achieve a potential difference of between one and two volts, which is significantly lower than lithium-ion. Energy density is lower as well. Even the long-term projection is for a gravimetric density somewhere between fifty and a hundred-and-twenty Watt-hours per kilogram, so we’re probably not looking at the future of electric mobility here.**

**Having said that, water-based electrolytes are non-flammable, so a zinc-ion battery will be a very safe battery, and there may be some applications where that gives it the edge, for example in utility-scale stationary energy storage or as a direct replacement for lead acid batteries.**

**Just like magnesium though, Zinc-ion is only at the very early stages of its development.**

**There are a lot of challenges to overcome, including hydrogen generation at the anode which can cause loss of zinc-ions, and unwanted side-reactions as the zinc-ions intercalate, or nestle, into the anode materials. For all those reasons, Zinc joins magnesium on rung number three of our TRL ladder.**

**A more recent development has been in Aluminium-ion batteries. Aluminium is a metal we’re all very familiar with. It’s highly abundant and already one of the most recycled materials on the planet.**

**What’s attracting the battery chemists though is the potential of aluminium-ion to be used as a link between lithium-ion batteries and so-called hybrid-ion-capacitors. That’s because they can achieve a power density of nine thousand Watts per kilogram, which is way higher than lithium-ion, with a potential C-rate, which means how many times a cell can be charged or discharged in one hour, of a hundred and eighty. That equates to three full charges every minute, which is much more like a capacitor than a battery. They also keep going for more than twenty-thousand charge cycles.**

**The boffins reckon they can potentially double those figures in the short to medium term too, so there’s a lot to like here as an extremely useful complimentary technology to work alongside lithium-ion for fast power delivery tasks in electric vehicles, or for stabilization of smart grids and micro grids. Challenges include the highly corrosive nature of the ionic electrolyte fluid and less corrosive but still problematic materials in the current collectors and cell casings. They are expected to be very cheap though when they come to market – maybe twenty percent less expensive than lithium-ion.**

**Nevertheless, we’re still a few years away from a commercial product so TRL ladder rung three it is.**

**Metal-sulphur batteries work in a very different way to metal-ion batteries.**

**Sulphur can react with lithium, sodium, magnesium and some other metals to form metal-sulphides. This is another one we’ve looked at in a couple of previous videos which I’ve linked in the description section below.**

**Lithium-Sulphur batteries operate at room temperature with discharge voltages between two and two-point four volts and very decent energy densities between three and four hundred watt-hours per kilogram, at least at cell level anyway.**

**You do need more individual cells at that lower voltage though, to reach the same system level voltage as a lithium-ion battery, so it’s not yet clear whether that cell energy density will scale up. The study points out that lithium sulphur cells might require higher external pressure and have a cycling stability that’s not as good as lithium-ion. So, the development goal here is to design large format cells that have both high energy density and can last more than a few hundred charge cycles.**

**They won’t be fast charges though. The chemical nature of the interaction between lithium and sulphur means you’re looking at one full charge per hour or maybe even less, so again, we won’t be seeing these things in electric vehicles. Lithium sulphur cells also currently use a flammable electrolyte, and you still have the propensity of lithium to build up into dendrites at the electrode face. So, there’s still a lot of work ahead, part of which will also be in finding the optimum carbon scaffold structures to minimise the polysulphide shuttle effect that we looked at in our previous video on sulphur batteries, where polysulphides get into a bit of a doom loop of continuous movement from anode to cathode and back again, effectively making the cell useless after the first charge.**

**There are already pretty good working solutions for that though, so it is by far an insurmountable goal. All in all, lithium-sulphur is looking reasonably promising for stationary storage applications, and in fact the technology using liquid electrolytes sits somewhere between rung five and rung seven on our ladder. Solid electrolytes are also being developed, although they’re a couple of rungs behind in terms of technology readiness.**

**Just as we saw earlier with metal-ion batteries, sodium represents an interesting alternative to lithium in metal-sulphur chemistry and most of the operational parameters are very similar.**

**Sodium-sulphur probably won’t pack the same punch as lithium-sulphur but you do win that important advantage of resource availability, so in some applications that may be the check box that seals the deal. But again, there are plenty of challenges to overcome. Sodium has an even greater tendency than lithium to lay down dendrites and its higher reactivity combined with a flammable organic electrolyte is far from ideal from a safety perspective.**

**Ceramic solid electrolytes would mostly get around that problem, and exotic materials like hollow carbon tubes and graphene will help with some performance issues, but those materials are by no means cheap or commonplace. So, the study puts sodium-sulphur on rung four.**

**The third category on the Fraunhofer list is Metal-air batteries, which, as the name suggests, comprise a metal electrode, some sort of electrolyte and what’s known as a ‘gas diffusion electrode’ or GDE on the opposite side of the cell. That set up allows oxygen to be drawn from the surrounding atmosphere or in some cases from an oxygen tank. You get electrical energy from a chemical reaction between the metal and oxygen, so the capacity of the cell is largely dependent on the type of metal used.**

**Yet again, Lithium is a promising candidate in this sector because it offers a very high theoretical energy density and decent voltage. On paper you could be getting as high as three-thousand-five-hundred Watt-hours per kilogram at three volts, but in real world prototyping, the higher the energy density, the lower the number of cycles achieved. Best results so far have been five hundred watt-hours per kilogram but with only ten useful charge cycles.**

**You also still get the dendrite problem, so these things are a long way off, and although substantial improvements have been made during the past decades, the study suggests this chemistry still needs some more basic research work, so it’s currently at the bottom of our TRL ladder.**

**Zinc-air batteries, on the other hand, have been commercially available for several years. The trouble is, the zinc oxide produced by the oxygen reduction reaction can’t be recovered, so it massively inhibits the capacity to recharge the battery by effectively absorbing the anode during discharge.**

**There are ways around even that limitation though, for example by mechanically replacing the zinc anode or by replacing the electrolyte within a flow system. That research work has apparently been going on for several years, but despite many announcements and a few prototype systems, no-one has yet managed to produce a commercially available rechargeable Zinc-air battery, so for the purposes of the energy transition, zinc-air also languishes towards the bottom of the ladder.**

**Last but by no means least, comes the good old Redox Flow Battery, which we’ve looked at several times here on the Just Have a Think channel.**

**These things have two tanks of electrolyte solution on either side of a cell stack. As the two solutions are pumped in, the cell stack converts electrical energy into chemical energy and vice versa.**

**Vanadium is the most common and most mature technology in this sector, and Vanadium redox flow batteries, or V-RFBs are currently already commercially available, so they sit right at the top of the TRL ladder.**

**Redox flow batteries really aren’t trying to perform the same role as the rest of the technologies featured in this report. They are by their very nature relatively heavy and bulky bits of kit, so they are firmly aimed at the stationary energy storage market. They don’t have the same high energy density as lithium-ion batteries, but they are very well suited to longer duration discharge between five and ten hours, and they offer an extremely long operational lifetime because you’re not getting any electrode deformation on each charge and discharge cycle. They’re also easily scalable. If you want a bigger system, you simply increase the size of the electrolyte tanks, or add more tanks.**

**Now, you might be asking “what about Solid State batteries, Dave”. That’s a fair question. And it’s a big question. So big in fact that the Fraunhofer institute is currently producing an entirely separate study dedicated solely to analysing the various solid-state options that are in development around the world right now.**

**And, of course, when I get my hands on that report, I will bring you those findings as well, so stay tuned, make sure you’re subscribed to the channel on YouTube and make sure you’ve hit the notification bell too so you don’t miss it.**

**That’s it for this week though.**

**I’ve been away for my editing desk for the last few days, while I’ve been busy hosting discussion panels at the Everything Electric LIVE show up in Harrogate, so there’s no video next week, but I’ll be back on Sunday the 9th June with more news and views from the world of climate change and sustainable energy.**

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**Whichever way you support the channel though, whether it’s via free subscription on YouTube or by joining Patreon, your help is massively appreciated.**

**Most importantly of all though, thanks very much for watching. Have a great week and remember to just have a think.**

**See you next week.**