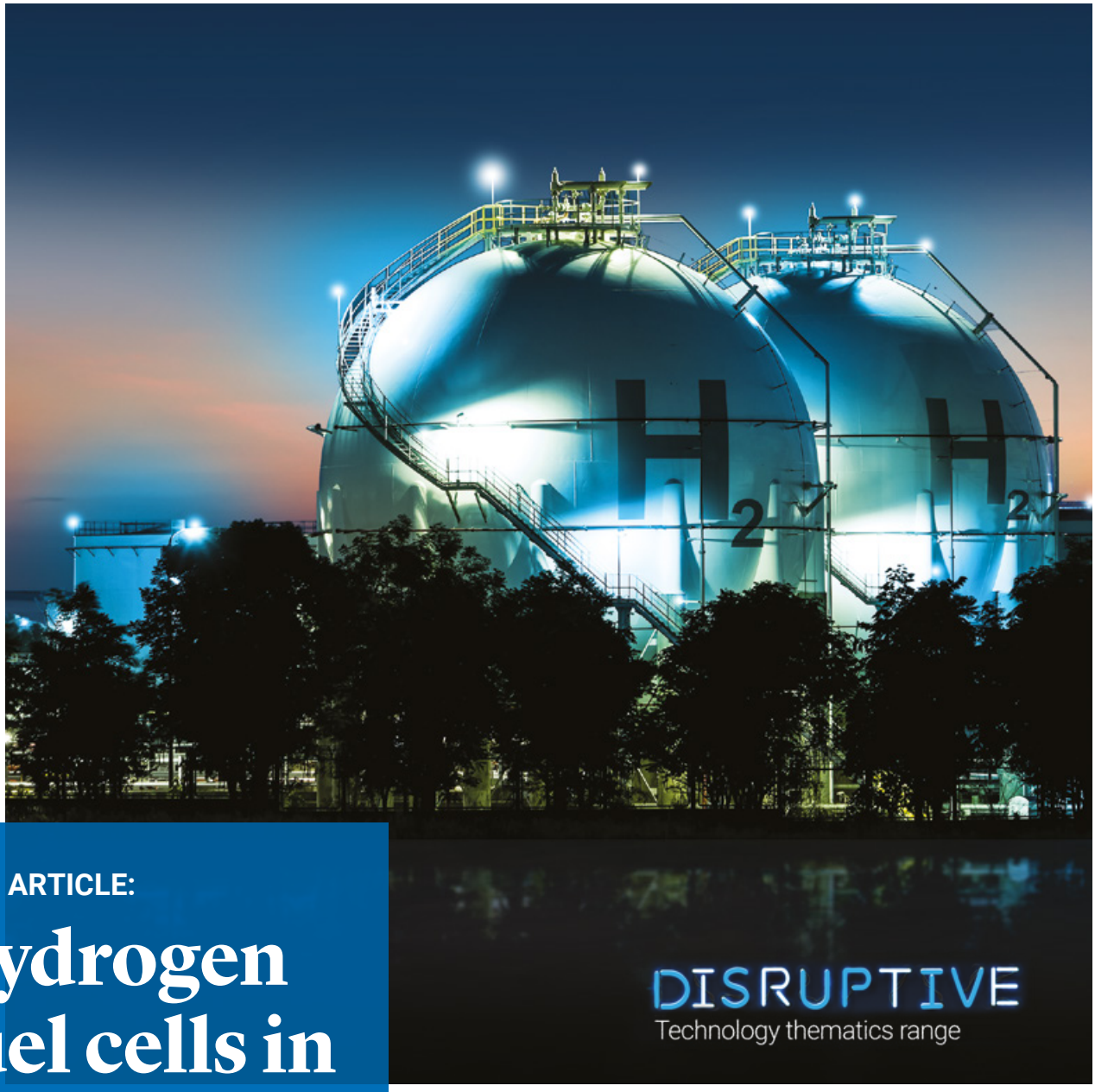

LGIM ARTICLE:

Hydrogen fuel cells in the battery economy

At L&G ETF, we remain open to new technologies and constantly monitor developments like hydrogen fuel cells and other market trends.

However, we believe that hydrogen fuel-cell technology has more distance to cover and that electro-chemical battery technology will dominate both the emission-free transportation and grid-storage sectors for at least the next decade.

Legal & General
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Hydrogen fuel cells in the battery economy

Hydrogen-based fuel cells have attracted plenty of attention recently. We've seen industry leaders expressing views both in favour of and against the technology. For instance, in 2019 Elon Musk said that 'success was just not possible' with fuel cells, but a 2017 survey of a thousand global automotive executives concluded that fuel-cell technology would ultimately outperform batteries.

At L&G ETF, we remain open to the possibility of fuel cells gaining more traction in the future and constantly engage with market participants to track the changing dynamics around the technology. Hydrogen could well be the technology of the future, but things are at a very early stage right now.

In its Energy Transition Outlook (2019), DNV GL observed that the fuel-cell electric vehicle (FCEV) and battery electric vehicle (BEV) target numbers for 2020 as forecast 10 years ago were similar. In reality, though, current fleet sizes show that less than 1% of zero-emission vehicles today are actually being propelled by fuel-cell technology in California.

According to the California Fuel Cell Partnership, 'green' hydrogen fuel prices currently average around $13.99/kg, which corresponds on a price-per-energy basis to $5.6 per gallon of gasoline. US gasoline prices are currently closer to $2 per gallon. Global Data, a leading FTSE 250 research firm, pegs the figure at around $6/kg. The Hydrogen Council, a global CEO-led initiative of 81 leading companies, estimates that fuel-cell passenger vehicles could only become viable when hydrogen prices average around $2/kg.

So simply in terms of cost of production – we will come shortly to other challenges such as fuel cells' high carbon footprint, safety issues, lack of distribution infrastructure, and loss of efficiency – the technology has more distance to cover before it can seriously challenge batteries.

Furthermore, breakthroughs in solid-state lithium-ion batteries (which are lighter, denser, more efficient, and have much longer charge cycles) and other advanced battery technologies – notably significant reductions in charging time – could make batteries even more competitive against hydrogen.

Hydrogen could well be the technology of the future, but things are at a very early stage right now.

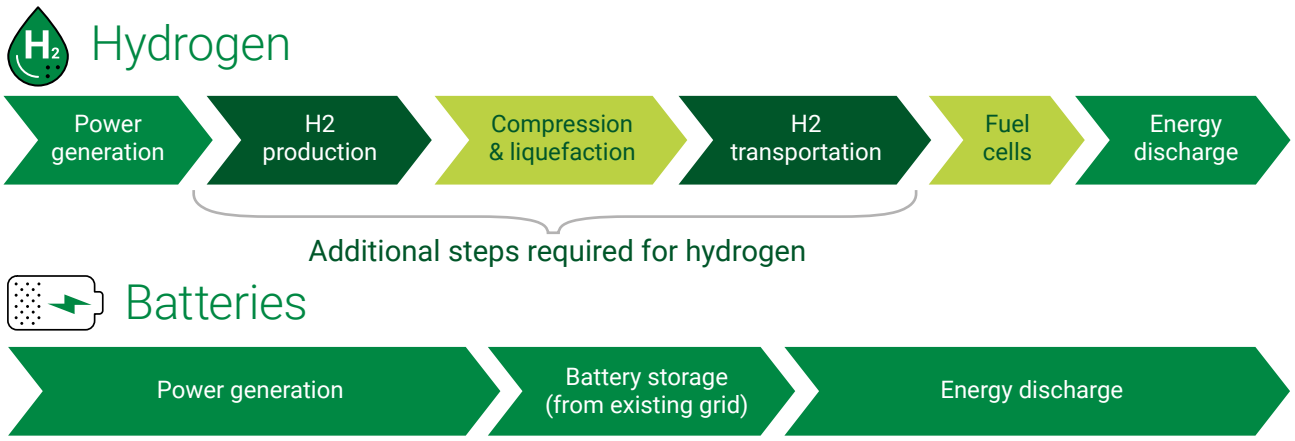
Efficiency losses for hydrogen are significant

The 'well-to-wheel cycle' of hydrogen-based FCEVs involves (i) the production of hydrogen, (ii) its storage as compressed or liquefied gas, (iii) transportation through pipelines or tankers, and (iv) extracting power through fuel cells. Compared with batteries, steps (i), (ii) and (iii) are applicable only to hydrogen fuel cells and each of these steps incurs efficiency losses.

Starting with electricity, there is a significant loss when converting hydrogen through the process of electrolysis or steam methane reforming. Second, FCEVs suffer from a vehicle energy efficiency that is only half that of BEVs. Third, FCEV propulsion technology is more complicated – and thus more costly – than that of BEVs.

Each conversion uses a significant amount of energy, and this means that (i) even allowing for low electricity prices, **with round-trip energy losses of over 50%, hydrogen energy storage options will remain marginal,** and (ii) **will have a much greater carbon footprint** if hydrogen is produced from fossil fuels as discussed on the next page.

Well-to-wheel cycle



Source: LGIM

Hydrogen production isn't as green as one may think

Hydrogen gas can be produced through electrolysis or from fossil fuels via a process such as steam methane reforming (SMR), the latter being the most common method right now. Hydrogen produced through electrolysis is commonly known as 'green' hydrogen, while the one produced through SMR is known as 'blue' hydrogen.

This blue production method, via SMR, is capex and opex intensive. Around 70 million tonnes of dedicated hydrogen is currently produced annually, 75% from natural gas and 22% from coal. Such hydrogen production generates significant CO2 emissions: 10 tonnes of carbon dioxide per tonne of natural gas (tCO2/tH2) and 19 tCO2/tH2 from coal. While the SMR process is mature and costs are expected to stay at current levels, the overall costs are sensitive to expenses related to capturing and storing CO2, which is essential to minimise the carbon footprint.

On the other hand, carbon-free 'green' hydrogen production is currently in early states of deployment and will require massive technological learning and scaling. Its weakness is that its transformation from electricity requires costly electrolysis equipment and generates substantial energy losses. However, after 2035, abundant renewable energy could potentially result in increasing shares of electrolysis-based 'green' hydrogen.

According to the International Renewable Energy Agency, the cost of electrolysers is expected to decrease by 50% by 2040-2050, from $840/kW today. The International Energy Agency estimates that green hydrogen will only become cheaper than blue hydrogen by 2030.

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Hydrogen could be economically viable but there are many challenges

Hydrogen emits only water when consumed for energy. Conversely, only water and energy are needed to produce hydrogen. This is hydrogen's main advantage.

However, there is a lack of distribution infrastructure and the storage of hydrogen is complex, which comes with a loss in energy efficiency. Building hydrogen distribution networks and refuelling stations requires far more investment and greater effort when compared to building BEV charging infrastructure (which can leverage existing grid networks).

Although the refuelling ranges of passenger FCEVs will be on a par with those of internal combustion engines for the next decades – i.e. far superior to those of BEVs – analysts at DNV GL do not expect that this advantage will be enough to offset FCEVs' cost disadvantage, where high costs associated with hydrogen-refuelling infrastructure play a prominent role.

Summary comparison between battery and hydrogen technology

	Battery technology	Hydrogen technology
Efficiency	High	Lower than batteries
Cost	Lower but still few years before breaking even with fossil fuels	Much higher than batteries
EV Range (miles)	300-350 on average	Up to 600 miles
Charge/Refill time	From 15 min superchargers to a few hours (An 80% charge in 15 mins is likely to be widely achieved within the next few years)	Under 10 mins
Technology	Simple	Complex
Transmission & distribution infrastructure	Existing infrastructure can be leveraged	Early stages to non-existent in many parts of the world
Charging points / refuelling stations	Early stages but easy to install; the charging infrastructure market is estimated to grow at a CAGR of 31.2% between 2019 and 2030, according to Research and Markets	Very early stages; only 42 stations added globally in 2019
Safety	Medium to high, depending on technology	Medium to high
Key near-term risks	- Longer charging times - Range anxiety	- Cost and loss of efficiency - Rapid advancements in battery technology - High capex and opex
Estimated EV market size by 2025 (according to Global Market Insights)	>$425 billion	$11.6 billion
Estimated EV fleet size by 2030 (according to BNEF)	>1.7 billion	0.5m-3.5m+ (7x-50x versus 2020)

Many companies in the L&G Battery Value-Chain UCITS ETF are already engaged in fuel cells

Our Battery Value-Chain UCITS ETF[1] uses Clean Horizon's real-time database of global energy storage projects to identify companies with proven energy storage technologies. The underlying index adopts an evidence-based selection approach, with electro-chemical storage providers selected based on installed grid storage capacity across various storage technologies.

Currently, Clean Horizon's database does not include any hydrogen fuel-cell related projects, partly due to the fact that there is very little installed capacity on the ground. Our ETF therefore does not currently include any hydrogen pure players, such as PowerCell or Ballard[2]. However, companies such as Nissan, BMW, and LG Chem[3] – which are included in our ETF – are already working on fuel-cell technologies and the ETF therefore derives indirect exposure to that technology. However, please note that fuel-cell technology hasn't had much commercial success yet, mainly due to inefficiencies in the production, storage and distribution of hydrogen.

Based on various third-party research, we believe that it is less likely that hydrogen will be widely used for passenger (light vehicle) road transport, at least in the near term. In fact, various automobile manufacturers are looking at hydrogen only as an alternative fuel for long-haul trucks and industrial trucks such as fork-lifts in the near-to-medium term, and appear to be solely introducing BEV models at the moment.

On the other hand, Clean Horizon's research suggests that a few countries, particularly with colder climates, may blend hydrogen with natural gas and distribute the blended fuel through existing pipelines to meet their heating needs. That could prove to be more economical when electricity prices and/or carbon-capture costs reduce to an extent that makes green and blue hydrogen cheaper than natural gas.

Although challenges remain in the near term, we remain optimistic that with continued investment and further research and development, the costs and efficiency losses will decrease over the next few years and make the case for hydrogen more attractive. While there are many hurdles for hydrogen to overcome, we will continue to monitor the market for opportunities.

Aanand Venkatramanan
Head of ETF Investment Strategies

Aanand currently works at LGIM within the Exchange Traded Funds team that was acquired from ETF Securities in March 2018. He joined ETF Securities as a Director, Quantitative Investment Strategies in May 2017. Prior to that, he worked at Barclays Capital and Goldman Sachs International as a vice president within their index research and structuring groups respectively; and at University of Sussex as an assistant professor in Finance. He has published papers in top academic journals and co authored book chapters. Aanand holds a PhD in Mathematical Finance and Master s in applied Mathematics from the University of Reading.

[1] The value of an investment and any income taken from it is not guaranteed and can go down as well as up; you may not get back the amount you originally invested.
[2,3] Reference to a particular security is for illustrative purposes only, is on a historic basis and does not mean that the security is currently held or will be held within an LGIM portfolio. The above information does not constitute a recommendation to buy or sell any security.

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