HOW TO | BUILD A HYDROGEN

BAE Systems is a world-leading developer of electric propulsion systems for buses, with a standard electric powertrain platform that covers a variety of power generation means, from diesel hybrid to full-electric. In the past, that range has also included production of hydrogen fuel cell-powered drivetrains. Now, thanks to a framework agreement with hydrogen systems supplier Plug Power, that capability has been reinforced, as the two companies are collaborating to supply zero-emissions powertrains to medium- and heavy-duty vehicles.

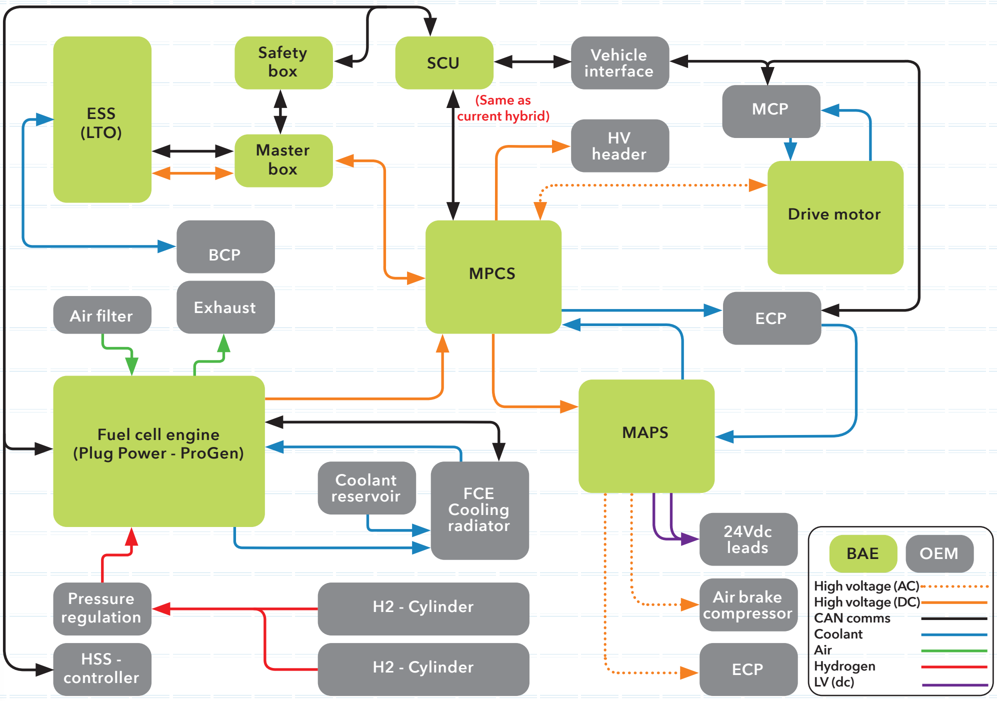
Hydrogen-electric powertrains enable transit fleets to operate cleanly, quietly and efficiently at extended ranges over battery electric vehicles. Unlike electric trams or EVs, which require extensive route infrastructure, hydrogen fuel cell buses can be quickly refuelled in existing city fleet facilities equipped with hydrogen dispensers.

Although bus operators will have to adapt to hydrogen fuel – which is stored as a gas rather than liquid – and tap into a completely different supply chain, there are a number of reasons why hydrogen may well seem much more familiar than it appears at first glance, particularly to vehicle technicians.

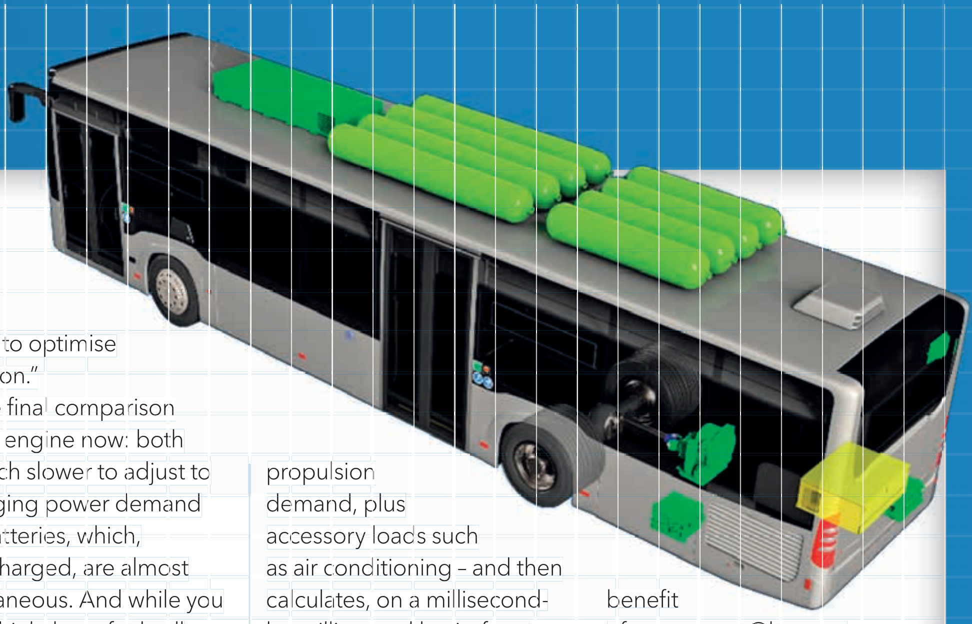
A fuel cell generates electricity by combining on-board hydrogen and oxygen (from air), in an energy-producing chemical reaction whose other product is water (H_2O). Fuel cells are more thermally-efficient than internal combustion engines, but not by so much: 50% as opposed to 40%. So, like an engine, this process generates a lot of waste heat. As a result, they require a closed-loop cooling system, just as internal combustion engines do, which includes the usual pump, radiator and coolant reservoir. One quirk is that fuel cells don't use engine oil as coolant but deionised water. (The lack of ions is very important to prevent damaging the metals, leading to a short circuit in the high-voltage plates).

Also, like an engine, the exact fuel-air mix affects the fuel cell's ability to produce energy; it is possible to 'throttle' the fuel cell by increasing the fuel-richness of the mix. Fuel comes from onboard tanks filled with hydrogen, fed under high pressure. And as for modern engines, a dedicated ECU in the fuel cell manages air and fuel (and temperature, actually) within a closed-loop control system.

A diesel engine's performance is often described with a torque curve, which maps torque and



POWERED BUS



power against load (measured in RPM). Fuel cells, too, have a characteristic output described by a polarisation curve that expresses the relationship between voltage output and load (which in this case is 'current density' or the amount of hydrogen pushed through the fuel cell).

What this means is that fuel cells also have a sweet spot. While for diesels it's where torque tops out, for fuel cells this is the point of greatest electrical efficiency. Both are generally to be found somewhere in the middle of the load range.

While buses can run on fuel cells alone, that configuration requires them to shoulder all of the load, all of the time. That's not conducive to achieving greatest efficiency, because bus duty cycles impose high peak loads under certain conditions, such as pull-away. Derek Matthews, BAE Systems power and propulsion solutions partnership manager, explains: "With a battery, you stabilise those transitions and spend more time in the fuel cell's optimal range. Like on the diesel hybrid, the ESS [energy storage system] takes the transient response requirements off of the engine to optimise operation."

One final comparison with an engine now: both are much slower to adjust to a changing power demand than batteries, which, when charged, are almost instantaneous. And while you might think that a fuel cell would be easier to integrate with a battery than the diesel-generator combination used on a hybrid, since both deal in Volts DC (rather than AC for the generator), it's not quite that simple. A battery's output curve is at a higher voltage, and a different shape, from a fuel cell's.

TASKMASTER

Managing both requires some clever engineering. This is the speciality of BAE Systems, and in particular of its ESS controllers, which consider a fuel cell as just another node on the main DC bus. The lynchpin is a device called a boost converter. This DC-DC component aims to make the fuel cell power output compatible with the battery system. A transformer helps by raising the fuel cell voltage to the battery's 700V.

Matthews explains how this works. The controller senses the total load – that's propulsion demand, plus accessory loads such as air conditioning – and then calculates, on a millisecond-by-millisecond basis, from where to draw the required power. He explains: "It says, 'I want a certain amount X from the battery, and certain amount Y from the fuel cell'. But the fuel cell can't give Y immediately, so it says, 'ramp up towards that and tell us when you reach that power, and meanwhile I will take it from the battery, but I'm expecting it in three seconds, and I will keep asking until then'. It's about a balance between energy sources. And the controller knows the efficiency and effects on lifetime if you take energy from different load points and transitions. We have mapped out all of that in our algorithm: how best to maximise the life of a battery and fuel cell."

Thanks to the new framework agreement with Plug Power announced in April 2021, the two companies have been able to optimise the compatibility of the component parts, to the benefit of customers. Observes Matthews: "Typically if you integrate with a fuel cell, you often have to do it at the bus level. In the case of Plug Power, we're going to do all of that at our facility. When we come to OEMs [bus manufacturers], it will be as plug-and-play as possible."

In describing optimisation, Matthews offers an example of an ongoing project: to combine the cooling circuits for the fuel cell, the central motor and the DC electronics, to cut down the number of redundant pumps, reservoirs and fans included. Matthews points out: "This is one of the benefits of our relationship with Plug Power. We can have more optimal integration discussions, and we have a lab where we can do this. Here there are opportunities to streamline the system to make it lightweight, low cost, sharing features and functions." TE

GAS TANKS

For bus customers, Plug Power also brings other resources to bear to solve the infrastructure issues posed by hydrogen. It offers a number of ways to provide the hydrogen gas fuel required to power the buses. And one of the most common ways is familiar to existing users of Derv: on-site storage, replenished on a daily or weekly basis by tanker. In actual fact Plug Power is bringing more to the party than this, including installing extra systems such as a compressor, as the fuel is typically transported as a cryogenic (super-cold) liquid, and then stored as a high-pressure gas. Oh, and it supplies the gas, too.