IMechE response to the House of Lords Science and Technology Committee's call for evidence on the role of batteries and fuel cells in achieving Net Zero

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About the Institution of Mechanical Engineers

The Institution of Mechanical Engineers (IMechE) represents 115,000 engineering professionals and students in the UK and across the world.

The Engineering Policy Unit of the IMechE informs and responds to UK policy developments by drawing on the expertise of our members and partners.

Reason for submitting a consultation response

The IMechE's Special Interest Groups include those covering power, energy, buildings, process industries, alternative fuels, and road and rail transport. As such, we are responding to this enquiry to lend our engineering knowledge and expertise to the Science and Technology Committee on what is an important and cross-cutting topic in energy policy.

1. To what extent are battery and fuel cell technologies currently contributing to decarbonisation efforts in the UK?

- **What are the primary applications of battery and fuel cell technologies for decarbonisation, and at what scale have they been deployed?**

Applications of batteries and fuel cells as low carbon technologies for decarbonisation include:

- Power generation and energy storage at utility scale.
- Power Grid balancing services.
- Energy storage in individual renewable energy applications in off-grid and on-grid installations and community energy / distributed energy applications, including micro-grid deployments.
- Cogeneration (i.e. heat and power in micro CHP).
- Motive power (cars, buses, forklift trucks, motorbikes, aeroplanes, ships, submarines, and in heavy industry).

Power

Large-scale battery storage in the power sector is potentially useful in smoothing short term supply/demand imbalances and in managing system voltage and frequency. Although beginning to scale up, to date the deployment of battery technology in the power sector has been at megawatt/megawatt-hour (MW/MWh) levels. By comparison, fossil fuels have historically been used to provide energy system resilience and security of supply providing terawatt/terawatt-hour (TW/TWh) levels of storage capability, i.e. a factor of a million times more.

Road transport

The primary use of battery technology in the UK today in decarbonising our energy system is in light duty road transport. The uptake of electric cars, taxis, and delivery vans is increasing, but from a very low base. The purchase of these vehicles has been incentivised through Government subsidies to reduce the upfront cost to consumers, like the Plug-In Car Grant. The level of this grant has been reduced recently in recognition that the cost of battery electric vehicles (BEVs) has decreased significantly and they may even achieve cost parity with conventional vehicles in the 2020s.[1]

The switch from petrol/diesel vehicles to fully electric is beginning to reduce tailpipe emissions in the road transport sector. However, as we move towards a more electrified transport system, we should increasingly take life-cycle emissions into account. Due to the embedded emissions resulting from battery

[1] Bloomberg (2020). 'Batteries For Electric Cars Speed Toward a Tipping Point'. https://www.bloomberg.com/news/articles/2020-12-16/electric-cars-are-about-to-be-as-cheap-as-gas-powered-models

manufacture, which occur sooner than tailpipe emissions and therefore have a greater climate impact, the true emissions savings from BEVs may not be achieved until the 2030s.[2]

The vehicle that was purchased most using the Plug-In Car Grant was the Mitsubishi Outlander Hybrid SUV.[3] This would have relatively high embedded emissions associated with its manufacture and, because it is a hybrid, even the tailpipe emissions depend strongly on how it is driven and if it is actually charged up. The list of cars eligible for the grant has recently been updated to focus on smaller, affordable vehicles.[4]

Despite the Government's high-profile campaign to ban the sale of petrol and diesel vehicles by 2030, greater recognition is required for the fact that vehicles with internal combustion engines will still be on our roads for some quite time. Firstly, the 2030 ban excludes hybrid vehicles, which are allowed to be sold until 2035. The ban also only applies to light fleet. This is in recognition of the fact that long distance HGVs in particular may not be able to make the switch to zero carbon alternatives by this date. Cars and vans sold up to 2035 and HGVs with internal combustion engines sold in the late 2030s will still be on the road in the late 2040s. This is why the IMechE has advocated[5] for a greater emphasis on biofuels and synthetic fuels that have the potential to significantly reduce emissions for existing vehicles that are powered by internal combustion engines.

Although overall UK road transport emissions have remained broadly flat for the last 20 years, the average car today compared with an equivalent model sold in 2001 is more efficient. The main reasons that total road transport emissions have not fallen in kind is a trend for people to buy larger vehicles and an increase in total road miles.[6] Progressive engineering improvements to increase the efficiency of conventional vehicles, along with more use of low carbon bio- and synthetic fuels can achieve valuable near-term emissions reductions, particularly when combined with a reduction in usage (miles driven).

Hydrogen fuel cells have potential to contribute to the decarbonisation of our energy system, but their deployment so far has mostly been limited to demonstration projects so their impact on emissions reduction to this point is insignificant.

2. What advances have been made in battery and fuel cell technologies in recent years and what changes can we expect in the next ten years

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[2] Hill, G. et al (2019). 'The role of electric vehicles in near-term mitigation pathways and achieving the UK's carbon budget', *Applied Energy*, Vol. 251. https://www.sciencedirect.com/science/article/pii/S0306261919307834

[3] https://www.nextgreencar.com/electric-cars/statistics/

[4] https://www.gov.uk/plug-in-car-van-grants

[5] IMechE (2020). *Accelerating Road Transport Decarbonisation*. https://www.imeche.org/policy-and-press/reports/detail/accelerating-road-transport-decarbonisation

[6] CCC (2020). *The Sixth Carbon Budget: Surface Transport*. https://www.theccc.org.uk/publication/sixth-carbon-budget/

(for example, in terms of energy density, capacity, charging times, lifetimes and cost reduction)?

- **What advances are expected beyond this timeframe, but in time to have an impact upon the 2050 net-zero target? Are there any fundamental limits to these technologies that would affect their contribution to the target?**
- **Are there any implications of next generation battery technologies that could make the charging infrastructure we will be installing between now and 2030 obsolete?**
- **What are the implications on battery life of multiple charge/discharge cycles, for example when used to support storage and frequency management on the grid?**

In using batteries in the power sector, the regular charge/discharge cycles associated with frequency regulation place added stress on the most commonly deployed battery technology (lithium-ion). While participation in the frequency regulation markets may be initially lucrative, the increased cycle of operations results in loss of capacity, efficiency, and premature requirement to replace battery modules for such applications. The intended operational duty of battery projects should be assessed in the development stage (pre-Financial Investment Decision) to confirm that high cycling projects are financially viable. Shorter battery life due to an increased cycling frequency would not necessarily be a negative outcome – especially if increased cycling led to increased revenue in the short to medium term.

In transport, research and development has considerably improved the energy density of batteries meaning that the range of BEVs has increased considerably, though is still some way from conventional petrol/diesel vehicles. The next technological leap in the sector will come from the development and scale-up of solid-state batteries.

3. What are the opportunities and challenges associated with scaling up the manufacture of batteries and fuel cells, and for manufacturing batteries and fuel cells for a greater number and variety of applications? Is the UK well placed to become a leader in battery and fuel cell manufacture?

- **What supply chain considerations need to be taken into account when scaling up battery and fuel cell manufacture in the UK?**

Research carried out on behalf of the Advanced Propulsion Centre (APC) looked at the breadth and depth of what was required within the battery supply chain.[7] This report pulled out various chemical companies that had footprints in the UK that supported a battery supply chain. Since this report was published the UK

[7] E4Tech (2018). *The UK chemicals and process supply chain for battery manufacture.* https://www.apcuk.co.uk/app/uploads/2018/06/E4tech_Report_UK-chemical-supply-chain-for-EV-batteries_25June2018-1.pdf

has starting to work on building a battery industry. Most of the ingredients are present to transition the UK from a pioneer in battery research to a regional manufacturing hub with both world-leading R&D *and* high-volume manufacturing. A specific sustainability issue that needs to be addressed in establishing a UK battery industry and scaling-up the feedstock supply chain is the sourcing of the lithium and cobalt which is central to production. Pioneering UK sourcing and processing innovations, such as for example those developed by Cornish Lithium, need to be strategically supported in scale-up.

In contrast to fuel cells and internal combustion engines, large batteries for motive applications are difficult and expensive to transport, so they are generally manufactured in the market the vehicles are intended for.

It is important that local battery demand is enough to justify a Gigafactory investment. In many European nations that have a strong automotive base they have attracted gigafactories to be built within their local vicinity. Currently the UK has three companies that have indicated a willingness to manufacture battery cells in the UK. They are: Envision AESC (Sunderland) / AMTE Power (Thurso) / Britishvolt (Blythe).

There are two real areas of importance to attract gigafactories: (1) the access to materials; (2) the access to clean and green energy.

Therefore plans for attracting battery supply chain investments must have synergies with the UK government's plans to create zero carbon energy clusters for businesses and be connected to the UK's offshore wind ramp up, especially in places like South Wales, the North East and North West, and Scotland.

UK has several companies developing and manufacturing fuel cells including, Arcola Energy, Ceres Power, Intelligent Energy, Johnson Matthey Fuel Cells, Ryse and Adelan. Alongside this there are vehicle manufacturers that are starting to use and be involved with these organisations to develop hydrogen and fuel cell vehicles including Alexander Dennis, Changan UK, Delta Motorsport, Jaguar Land Rover, Alstom, Translink, Wrightbus, Bramble, and Arrival.

In terms of timelines on how the different vehicles may use these technologies please refer to the Product Roadmaps.[8] For detailed insight on these technologies and the challenges that they have please refer to the Technology Roadmaps.[9]

4. Is the right strategy, funding and support in place to enable the research, innovation and commercialisation of battery and fuel cell technologies in the UK?

[8] APC (2020). 'The New 2020 Product Roadmaps'. https://www.apcuk.co.uk/product-roadmaps/
[9] APC (2020). 'The new 2020 technology roadmaps'. https://www.apcuk.co.uk/technology-roadmaps/

- **Is the UK doing enough to accelerate new developments from low technology readiness levels right through to commercial application in the UK?**
- **Does the UK have the workforce and skillsets required for battery and fuel cell research and manufacture? If not, what are the challenges associated with developing this expertise?**

If this sector is priority for the Government, a more joined-up approach will be required with a clear plan to bring technologies to market.

The funding landscape is quite clear for batteries and electrification with early stage innovation funded through EPSRC and the Faraday Battery Challenge (FBC). The mid-stage innovation phases are then funded through Innovate UK, Driving the Electric Revolution (DER – which focusses on power electronics and electric machines) and FBC. Then as it gets to the challenging aspect of commercialisation the APC funding comes into play (TRLs 6-8). Finally announced last autumn was the Automotive Transformation Fund, with nearly £500m announced last year to support and de-risk investment into large capital projects.

From a hydrogen and fuel cell perspective the incentives are less focussed. Funding to pull this technology through from research to application in the UK is somewhat disparate, as are the many advocacy groups. The hydrogen and fuel cells SUPERGEN is funded by the Research Councils UK Energy Programme, as part of the government's Sustainable Power Generation and Supply initiative. It was set up in 2012 to address the key challenges facing the hydrogen and fuel cell sector as it strives to provide cost competitive, low carbon technologies in a more secure UK energy landscape.

The APC is helping drive the UK's Green Recovery and position the UK at the forefront of vehicle decarbonisation. Since 2013 the APC has funded over 34 projects in hybrid and net-zero emission vehicle technology for passenger cars, with a combined investment of £576.1 million, through CR&D competition funding (APC1 – APC16 inclusive).

In 2020 the Automotive Transformation Fund was launched with the prime objective to accelerate UK manufacturing investment of new electrification technologies, including hydrogen fuel cells.

Hydrogen, generated from renewable electricity, is at the core of road and non-road vehicle product strategy. Manufacturers see proton exchange membrane (PEM) fuel cells and hydrogen combustion engines integral to delivering UK's net-zero carbon ambitions.

5. Not answered

6. Covered in other sections

7. How should battery and fuel cell technologies be integrated into the wider UK energy system, and what are the challenges associated with integration (e.g. infrastructure, deployment, system operation, regulatory frameworks)?

- **To what extent can batteries (including vehicle batteries) be used for energy storage and frequency management on the grid, and what needs to happen to enable this?**
- **Into which other parts of the UK's energy system could batteries or fuel cells be integrated, and what would be the challenges and opportunities associated with these uses?**

Battery and fuel cell technologies could potentially play a significant role in the supply of power and energy. To some extent, possible solutions will be location specific (i.e. perhaps for heating and/or cooling) while others (e.g. long-distance transport, whether via HGVs, shipping and aviation) will require common solutions, for example in refuelling. However, our resources are finite and infrastructure can either act as an enabler or a constraint, it is not certain that having batteries and fuel cell technologies playing a significant role in decarbonising the power and energy supply sectors would be an optimal solution in supporting the UK achieve net zero 2050 as a whole.

In the power sector, batteries provide storage durations ranging from minutes to hours and can be a very useful although short term solution to support balancing fluctuations in the electricity system and imbalance between electricity system supply and demand.

The most significant challenge to greater deployment of batteries in the power sector is the fact that they only address part of the system's requirements in managing system stability, resilience and security of supply. Our present-day secure, resilience electricity system has become a foundational element of modern society over the past 50 years. It is therefore assumed that a no less resilient and secure electricity and energy supply system will be required in future.

No comprehensive legacy design basis has ever been developed for the UK's electricity or energy systems. Therefore, while system resilience and security of supply might have been plentiful in the past, no definition exists of the minimum present or future storage requirements from a whole system perspective. Also, where technology such as batteries offer a partial solution to address the overall system requirements, the remainder of which is still largely addressed by using unabated fossil fuels, it is not clear whether the use of batteries in a power application is a low or 'no regrets' solution, or whether there may be an opportunity cost which makes it harder to tackle the more difficult to decarbonise aspects of electricity and energy system operations which have not yet been addressed.

Nearly 33 million cars are registered on the road in the UK in 2020. Transitioning to battery electric vehicles and/or hydrogen fuel cell vehicles in the same time period we are intending to phase out the use of unabated fossil fuels in the UK's power and energy systems and replace them at least in part with intermittent renewable generating sources is potentially a huge opportunity for batteries (including vehicle batteries) to be used for energy storage and frequency management on the grid.

However, our focus to date has been largely on the extent that we are able to integrate new technologies (e.g. renewables, batteries etc.) onto the electricity grid. This is not an approach which will certainly allow us to deliver on our net zero 2050 aspirations. Instead, having set the UK the target of achieving net zero 2050, it now necessary to take responsibility for designing and engineering how such a system might be delivered.

Comprehensive electricity system requirements were never fully defined for the legacy electricity system which was predicated upon fossil fuel based generating plants. In particular, minimum operability requirements for aspects such as inertia and short circuit level have never been defined, either for the system as a whole, or in terms of a profile across the electricity system.

Better definition of the present whole electricity system operability requirements (and the understanding of system operations achieved in developing such a definition) is an essential first step (which we have not yet taken) if we are to then be able to understand the impact(s), or indeed feasibility, of any proposed alternative operating scenarios.

Conventional batteries cannot provide sustained system support to help address a longer-term requirements. They are also incapable of providing the long term (inter-seasonal or inter-annual) storage capability, which is presently sourced from fossil fuels (presently largely gas), to hedge against the likelihood of an exceptionally cold winter and that coinciding with a period of high pressure and a period of lower electricity generation from wind.

Utility scale energy storage technologies exist as alternatives for a range of durations, including the long-duration liquid air process energy storage system developed by Highview Power and flow batteries including vanadium-based technologies. Hydrogen could also be one way forward for long term grid balancing, and several pilot projects are underway, for example HyNet[10] and H21[11]. These potential alternatives need to be considered when considering the appropriate role of batteries and fuel cells at a whole energy system level.

There are tentative plans and proposals to repurpose Britain's gas grid so that it can be used to transport hydrogen in the future, primarily to decarbonise domestic heating. This could bring synergies with other sectors, but it should be

[10] https://hynet.co.uk/
[11] https://www.h21.green/about/

noted that if the gas network is used to transport hydrogen for fuel cell applications, work is still required to clean the hydrogen exiting the network to meet fuel standards.

As a final general comment, the fire risk affiliated with new and alternative energy carriers is an area of active research with lots of unanswered questions/uncertainties related to for example (1) likelihood, cause and prediction of ignition, (2) suitable safety measures and design approaches, and (3) fire hazard. New scientific knowledge will need to be generated and new engineering solutions developed to adequately address these challenges.

8. What are the life cycle environmental impacts associated with batteries and fuel cells (e.g. in resource extraction, product manufacture, operation, reuse and recycling), and how can these be managed as production and usage increase?

- **Please give examples of successful battery reuse or recycling, including the intentional design of second life applications.**
- **Given a potential global vehicle fleet approaching 2 billion vehicles by 2050, will all of the materials needed for battery and fuel cell production be available for manufacturing based in the UK?**

There are potential risks associated with the availability of key resources and for increased battery production rates required to serve a transition to zero emission vehicles by 2035.

The British Geological Survey (BGS) last year produced a Science Briefing Paper[12] describing in detail the complexity of the relationship of primary metals extracted from Earth for use in our decarbonisation technologies and that of recycled metals, particularly for batteries.

The BGS had extrapolated a likely increase of annual metal ore extraction of more than 50% by 2060 and emphasised that the recycling industry for these metals is struggling technically and socioeconomically and current recycling methods are ineffective. Even with recycling of these metals it will be unlikely that the primary extraction of required metals will be sustainable. It is important to consider both primary and recycled metals as part of the same system and not in isolation.

Cobalt and lithium extraction currently raise widespread concerns regarding the exploitation of the poor in developing economies in Africa and South America respectively and these ethical issues need to be fully addressed. It is analogous to the export of high carbon manufacturing while retaining the demand. The social consequences of cheaply extracted metals are well defined. It is likely that

[12] Bloodworth, A. et al (2019). 'Metals and Decarbonisation: A Geological Perspective', British Geological Survey. https://www2.bgs.ac.uk/mineralsuk/statistics/rawMaterialsForALowCarbonFuture.html

rapid increases in the demand for cheap metals will increase the numbers of illegal and poorly operated mines globally.

Additionally, the calculation of global warming potential from the manufacturing stages of the battery must account for where production is taking place and the subsequent carbon intensity of electricity generation. BGS modelling assumes that the future projections rely heavily on a shift towards Europe for the key stages of battery pack manufacture and assembly. If this does not happen, the country risks the embedded emissions in battery manufacture remaining relatively high as we currently rely on nations with significantly higher grid intensity than Europe or the UK. Additionally, the current focus on tailpipe currently ignores these offshored emissions and even a move to well-to-wheel (WTW) will not capture them – full life cycle assessments are required. In the final judgement, all these emissions will have been generated and released into the atmosphere, so we need to move to life-cycle accounting if we are to try and avoid unforeseen consequences driven simply by where we choose to draw the system boundary.

To avoid these unintended consequences, the Government should encourage innovation in low carbon vehicles beyond BEV/FCEVs and move the focus away from simply considering the tailpipe emissions of vehicles by taking into account the whole lifecycle effects on the environment.

At the end of life, safe disposal and re-use of materials is not well developed, but this presents an opportunity for the UK to lead on pioneering effective technology for recycling lithium-ion batteries. This would both improve the sustainability of the industry and present a hedge for the UK against risks to global supply chains.

9. What are the costs and benefits of using battery and fuel cell technologies in their various applications, including when integrated into the wider energy system?

- **To what extent are costs and benefits of the technologies affected by the levels of deployment or their regulatory treatment?**
- **Are there alternatives that should be considered for particular sectors?**

The uptake of electric vehicles will impose costs on our electricity system through the requirement for upgrades to national generation capacity in addition to local network upgrades and the installation of charge-points. The extent of the system upgrade will depend strongly on how and when vehicles are charged.

Wide deployment of battery electric vehicles offers the potential advantage of helping to balance electricity supply and demand, but only if combined with enabling technology and consumer trust. If domestic charge-points are combined with smart charging systems and time-of-use tariffs then wide uptake of electric vehicles is achievable with associated upgrades to local and national electricity supply infrastructure. Without smart charging, there is a risk of damage to local electricity networks through electric vehicle owners charging their vehicles simultaneously at evening peak demand.

Smart meters and time-of-use tariffs are relatively low tech and their uptake will depend more on consumers being convinced of the value of signing up. More technically challenging is the idea of vehicle-to-grid, where electricity would not just flow to plugged-in electric vehicles during time of low system demand, but also from these batteries back to the grid during periods of high demand. There are trials taking place to demonstrate whether this is feasible, including the Vehicle-to-Grid-Oxford (VTGO).[13]

In the rail network, full electrification is the most appropriate solution to decarbonise most lines that are currently running diesel trains.[14] The high cost of electrification is sometimes put forward as a reason by the Government to forego necessary upgrades, but costs are only high when individual projects are considered in isolation. A rolling national programme of rail network electrification, where supply chains and skills are maintained, would significantly reduce the over cost.

Trains powered by hydrogen fuel cells will still be appropriate in certain places where full electrification of lines is particularly challenging. There will be opportunities for synergies here if such lines link up with areas that already produce hydrogen or those that are planning to scale up production through the creation of low carbon industrial hubs, for example in South Wales, the North East and North West England, and Scotland.

In heavy goods vehicles, shipping, and certain other applications, hydrogen fuel cell electric vehicles can play a role. For example, taxis on multiple shift cycles, buses, long distance coaches, heavy goods vehicles, etc. all benefit from fast refilling and greater payload capacity offered by the lighter (than electric) hydrogen fuel cell powertrain.

However, there should be a greater focus on non-fuel cell applications of hydrogen as a transport fuel. For example, hydrogen internal combustion engines are feasible for heavy duty applications and can operate with lower purity hydrogen than some fuel cells.

Hydrogen can also play an important role as a feedstock in the manufacture of synthetic hydrocarbon and non-hydrocarbon liquid fuels. These could replace petrol or diesel in existing on- and off-highway vehicles, sustainable aviation fuels and ammonia for marine, thereby helping to reduce emissions from

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[13] EDF (2020). 'Completion of the exciting Vehicle to Grid Oxford project'. https://www.edfenergy.com/for-home/energywise/research-development-completion-exciting-vehicle-grid-oxford-project

[14] IMechE (2019). *The Future of Hydrogen Trains in the UK.* https://www.imeche.org/policy-and-press/reports/detail/the-future-for-hydrogen-trains-in-the-uk

internal combustion engines. This complementary approach to road transport decarbonisation was laid out in a report by the IMechE published in 2020.[15]

[15] IMechE (2020). Accelerating Road Transport Decarbonisation. https://www.imeche.org/policy-and-press/reports/detail/accelerating-road-transport-decarbonisation