Space age

Using the lightest element in the universe, hydrogen, produces only energy and water vapour, which is why some see it as the future of fuel in the long term. Publicly funded bus trials have been overcoming some of its issues – including price, reports Will Dalrymple

Like other chemical elements, hydrogen joins with others to create an alphabet soup of molecules. Bus operators' experience of implementing hydrogen power in the fleet has also resulted in a similar alphabet soup: CUTE, HyFleet:CUTE, 3Motion, CHiC, JIVE. These are the names of some of the publicly funded projects for demonstration and deployment of fuel cell electric vehicles (FCEVs) on real UK bus routes.

They represent essentially the entire British operational experience of hydrogen-fuelled PSVs, because the excessive cost of hydrogen fuel cells, which emit no pollutants during operation, has ruled them out of competitive least-cost tendering processes for bus supply contracts.

But that may be set to change. First, bodybuilder WrightBus, which is participating in the latest project called JIVE (see also *www.is.gd/yunaxe*), intended to commercialise hydrogen buses, has committed to offer them post-JIVE at a price that assumes a volume production figure that does not yet exist. It's a strategy that is not without "a certain element of commercial risk," admits business development director David Barnett. [Editor's note: this article was written before news broke of WrightBus entering administration last month.]

Second, the enabling technology of fuel cells continues to drop in price as production expands. Ballard's latest generation fuel cell power system, launched earlier this year, is said to cost only half as much as the previous model. Ballard predicts that the size of the hydrogen-powered global bus fleet will increase from 400 today to over 2,000 fuel cell buses by the end of 2020, most of which in China.

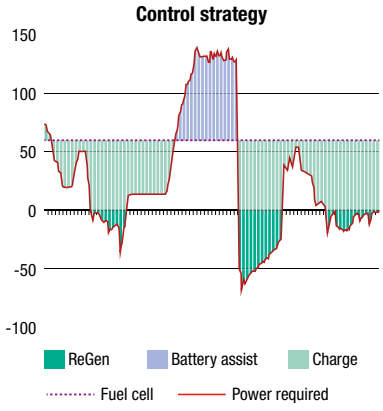
And there are some very good reasons for all of the fuss. Per 100MJ of energy, hydrogen is lighter-weight than even diesel: 0.833, compared to 2.32kg for diesel and 166.67kg for electricity when stored in a battery according to figures from WrightBus. That translates

BEING AN EARLY ADOPTER

Tower Transit's Yorke says that being the guinea pig for hydrogen buses in London did cause some operational stresses; also, it was particularly unfortunate in that the technology integrator responsible for tying together the fuel cell, hybrid circuit and bus driveline went bust after the project started. "There were a lot of issues that the garage had not seen before. There was also some basic information that was missing." He says Tower relied on a good relationship with the OEMs to solve the problems.

REFUELLING PROCESS

Tower Transit refuels the fleet from a permanently installed fenced-off hydrogen tank on site, replenished every four or five days by tanker. The tank on the bus is a type III aluminium-lined, carbon fibre-wrapped tank storing hydrogen. Refuellers are required to have conducted a one-hour training session with the fuel supplier. They must attach a grounding cable, wear safety glasses and may not use mobile phones. However, the system forms a sealed unit, like LPG, so no fumes are released. Before fuel delivery begins, the system equalises pressure in the tanks; if it cannot, it will not dispense any fuel. That is a failsafe against leaks.



The power management profile in the RV1 bus drive cycle was based on meeting peak loads; that consumed lots of power at idle. David Barnett at WrightBus argues that if the fuel cell is run at a steady state, which is the most efficient point, its energy demand can be reduced. Extra energy comes from regenerative braking.

into a long range before refuelling: it claims its single-decker can go 215 miles before a refill, and its double-decker 200mi. Laden with large and relatively heavy batteries, full-electric buses wouldn't be able to achieve that range.

One of the most long-standing users of hydrogen-powered buses is Tower Transit, which operates and maintains a fleet of 10 (alongside conventional diesel buses) at its Lea Interchange depot in Stratford, East London. New technology and products manager David Yorke argues: "FCEV is a drop-in replacement. It offers operational leeway. You can go to 24-hour routes, for which battery electric vehicles (BEVs) won't work. Even if FCEV [technology] is more expensive per bus, the overall cost of the route might be less than BEVs, if you consider the number of buses that have to be bought."

Also, the refuelling process is as short as going down to a petrol station forecourt; it takes five or ten minutes to refill the on-board tanks. That's where

the similarity ends though, because the hydrogen gas is stored on the vehicle at 350bar, because its energy/volume ratio is not as favourable as that of diesel (though still slightly better than electric): 3.2, 1.4 and 4.05m³, respectively.

Within the fuel cell, hydrogen reacts with naturally-occurring oxygen in the atmosphere (see video: *www.is.gd/tutobo*). As it does so, the reaction generates energy at about 60% efficiency, as well as water, since two atoms of hydrogen and one of oxygen

FUEL CELLS FOR TRUCKS?

Ballard offers a few examples of FCEV driveline trials in heavy goods vehicles, although with the proviso that it has generally received very little commitment from industry to try out the technology.

First, Kenworth, the US cousin of DAF Trucks, has partnered with Toyota Motor North America to develop 10 units of the Kenworth T680 44t tractor for operations at the Long Beach, California Port of Los Angeles (pictured). The project is part-funded by the California Air Resources Board; other partners are the Port of Los Angeles and Shell (which will set up two hydrogen filling stations); trucking partners are Toyota Logistics Services, UPS, TTSI and Southern Counties Express. For more information, see also *www.is.gd/rinozu*.

Second, it claims that the world's largest deployment of FCEVs in commercial trucks is a fleet of 500 distribution rigids operated by Shanghai Sinotran New Energy Automobile out of Shanghai. The Dongfeng 6x2s, rated at 7.5 tonnes and measuring 6.4m long, are powered by a Re-Fire Caven 3 with a Ballard 9SSL stack. As of mid-June, the fleet had clocked up more than 8 million km.

Third, Ballard is readying a new unit, a 250kW-capacity fuel cell specifically designed for truck applications, for launch in 2020-2021; that might turn a few heads.

WHERE DOES THE HYDROGEN COME FROM?

While traditional sources of hydrogen originate from fossil fuel, green hydrogen can be produced utilising surplus renewable energy via electrolysis in a PEM electrolyser system. This splits water into hydrogen and oxygen using electricity, with an efficiency said to range from 70%-86% with heat recovery, according to UK manufacturer ITM Power. It says that plants like these balance out the peaks and troughs caused by variable renewable power sources such as solar and wind. In any case, a 2MW system can produce up to 800kg of hydrogen/day; a typical bus requires 20-40kg/day. A 3MW electrolyser funded by Innovate UK will produce hydrogen on-site at a bus refuelling station in Birmingham next year.

combine to make H_2O The water drips out of the vehicle; the electricity produced is funnelled into a 600V DC electric circuit, powering motors in a series hybrid configuration to drive the bus. The series hybrid configuration uses either power from the fuel cell, battery or both for drive. The on-board DC-DC converter sends that power to a battery pack; a separate 24V circuit powers lights and CCTV.

Yorke recalls that the company has been running FCEV buses for more than ten years, through its customer Transport for London. An early project included buses for TfL's RV1 route in central London (pictured p17), which was recently terminated. Initially specified with six hydrogen tanks for a range greater than 200mi, that capacity actually proved too great for the 120mi route, recalls Yorke. Even after removing two of the tanks, the bus was only using two-thirds of the 30kg of hydrogen carried.

To mitigate the risk of fires caused by leaking hydrogen gas – which can form an explosive mixture with air in concentrations as low as 4% – Tower Transit moved FCEV bus servicing and repair work to a dedicated, specially equipped two-bay workshop. Just like diesel buses, these units must pass an inspection every 28 days as part of Tower Transit's operational licence. Examples of extra maintenance include calibration of hydrogen sensors and hydrogen tank inspection.

To prevent making sparks, technicians attach a grounding cable to the bus before starting work; they wear antistatic overalls, and use spark-proof tools when working on the hydrogen system. Workshop lighting and electrics are ATEX-compliant. Naked flames are prohibited in the workshop; that means that no welding is allowed except in very particular circumstances (and only after the fuel tanks have been emptied). In an emergency, all of the workshop power (except the ATEX circuit) switches off.

To mitigate against the presence of hydrogen, every bus's hydrogen pressure release device (PRD) system is plugged into an emergency ventilation system when it enters the garage. As hydrogen is odourless and invisible, the garage is fitted with hydrogen detectors (and technicians wear personal alarms). The workshop system has a two-stage alarm, at 20% and 40% of the lower explosion limit. At the higher level, everyone is evacuated and fans mounted in vents on the roof turn on automatically to pull the light gas out of the workshop.

Partly because of these extra risks, as well as the value of each bus, technicians are particularly prized in the hydrogen fleet and have received extra training. No wonder that currently the bus:technician ratio is 5:1 in the hydrogen fleet, higher than for diesels.

Concludes Yorke: "Some of the things that we've identified as problems won't ever appear again. I would love to run more of these vehicles. It's my personal opinion that they are definitely going to play a part in the future." TE

HYDROGEN REFUELLING IN THE UK

Air Products supplies Tower Transit buses with hydrogen at its 350 bar storage facility. It also operates a public hydrogen refuelling station next to Heathrow Airport. A larger network of eight stations is operated by ITM Power, working with Open Energi. Together they dispense 20 tonnes per year.

	OPENING	ELECTROLYSER (KG/DAY)	DISPENSER KG/DAY
Rotherham	2015	100	200
Teddington	2016	100	570
Rainham	2016	100	570
Cobham	2017	100	570
Beaconsfield	2017	100	570
Swindon	2018	100	570
Kirkwall	2018	400	200
Gatwick	2019	100	570

Linde operates a 100kg/day electrolyser in Scotland to produce hydrogen for buses as part of the Aberdeen Bus Project. Also, small-scale fuelling stations have been built at universities in Abergavenny, Port Talbot, Coventry and Birmingham as part of the SWARM project.

	CONSTRUCTION	
Derby	100	570
Birmingham bus	1400	1100
Birmingham public		570

In addition, there is funding to build two 570kg/day sites in central and west London.