**I don’t know about you, but one of the things I’ve been trying very hard to avoid during the last twelve months of lockdown… is snacking. But as always, I am prepared to make certain sacrifices in the pursuit of scientific knowledge, so I’ve been forced to buy this bag of crisps, or chips to you folks in America, in order to demonstrate a point.**

**You might have noticed that these bags always seem to contain more air than food, which is something I find quite irritating. But the air inside the bag isn’t ambient air. It’s pure nitrogen, pumped into the packaging during the manufacturing process. And that nitrogen is separated from the air around us by a cryogenic cooling process that was invented by these two characters way back in 1883.**

**Once it’s in liquid form, the nitrogen gas can transported quite easily in insulated cylinders all over the world, and nowadays, as well as being a major component of agricultural fertilizer, it’s also used by pretty much all the major food processing companies in their production facilities because it’s an inert gas that can keep the food inside the bag fresher for longer. [opens bag]**

**So, cryogenic air cooling is already a widely used and extremely well-established technology. In the last ten years or so though, as renewable power sources have become much more prevalent on our electricity grids, that industry has started to seriously consider cryogenic air as an energy storage medium. A grid scale version of this so-called liquid air process already exists, run by a company called Highview Power. And now a Florida based company, called Cryomatiks, has developed a portable system that could bring the benefits of liquid air energy storage to the rapidly growing, and potentially enormous market for electric commercial fleet vehicles.**

**[looks sheepish and dives into crisps]**

**Hello and welcome to just have a think.**

**The benefits of cryogenically cooling air into a liquid were recognised by industrialists pretty much straight away, and it’s now what they call a mature technology. It’s one of those processes that runs constantly in the background, at vast industrial scale all over the world. You might be forgiven for thinking that air is mostly oxygen. After all, that‘s why we breathe it in to keep ourselves alive. But in fact, oxygen is only about twenty-one percent of the air we breathe. Nitrogen makes up about seventy eight percent.**

**Essentially the ambient air from the surrounding atmosphere is drawn into a liquefier where it’s chilled and compressed. As the air is being liquified at those very cold temperatures, most of the impurities and contaminants are filtered out, and once it’s been compressed and chilled, the air becomes a liquid, seven hundred times denser than the atmospheric air we breathe. It emerges from the process at about 15 times atmospheric pressure and is then channelled either into large, insulated storage vessels in grid scale applications, or portable cylinders to be transported. A bit like industrial versions of a thermos flask.**

**Then, when you need the energy back, you release the liquid from the storage container so that it can be rapidly warmed by the ambient air to produce a very high pressure stream of gas that can then be passed across a turbine to generate electrical power. It’s a remarkably efficient process and makes a lot of sense at the large grid scale that Highview power operate at.**

**Cryomatiks don’t actually do the cryogenic cooling of the air. They leave that to the industry incumbents. What they have created and patented though, is a high-speed liquid air or liquid nitrogen expander about the size of an electric drill, but with some very smart engineering that improves its efficiency up to levels similar to its much larger cousin. Potentially there are many applications for a device like this, but Cryomatiks are primarily focussed on the benefits of employing it as a range extender to electric commercial vehicles, particularly urban delivery vehicles.**

**It works a little bit like a jet engine but without any fossil fuels or combustion.**

**Fundamentally what the process requires is thermal energy to convert the liquid air back into a vapour. It also needs thermal energy to ensure that the gas expands as close to isothermally as possible. We looked at isothermal and adiabatic gas expansion in a video a couple of weeks ago, and you can click up there somewhere to jump back to that one.**

**The Cryomatiks expander gets that energy in a number of ways. Firstly, ambient air is drawn in at one end of the expander. Some of that air is passed across a compressor, which makes it hot. The rest of the air bypasses the compressor, and we’ll come back to why that happens in a moment. Secondly heat is harvested from the regenerative braking system of the electric vehicle, and from otherwise wasted heat from the vehicles system components. That energy goes into a heat transfer fluid, which is essentially a carefully calibrated mix of water and glycol. The heat transfer fluid is injected into the chamber at the same expansion stage as the liquid air, to maintain those near isothermal levels of expansion.**

**What you’ve got here is a fancy version of a heat exchanger, and in fact there are older designs for liquid air expanders that are also just fancy heat exchangers. The difference in this design is that rather than have the air flow around the outside of the chamber, it is injected directly inside the chamber, via the compressor at the front and from the heat transfer fluid injectors in the middle. I know you folks in colder northern climes might point out that a heat exchanger won’t work so well in freezing cold air, but the arithmetic for that is done using the Kelvin scale not Celsius or Fahrenheit. The liquid air is at 77 Kelvin and once the ambient air has been through the compressor and been combined with the heat transfer fluid, you get an average temperature of about 300 Kelvin. And if we delve very briefly into something called the Carnot Cycle, it shows us that the efficiency of heat exchange is governed by the temperature difference in Kelvin. In this case its one minus seventy-seven over three hundred, which works out at seventy four percent efficiency, which is not bad.**

**The crucial advantage of setting up the device as an internal heat exchanger instead of an external heat exchanger is that now you’ve not only got high temperature fluid acting on the liquid air, but you’ve also added the mass of that fluid to the overall mass flow rate going across the final turbine producing electricity. And of course, that ramps up the efficiency of the system very significantly.**

**So why not shove a hundred percent of the ambient air across that compressor at the front then?**

**That’s a good question, and one that I put directly to Cryomatiks founder Mark Cann.**

**Mark explained that high speed expanders have a specific operating RPM window which is governed by the velocity of the air flow across them. If you get the air flow velocity wrong, the expander simply stops rotating. That’s similar to what happens when an airplane engine stalls. So, to maintain that minimum velocity, some of the ambient air has to be diverted around the compressor instead of through it. The exact ratio is something that has been an important element of the development work and is a proprietary detail of the patented design.**

**Now, you might be thinking to yourself ‘what’s the point of using energy from the regenerative braking system when most electric vehicles already use that energy to recharge the lithium-ion batteries’? Surely we’re just robbing Peter to pay Paul here?**

**That’s another good question, which I also posed to Mark Cann.**

**Mark pointed out that most battery packs for EVs have the regen energy capped to a certain percentage in order to preserve the life of the battery cells. As the mass of the vehicle increases, that percentage gets reduced even more, in order to protect the pack. Any excess, unwanted energy is just dissipated into the air and wasted. It’s this excess energy that the Cryomatiks system captures in its heat transfer fluid. That means that as much as ninety percent of the potential energy available from regenerative braking is captured, compared to about fifty percent in a normal EV. Commercial vehicles, especially urban delivery vehicles and buses, have a very heavy stop and go duty cycle. That means regen braking is being employed a great deal of the time so the more of that energy you can recoup and use, the more efficient your vehicle is and the longer it’s range will be each day.**

**The Cryomatiks expander also recovers thermal energy from the electrical generator itself and the electronics that power the system. In some cases, they will even be able to incorporate the thermal inputs and outputs of the cabin air conditioning systems as well. When the AC system is cooling the cabin, the heat is captured and used in the expander. When the AC system is heating, the expander can use thermal energy from the regen braking to assist the AC heat pump.**

**Liquid air, or more specifically liquid nitrogen, has a potential energy of just over 200 watt hours per kilogram. After allowing for the Carnot efficiency losses and other system losses, the Cryomatik Expander achieves something in the region of a hundred and twenty-five Watt hours per kilogram. To put that in perspective, that’s about the same output as the battery pack on the 2021 Audi eTron electric vehicle.**

**Cryomatiks have submitted fully costed documentation to two different government agencies for review and they are awaiting the results of those assessments. Right now, even in these very early stages with no economy of scale on the costs of components and tooling, the system works out slightly more expensive than diesel in terms of cost per unit of energy delivered. But of course, as economies of scale kick in, those costs will reduce quite significantly.**

**A test series of last mile electric delivery vehicles equipped with the prototype twenty kilowatt Liquid Nitrogen powered range extender will be on the road in Florida this year to collect real world data. A slightly smaller ten kilowatt model is also being developed for use in electric fork lift trucks. The plan for 2022 is to test a 30 kilowatt liquid air expander in Class 3 delivery vehicles, which are the FedEx/UPS style box vans we’re all familiar with. Initial contracts will be set up in the state of Florida where Cryomatiks are based, but there is already an existing network of five thousand service centres for deliveries of liquid air right across America, which means that ninety percent of the US population can get supplies delivered within about twenty minutes or so, even today. That’s a major advantage that overcomes the massive charging infrastructure hurdle that battery electric and hydrogen fuel celled vehicles both faced when they first came to market.**

**As with all these start up initiatives, there is of course a long way to go on the road to full production and economic scaling, but if its successful then the Cryomatiks expander will offer one more option to improve efficiency for fleet operators and drive down the all-important cost per mile that can mean the difference between profit and loss for those companies.**

**In the longer term, extenders of between fifty and more than a hundred and twenty kilowatts are planned, to cater for larger electric delivery vehicles, plus electric taxis and buses and agricultural vehicles like electric tractors. And there are potentially other applications as well. For example mobile chargers and generators, potentially replacing the existing diesel burning models currently in existence all over the world, and that would be one more step towards the global decarbonisation we so desperately need.**

**As always, if you’ve got views on the potential of this technology then jump down to the comments section below and leave your thoughts there.**

**That’s it for this week though.**

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