Solid state

Liquid and gas are the hydrogen storage methods on everyone's lips, but there may be an alternative solution to using the fuel safely.* Racecar *investigates

By ANDREW COTTON

It is well documented that burning hydrogen, either as a gas or a liquid, to power racecars produces minimal emissions at the tailpipe, and that the emissions that are produced are less harmful to the environment than those from fossil fuels. What is less clear is how to create that hydrogen, the environmental impact of doing so, and then storing it safely and cheaply in order to be able to use it in a vehicle.

Even ignoring all the impact of creating hydrogen in the first place, storing it as a gas in a chamber suitable for cars requires extreme levels of pressure, which then need to be contained. Put a high-pressure gas tank in a racecar and immediately there are some obvious concerns. Hang any such tanks outside the crash structure and there will be more questions than answers.

On the other hand, if you put hydrogen into a racecar in liquid form, it has to be cooled to around -253degC, which comes with its own challenges, both in storage and delivery of fuel to the power unit.

The Automobile Club de l'Ouest (ACO), which organises the 24 Hours of Le Mans, is working on its third iteration of laboratory car to test and demonstrate hydrogen technology. While the ACO has invested in gas storage in the past, it is now following the FIA's direction for circuit racing and will convert the H24EVO to run on liquid hydrogen. This has made it seem like there are only two solutions to the hydrogen storage problem, yet there are other potential options coming to light.

Ian Dawson, who ran a pioneering diesel car at Le Mans with backing from Caterpillar in 2004, using a VW Touareg engine in a Lola chassis two years before Audi started its famous project with the fuel, is working to integrate a solid-state hydrogen storage system into a racecar, with hopes it will one day lead to a one-make series.

The idea started nearly 10 years ago, when it dawned on Dawson that he was not enjoying modern day motor racing. With development limited, there was very little innovation he could do on the car he was running in an American series, so he decided to either stop altogether, or build his own car, but with new technology.

He opted for the latter and started to look at alternative fuel solutions, eventually settling on hydrogen. His path to creating a car was given a boost by a link with Chevron Ventures, which allowed him the luxury of investigating the latest hydrogen technology.

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Low pressure

'I stumbled across a project in Austin University where the professor said to me that I didn't want high pressure, I needed low pressure hydrogen,' recalls Dawson.

To achieve this, he had to focus on solid state hydrogen cells. This is not new. Such cells were first developed in the 1950s, but the sector is evolving quickly and is now at a stage where a solid-state hydrogen system is more power dense than a lithium-ion battery.

With manufacturers like Toyota and Alpine developing their own hydrogen prototypes, Dawson faced a dilemma of where to fit his car in the racing spectrum. Then it was a race against time (and money) to have his system in a vehicle, ready for testing, and reliable.

Covid then put the development world on pause, although Dawson was able to continue some of his investigations and partnerships.

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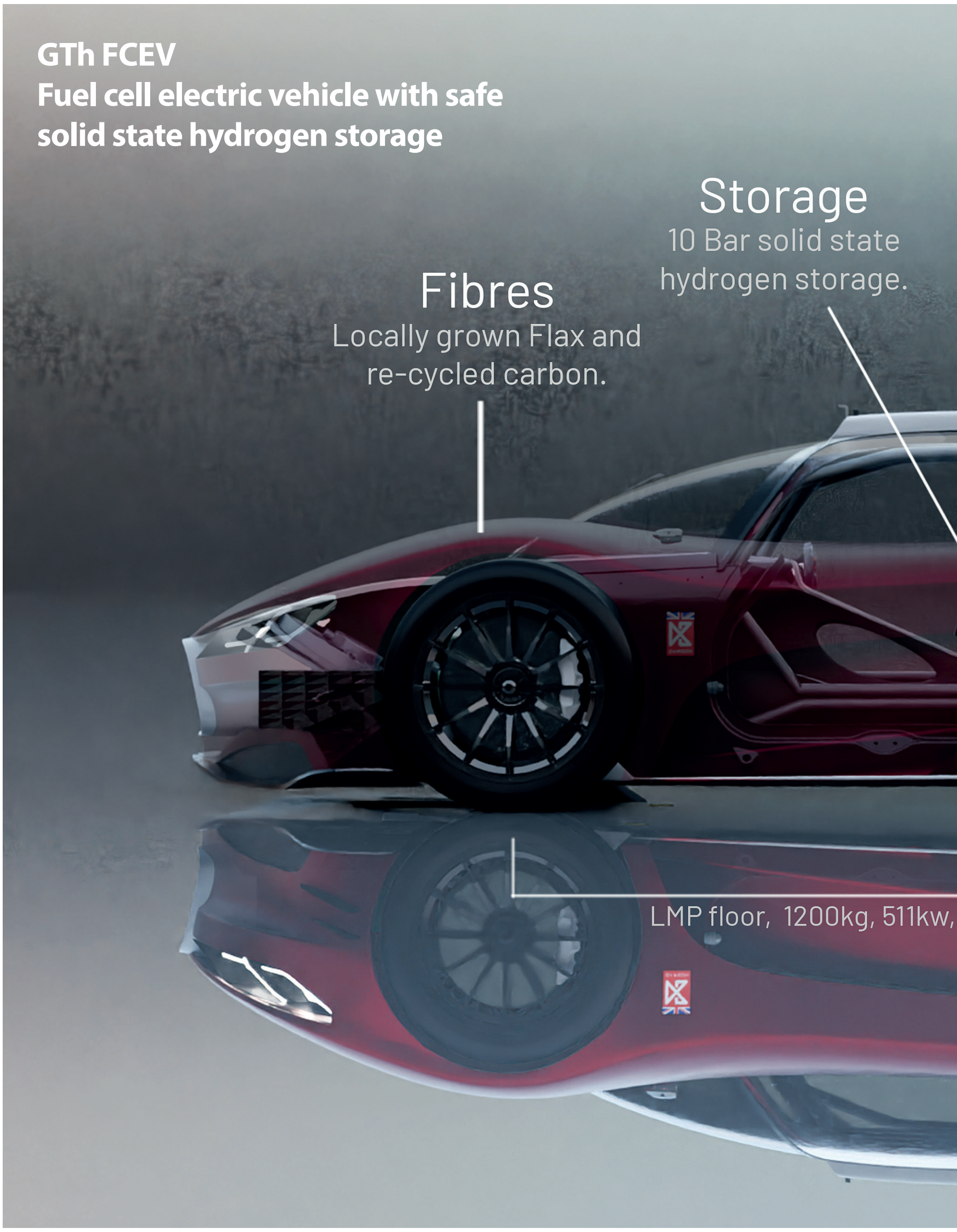


Having made the decision to build a new car outside of any existing regulations, Dawson partnered with an expert in fuel stack technology, and other industry leaders, including Empel Systems. The decision was made to move the company back to the UK from Texas and set up Dawson Technologies Limited with Dawson and his son, Simon, mid-2023, along with a small design team.

Powder pouches

Key to the project is the hydrogen storage in the car. Dawson's team locked into storage pouches filled with a sodium-based powder that produces hydrogen when wet. The team committed to work with Aich 2, a US company based in South Carolina and which has a programme in Scotland. The company has developed the pouches, which are sealed and dried as the powder is extremely sensitive when exposed to moisture.

Sodium borohydride is a crystalline powder. It is decomposed by water to form sodium hydroxide, a corrosive material, and hydrogen. It is, says Dawson, a safe, light and effective method to produce the gas: 'It's a chemical absorption through something like a powder, a sponge process, which is very like taking a tennis ball and infusing it with hydrogen molecules. It doesn't need heating or cooling and it has three times the density of conventional hydrogen.'

As spent hydrogen naturally produces water as a by-product, gaining access to water is not difficult. Two other factors make this a more viable solution: one is that it is stored at low pressure, just 10bar, compared to 700bar for the gas form. The other is that its creation of hydrogen does not produce high temperatures. The fuel itself does therefore not need to be cooled to extreme temperatures, and there is no large change in pressure within a fuel cell from empty to full, which is another source of heat generation.

The hydrogen is then used in a fuel stack, each one capable of producing up to 220kW of power per stack. Dawson believes around 30kg of sodium borohydride will be required to power his car for two hours.

The system he has developed has low pressure drop, which means it is not susceptible to overheating from the chemical reaction required to produce the hydrogen gas, and it can run on either pure hydrogen or reformate gas.

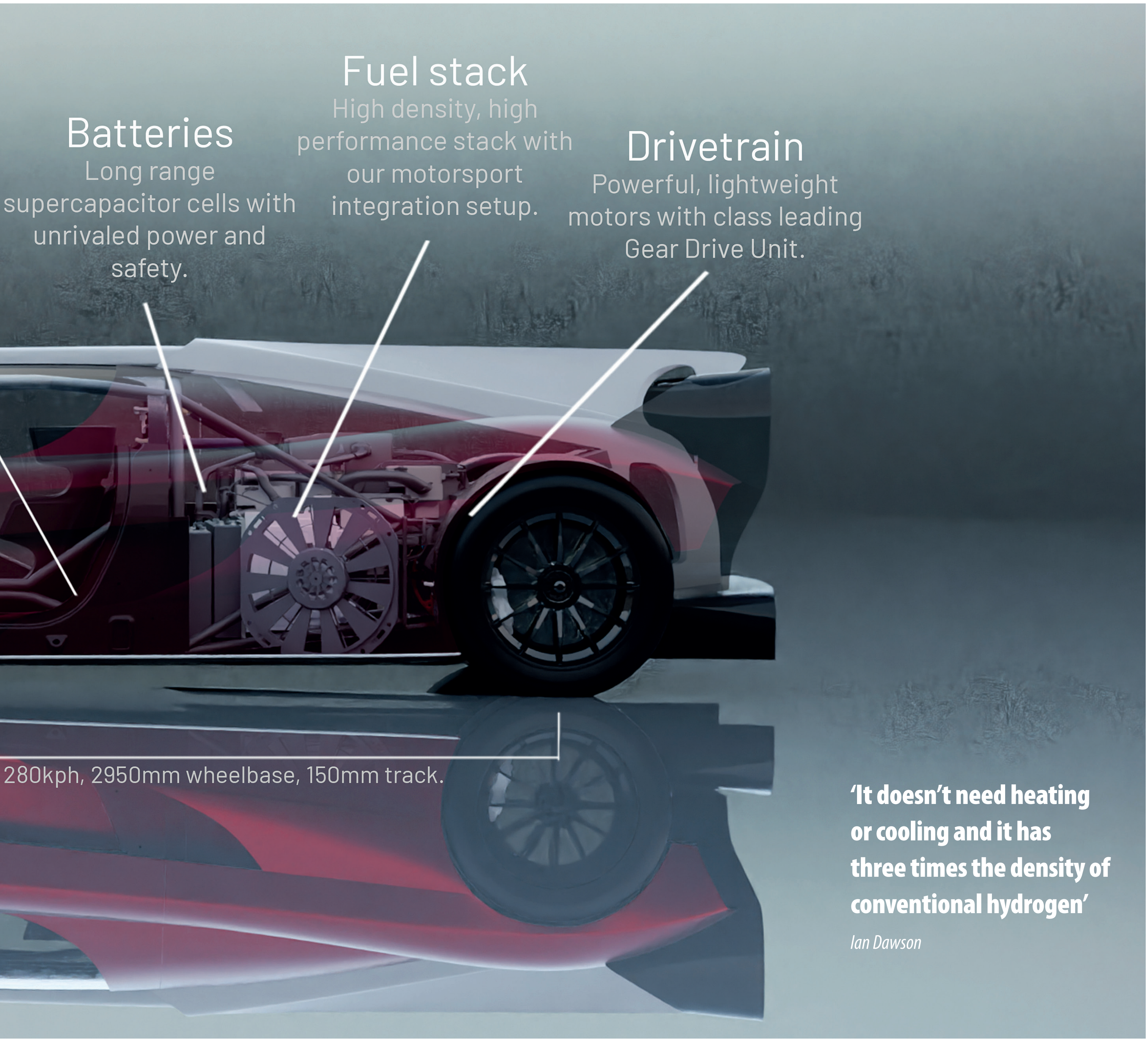
Once created, the hydrogen gas is fed into the stack, which then delivers power to a supercapacitor hybrid system. This is similar technology to that used by Toyota at the start of the LMP1 hybrid era with its TS030. Much as the current Hypercars balance electrical and combustion power to a maximum of 520kW, so complicated electronics manage power delivery from the supercapacitor battery and hydrogen cell.

Power delivery

Fitted to the rear wheels only are in-wheel motors that can deliver a maximum of 580kW, but which normally run closer to 300kW. 'The peak average is around 300kW of energy, and there are periods when you are probably going to have to ease out the throttle, just like in a fuel formula from years ago,' says Dawson.

Indications are that the car would lap Silverstone in a time similar to a current GT3 and would be able to do so for at least two hours. After that, the pouches would need to be cleaned out of the residue powder. At that point, they could either be replenished with new powder, or replaced. Dawson says the 'pit stop' would take approximately four minutes currently, if the car were to race. By which point the GT3 would have lapped it twice.

'It must be credible,' says Dawson of the car, and the technology. 'To do that, the car has to have the same wheelbase, same weight and same aero and mechanical balance as a GT or LMP car or you can't put the right size tyre on it, and get the tyre heat into it.



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State of play

Solid-state batteries were first developed in the 1950s, using silver-ion conducting electrolytes. The batteries had high internal resistance, while cell voltage and energy density were low. Over the next 40 years, the technology advanced, and a solid-state battery was incorporated with a thin film, lithium-ion battery. Further advances have seen solid-state batteries improve in both power density and reliability, but there is still some way to go before they can be mass produced.

A solid-state battery is one that uses a solid electrolyte instead of a liquid electrolyte, which is what is used in lithium-ion technology. Lithium-ion batteries use a polymer separator between the anode and cathode, which works as an insulator and allows the lithium ions to move through it.

In a solid-state battery, the cell is very different. While the cathode can be made of the same compounds as found in a lithium-ion battery, the separator is solid and also works as the electrolyte. The anode, meanwhile, is made of lithium metal. This is safer, increases energy density and extends the overall lifespan of the battery.

However, solid-state batteries do have their downsides. With a solid barrier between the anode and cathode, it can be subject to puncture by the solid mass dendrites that are produced as the battery degrades over time and use. The lithium ions move through the solid electrolyte by pathways between, or through, defects in the crystal lattice structure. Without the graphite intercalation anode, the cell is more compact, providing higher cell and module level energy density. With high limits of thermal operation for the solid electrolyte, solid-state batteries may require less thermal management. If dendrite growth can then also be suppressed, it may be possible to fast charge batteries at higher rates, with proposed charge times of 15 minutes or less.

If having an inert powder held in normal storage conditions sounds too good to be true, you might wonder why motor racing authorities have decided to focus solely on liquid storage. The answer is that the transformation from powder to gas is rather tricky to manage. There are a few ways of doing it: one is to use alkali metals, such as sodium, potassium and lithium, which are fairly potent when mixed with water. Another is to use alkaline earth metals, such as calcium, magnesium and barium, which react more slowly with water compared to alkali metals, but still produce a gas. A third way is to use metal hydrides; compounds of metals with hydrogen that can produce the gas. A fourth method is to use hydrazine compounds that can react with water under specific conditions.

The problem is all these processes create significant thermal energy and are prone to runaway, where the rising temperature attracts oxygen that then feeds the fire.

'Some of the technology we're doing, nobody's ever done it. There is no existing system. We've got a company to write algorithm programs that predict what can happen. They're doing it with information they've never had before, but they've been quite surprised, saying this is a game changer and we can store a hell of a lot of hydrogen.'

Prototype car

The car itself is being built with flax fibres, including hemp. It uses a Hewland transmission, AP Racing brakes and is based loosely on an LMP3 car crossed with a GT car. There is, reasons Dawson, not much point building a prototype to compete against the likes of Toyota, nor a production-style GT3 as there is no logical place to race it. What has been produced, then, is a rollcage that is certified by the FIA, front and rear clips much like those of the Ferrari 296 GT3, and a hydrogen storage mechanism.

Unfortunately, as it is not in keeping with the FIA's mandate of liquid storage in all of its racing activities, and so there is a target to race at events such as Pikes Peak, which sits outside of the FIA's remit and requires only safety assurances to allow concepts to run.

Much of the development behind it will likely benefit the marine and aerospace industries, so the car is really a proof of concept that may evolve into a one-make series if it can be shown to work in a hostile environment such as a racing car.

For the time being, the concept is demonstrating an alternative way of storing hydrogen, in a clean, safe environment, without the extremes of temperature and pressure traditionally associated with it.

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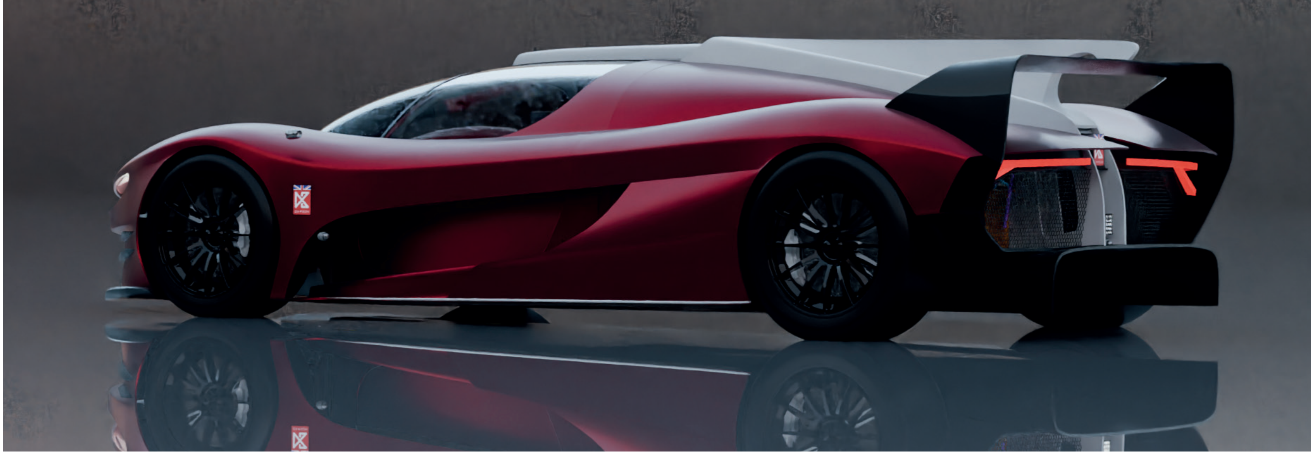

At present, because the FIA mandates liquid storage, the idea remains a proof of concept but, if Dawson can secure funding to build the car, it could take a run at Pikes Peak…