Hydrogen Network Event

Future Capability Group (FCG)

Operational Energy Centre of Expertise

Rolls-Royce Filton, Bristol

16th November 2022

Event Output Report

CONTENTS

INTRODUCTION

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CONTEXT

The Defence energy environment is changing; resilience and energy security acquire primary focus together with a host of social, economic, environmental and political aspects to be considered. The Future Capability Group (FCG) is part of the UK-MOD's DE&S organisation. FCG and Team Defence Information (TD-i) in collaboration with Rolls-Royce, launched the Hydrogen Network Event (16th November 2022) to investigate hydrogen power and technology and its place in the hybridized energy environment for the future Defence sector.

CUSTOMER THEMES

- Hydrogen as an energy vector.
- What are the challenges, what is the vision?
- Why should Defence invest in hydrogen?

EVENT

The event was well attended, with 86 guests signed-up and over 100 visiting on the day. Delegates from academia, science and technology, utilities, MOD, military and defence industry, were present.

The AM session comprised of addresses from MOD, RAF, Rolls-Royce, BP, Ryze, EMEC and DASA. This was followed by workshop discussions in mixed groups across a range of topics, facilitated by the Rolls-Royce Graduate team. Attendees were also asked to prioritise the discussion questions (topics) in a survey, the results of which can be seen overleaf. This report summarises the workshop discussions and the topics presented in priority order according to the survey.

THANKS

Our thanks go to the speakers who have developed our understanding of the hydrogen challenge. Also, Mr David Evry (FCG), Mr Darin Tudor (TD-I) and Mr Dave Gordon (RR) for their support throughout. Not least our thanks go to the Rolls-Royce Graduate team for their help in delivering a successful event and for taking the opportunity to grow their knowledge, interest and opinions in this vitally important field.

EXECUTIVE SUMMARY

This report summarises the workshop discussions which took place during the Hydrogen Networking Event.

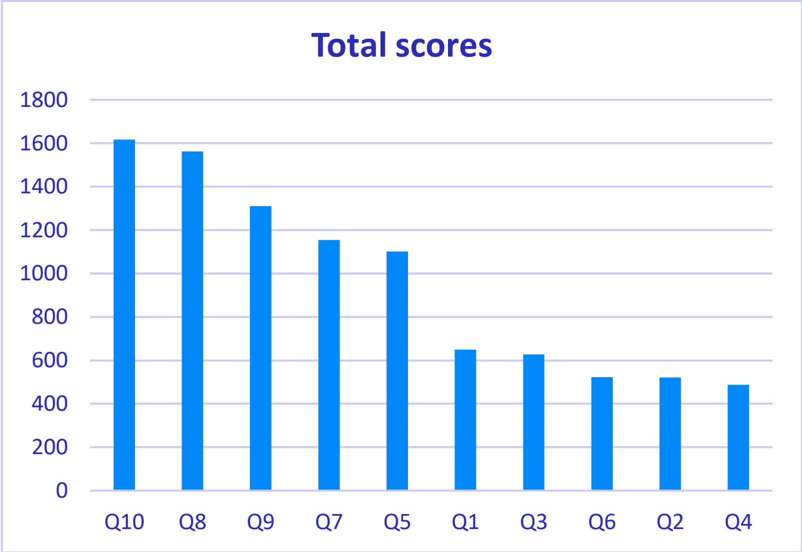
- Reveals the importance of resilience, energy security enhanced capability for the military end user.
- Reveals the advantages and challenges of elevating hydrogen technology to a more marketable position.
- Reveals the need for a Defence 'energy transition' roadmap.
- Reveals MOD opportunity to be pioneer of hydrogen technology, in the Defence sector.
- Reveals the need for new standards, policy and regulation that reflects the emergent needs.
- Reveals the need for investment and consideration of benefits social, economic and environmental.
- Reveals the need for cross-sector collaboration, to realise the potential of hydrogen technology.

SURVEY

Attendees were asked to prioritise the discussion questions (1-10) in a survey, the results of which can be seen here. This report is presented in priority order according to the survey responses

	Important			*Keep your eye on these*				*Will follow*		
Weighting	89	55	34	21	13	8	5	3	2	1
Number of q 1s	2	3	2	6	2	5	3	6	3	7
Number of q 2s	1	1	4	3	6	4	7	7	5	3
Number of q 3s	3	3	1	4	1	1	2	6	10	9
Number of q 4s	1	2	2	3	3	7	7	3	8	2
Number of q 5s	6	2	8	2	5	6	3	2	4	1
Number of q 6s	1	4	1	3	2	5	3	7	4	7
Number of q 7s	3	10	3	3	9	3	4	2	1	3
Number of q 8s	4	11	11	9	1	1	2	2	0	1
Number of q 9s	7	5	7	3	4	4	3	2	2	3
Number of q10s	14	1	2	5	7	3	4	1	1	2

Priority	Question	Total scores
1	**Q10**	**1616**
2	**Q8**	**1562**
3	**Q9**	**1311**
4	Q7	1154
5	Q5	1101
6	Q1	649
7	Q3	628
8	Q6	523
9	Q2	522
10	Q4	487



QUESTIONS:

1 (**INFLUENCE**) Hydrogen, what do we need to know?
2 (**PREPARED**) Now that we've got hydrogen, what are we going to do, with it?
3 (**EXPECTATION**) This time next year, we'll all be using hydrogen!
4 (**TRANSITION**) Hydrogen's coming - ready or not!
5 (**PERSONA**) Hydrogen, the Pros and Cons.
6 (**SUSTAINABILITY**) The Lean Green Fighting Machine!
7 (**TECHNOLOGY**) Hydrogen made easy!
8 (**EFFICIENT**) Hydrogen Production, Distribution and Storage.
9 (**REQUIREMENTS**) Standards, Policy, Regulation.
10 (**PROBLEM**) Bigger picture, understand the problem space.

1. PROBLEM

Bigger picture, understand the problem space

From the outside looking in, what does the MoD problem space look like? What are the main challenges or unknowns? What small steps can be taken now that build momentum and direction? Consider contracting for 'power as a capability' and the missing DLOD (Energy).

UK Net Zero (NZ50) and decarbonisation at a national level does include the MOD. However, the MOD must ensure that the implementation of novel energy technologies including hydrogen is done in such a way that military capability is enhanced (not undermined). MOD should also consider the lead time of implementing new technologies and that delays may also reduce Defence effectiveness.

Development of sustainable energy technologies and fuels is moving fast. Currently, MOD fleets of ships, tanks and aircraft are not inherently compatible with hydrogen fuel and given their long in-service lives, could prolong the introduction of hydrogen into the Defence network. The pro's and con's of hydrogen (and other fuels) needs further understanding. Could UK-Defence become a global leader in the use of hydrogen power?

Overarching logistical challenges can 'make-or-break' military operations. Reducing dependency on traditional supply chains (such as fuel) will reduce costs, risk to operations and life. The ability to make hydrogen fuel (or other fuels) 'at point of need' will address this to a degree. It is possible however, that local production of hydrogen fuel (at a deployed military base for example) could be equally complex? Feedback from the end-user community may provide valuable insight into making the process more efficient.

Hydrogen has to become a cost effective and viable energy solution for Defence. Fixed and deployed hydrogen infrastructure needs to be considered; transporting hydrogen fuel cells to a deployed base location does not eliminate the risk of attack.

Could 'locally' produced hydrogen be made in sufficient volume for the end user (fixed or deployed setting). Sewage and wastewater could be a source of hydrogen fuel (microbial production), as well as clean water and compost etc. Could the technology be scaled to meet the demands of the military user. The application of hydrogen technologies must be carefully targeted to maximise benefit, value and effect.

Hydrogen infrastructure requirements for production, storage, distribution are significant and likely to take time and considerable cost. If hydrogen is going to be part of the future defence energy environment, it needs to be planned, budgeted and started now.

Technology in the energy sector is moving fast (diversifying). Despite the MOD's current association with a NATO Single Fuels policy looking ahead, dependency on a single fuel type is a single point of failure. The implementation of multi-fuelled/powered equipment (different types of vehicles of all types) would enhance freedom of action, manoeuvre and resilience. Where are these capabilities (FoA, manoeuvre, endurance/resilience), likely to be of highest value in each command/domain?

Synthetic/biofuels could also be a useful stepping-stone towards decarbonisation. Hydrogen does not necessarily have to be a 'front-line' or end user fuel type. Hydrogen could be used in the process of synthesising 'hydrogenation-derived renewable diesel' (HDRD) for the front-line use.

For NetZero goals 2050 MOD (2040 RAF) the potential for hydrogen power to be realised. Greater MOD collaboration across academia, the technology sector and defence industry is essential.

2. EFFICIENCY

Hydrogen production, distribution, and storage

Matching supply with demand will be a vital component to the successful integration of hydrogen into the future Defence energy environment. What are the likely constraints? How can this be achieved efficiently?

Production: Electrolysis is a keen point of interest for Defence in terms of hydrogen production, where wind as a renewable energy source for green hydrogen is an emerging and promising solution. The challenge of intermittent supply of power from renewables for a constant demand or use (hydrogen production) can be addressed by using alternate sources of power (e.g., nuclear) to achieve this.

Storage: Metal hybrids provide real interest and scope for static or mobile storage of hydrogen, owing to the low pressures associated with this. On the downside, the relatively low hydrogen outputs to high metal ratio is of concern, such that it is heavy and may be difficult to transport. Extraction of hydrogen in a gaseous form from metal hydrides is good for power generation at source. Hydrogen in liquid form, where hydrogen needs to be created (made into liquid hydrogen), is even more energy intensive and requires alternative fuels to do so.

The industry (hydrogen technology sector) is currently trying to optimise this, with technology now at approximately TRL 4-5, achieving 7-8 before it can be used efficiently. Hydrogen stored as a liquid is more energy dense but much harder to contain (safely), particularly with larger loads (higher capacities) over longer distances. Fuel cells are promising but are currently in low supply.

Transport: Technology for the transportation of hydrogen is developing, even high-capacity loads over long distances within some economies in the world. Use of Ammonia powered transport is the most cost-effective way of moving large amounts of hydrogen. Furthermore, pipes can transport 10x more liquid hydrogen than trucks. The questions emerging from this are: how will hydrogen be transported to remote areas? Metal hybrids remain a possibility for this (not without their challenges), but may not become sufficiently mature, or produce hydrogen in sufficient volume?

Distribution: A safe, secure hydrogen infrastructure is required but is not currently available. In the case that production requirements are fulfilled, how will it be constantly fed along the appropriate channels?

Demand: Military demand is high and requires a constant supply. Green hydrogen requires a renewable source in large volume, which is available but intermittent. A possible solution is provided by the presentation given by Neil Kermode (EMEC), which has shown to be successful.

3. REQUIREMENTS

Standards, policy, regulation

Standards (policy and regulation) will help and hinder. Should the MoD lead in the development of new standards for the application of hydrogen power and powered applications for Defence and wider UK (cross-sector)? How can this be achieved?

International standards are globally implemented within the power industry, particularly where the energy source/type is common. Hydrogen currently does not have these same standards and regulations. If hydrogen is to become a global form of energy, a set of standards must be established and enforced internationally.

No singular entity (company/government department) should be solely responsible for the creation of these standards but they may need to initiate the process. In terms of national standards, it is the responsibility of the MoD, the Transportation Department and critically the operational energy authority to act. These standards can then be used to help guide regulations at a global level (similar to nuclear and aviation).

Due to a lack of existing standards, developments in hydrogen are being made without them. This could result in issues surrounding safety, compatibility, quality and commercial in the future. Standards, policy and regulation is therefore an urgent requirement in this industry. This will require a balancing act, not to stall innovation but ensure safety to protect a developing sector.

Producing standards will require a disciplined systems approach to prepare for the unknowns and provide a realistic operating minimum. A diverse range of standards will be required for hydrogen, covering production, purity levels, storage methods, pressure of storage, refuelling techniques, instrumentation, calibration, distribution (transportation) and use. Standards will also be required for operators of hydrogen powered ships, planes, vehicles. This diversity reinforces why no single entity could produce effective standards. It is in the interest of those working in this industry to assist in the creation of current/future standards.

Whilst difficult to produce a one-size fits all global standard for producers and users of hydrogen, standards should attempt to be as common as possible. International standards must prioritise safety and consider various national approaches to establish a global minimum standard.

4. TECHNOLOGY

Hydrogen made easy!

What technologies are likely to make hydrogen power and hydrogen powered applications a reliable, safe option in the Defence context? What adjacent technologies or capabilities become critical enablers to this?

A significant benefit of hydrogen power and technology is the potential to reduce dependency on traditional supply chains. This could increase resilience whilst reducing casualties. However, it may not be possible to produce hydrogen fuel in certain locations and in the volume required. Application of hydrogen technology in the Defence energy environment should be targeted for maximum benefit or effect.

The likelihood of (hydrogen) leakage needs to be minimised and the ability for the container to withstand a possible attack/blast is important. Implementing a safety mechanism (*e.g.,* flare disposal) is essential to mitigate potential damage during an attack.

Hydrogen can be integrated into applications requiring a quiet system with a low thermal signature. Currently, small petrol-based drones are loud and hot and are therefore more likely to be detected. Hydrogen can be applied to a range of water vehicles (vessels), particularly those too small for nuclear power. However, if these smaller vehicles are to operate with hydrogen, larger fuel tanks will be necessary, resulting in additional weight and size. Creating a lightweight fuel tank with the required strength properties remains a technical challenge. The ability to store hydrogen as a liquid is equally challenging.

If hydrogen products, services are to be introduced into the Defence environment the skills, knowledge and expertise to do so, safely and reliably will need to be developed. Defence should lead the initiative in the hydrogen revolution, collaborating cross-sector. Further efforts should be directed to improving battery technology, for potential hybrid systems involving hydrogen.

5. PERSONA

Hydrogen - the pros and cons

Consider the benefit of hydrogen power to the MoD (the government department) and also the military command (war fighter, land sea and air)? What are the trades that need to be understood?

Hydrogen powered front line vehicles are an unlikely development, given that diesel provides all the required capabilities. However, hybrid land vehicles (diesel/hydrogen or diesel/electric) could offer improvements (to operations) - acquired through the use of sustainable power. Trade-off: Diesel offers a level of energy security, although hydrogen or batteries will reduce the vehicles acoustic signature?

With regard to RAF transport aircraft (Air Mobility) such as the RAF's C-17 or A400M, hydrogen may not be the most suitable fuel. These aircraft travel to remote locations where the hydrogen infrastructure is not/will not be available. Therefore, these aircraft would benefit more from having a multi-fuel capability.

Consensus in this discussion group was that resilience is the critical or defining factor for military operations. However, resilience could be increased by diversifying the energy and fuel portfolio to eliminate reliance on a single fuel or energy source.

There is a need for Defence to decarbonize and hydrogen should become part of the response to this. Road transport is a good area to focus on, such as the MoD's white fleet and fixed location infrastructure.

Hydrogen could be used to power front line vehicles, where threat or effect determines a clear use case. If there is a requirement for hydrogen on the front line, this requirement must be satisfied with technological developments. For example, kerosene is less than 5% efficient with small UAVs (0.5-1 kW), therefore these vehicles would benefit from hydrogen.

Demand for the use of hydrogen power and technology across defence is low, which makes planning a transition to hydrogen difficult. It is recognised that hydrogen experiments are taking place in Defence (RAF Leeming). The MOD should conduct an analysis to determine where the use of hydrogen is likely to deliver the highest benefit over time (effect, decarbonisation, energy security and cost). Defence should act as pioneers in considering methods of measuring these benefits within their analysis.

6. INFLUENCE

Hydrogen, what do we need to know?

Knowledge and Skills, Hearts and Minds. What do we need to know about hydrogen technology and hydrogen powered applications to ensure that its potential is realised?

Currently, the barriers to expanding the use of hydrogen is the lack of investment (cross-sector) and shortage of skilled personnel with appropriate hydrogen expertise.

There is also (safety) apprehension regarding use of hydrogen which must be addressed. Strategically we must create a clear 'need' for the development of hydrogen power and associate technologies, then train and qualify the people required. If the need is already there, how can we exploit this? The aerospace industry uses traditional kerosene-based fuel systems, and the "rule book" on these is well understood. This does not yet exist for hydrogen – not a bad place to start!

How can hydrogen know-how grow? There is a 'chicken and egg' situation emerging. UK needs a good stock of hydrogen specialists, who are pioneering today to teach the next generation of those coming through. Note: The post graduate community in Sustainable and Renewable Technologies is vast.

What level of training is required? New types of knowledge transfer, training and qualifications are required for those entering or engaged in the hydrogen sector – make it attractive. It was suggested that a graduate secondment could be a way to promote the transfer of knowledge.

Hydrogen skills are niche. Research projects create some natural knowledge transfer, although questionable how useful this is in the mainstream. Demonstrator projects do not necessarily create the continuous flow of knowledge the sector requires but these are good starting points.

We should investigate how previous power technologies become mainstream and consider the importance of need and its influence on pace and uptake. Also, what can we learn from international partners – fast follower.

Consider how a local (off-grid or isolated) hydrogen infrastructure would be phased in to operate with hydrogen powered technology (vehicles, plant, power-gen) and the training/education requirements around this. Consider a modular approach.

7. EXPECTATION

This time next year we'll all be using hydrogen!

What are the likely expectations (user and supplier) in relation to the routine use of hydrogen power and hydrogen-powered applications in a Defence and military context?

The development of hydrogen technologies in Defence/military is reflected in the challenges the wider hydrogen industry faces today, such as transport, storage (containing hydrogen in its liquid or gaseous form) and new infrastructure requirements, such as complex pipelines and dispensing equipment. These are unlikely to be resolved quickly. The use of hydrogen power and technologies should target smaller lower risk functions, requiring moderate consumption of hydrogen.

To design and develop a safe, enduring, sustainable and cost-effective energy environment (which includes hydrogen), it will need to be scalable. One way to tackle the hydrogen transportation challenge is the local generation of hydrogen, such as modular hydrogen generators or via electrolysers and micro-reactors (no transport required).

Alternatively, Wastewater Fuels Ltd. are currently developing the technology to transform wastewater into 'biological hydrogen'. The wastewater may come from a variety of waste sources, including human, animal or food, or even rich waste from breweries. Using wastewater, as opposed to fresh water is cheaper and does not contribute to the water shortages experienced worldwide. This technology is on track to reach 500% efficiency in the coming year, thus making it an excellent candidate for local hydrogen generation (e.g., on military camps).

Duty holders have a responsibility to assess risk in their operation and so a thorough understanding of hydrogen technology is required. Looking at smaller applications of hydrogen powered technology first (*e.g.,* drones or airfield vehicles) would enable the spread of knowledge and confidence, as well as provide a baseline for future projects to come. Hydrogen can used to optimise the use of synthetic fuels and avoid costly engineering compatibility issues.

If the RAF are to achieve NetZero by 2040, it will be necessary to understand the distribution of power within military camps and estimate the power requirements per person over time. The creation of a model or simulation of a military base could be useful for this objective.

8. SUSTAINABILITY

The Lean Green Fighting Machine!

What sustainability opportunities should the MoD target in relation to the use of hydrogen power from a social, economic, and environmental perspective? How can they be measured? Where do the priorities lie?

Investing in hydrogen has the potential to create job opportunities, boost local communities and increase economic growth. If the UK can become a world leader in hydrogen technology, there is the potential to sell hydrogen technology products and services globally, creating an economic knock-on effect due to other countries adopting hydrogen.

The MoD will need to promote understanding of the full cycle/ supply chain of energy, as well as be transparent on scope 1, 2 & 3 emissions, to prevent "green washing".

Can both hydrogen and SAF (sustainable aviation fuel) be used together to meet demands? With the consensus that diesel remains a fuel with a compelling set of performance attributes customers, stakeholders, users of hydrogen fuel are considering if this is the correct approach to tackle environmental issues.

Customers are focused on the economic (cost and efficiency) aspects of hydrogen, with the social and environmental benefits following in 2^{nd} and 3^{rd} place. The MOD may consider promoting the environmental benefits first in order to influence the highest number of people, subsequently the demand for hydrogen should emerge.

It is important to be able to measure the value of a sustainable energy such as hydrogen, to make the assessment on how the operation benefits over time. No single energy solution will meet all the needs of the MOD going forward (2035 and beyond). Could hydrogen be used where gaps in the Defence energy environment emerge?

Priorities on the application of hydrogen in the Defence environment remain unclear, particularly due to the high cost of hydrogen and the technical barriers of safe use. The MAID (MOD's Approach to Investment Decisions 2020) process could be used to create sustainability benefit cases.

9. PREPARATION

Now that we've got hydrogen, what are we going to do with it?

How can the MoD take advantage of today's hydrogen power technologies and then scale the benefits across the future Defence Energy Environment?

A clear roadmap is required to bring novel (now existing) technologies into the MoD.

Consider forming an expert consortium (RR, JCB, Ryze, BP for example) to facilitate this roadmap and build on the case studies of Transport for London (Ryze) and Teeside hydrogen plant (BP). Implementing hydrogen will require collaboration across multiple companies to secure supply infrastructure, reduce time to market and minimise initial research and development costs.

Use digital modelling techniques (digital twins) to undertake digital trials and investigate methods of scaling. (understand where the bottlenecks (and sweet-spots) lie). Do this alongside actual trials, then actual scale.

BP and Ryze expect to see hydrogen in common use in the UK by 2030-2035. Sharing knowledge with the MOD would enable them to accelerate the use of hydrogen in military applications. It would also contribute to reaching price parity with existing hydrocarbon fuels. Demonstrator vehicles (tanks, tugs, HGV's, white fleet plus AIR and SEA applications where possible) may be trialled to gain insight into how hydrogen can be expanded across a defence network.

Current engines could also be converted to a 'dual fuel' system by adding a hydrogen storage tank. A good application for a dual fuel solution would be tanks, which are typically armoured and so could protect the hydrogen storage tank. The MoD could employ hydrogen delivery tanks to supply the Defence environment, and the development of small hydrogen canisters would allow a level of energy security (as batteries). The hydrogen combustion engines could be used in zones with 'dirty' air environments, to avoid the clogging of fuel cells.

Use of hydrogen for marine applications is limited at current level of TRL. It is difficult to refuel hydrogen at sea and the storage capacity is not sufficient for long missions. Ammonia or methanol fuels may be a suitable alternative for marine use. 'Fuel cell drones' have received funding from DASA. Hydrogen fuel cell drones are quieter, have a lower heat signature than gas turbines and in theory, have more range and a quicker refuel time than battery drones. Fuel cells are also more scalable than hydrogen combustion since the manufacturing industry is well established.

10. TRANSITION

Hydrogen's coming - ready or not!

How should the MoD implement hydrogen power and hydrogen-powered applications? Which actions, in what order and when are likely to inform a plan for success?

It is important that the MOD analyse where they are likely to achieve the best outcomes following investments in hydrogen technology. Consider TRL's cost, carbon and effects. There is little use in creating a hydrogen engine for a product that does not require that level of power.

The main consensus is that if you can electrify (such as transition vehicle transport to EV's) this should be the first step. If this is not practical, is there a slot for hydrogen? Again, if that is not possible, sustainable hydrocarbons can be employed *i.e.,* synthetic fuels.

There are many issues associated with hydrogen fuel and technology, largely linked to storage.

Can hydrogen fuel withstand the environment? In what state will the hydrogen be used: liquid (more dangerous) or gas (less effective)? Can it be used successfully in hot climates? Problems with both transport and storage in hot climates can cause issues, including replenishment.

Volatility is another consideration of this fuel source (which burns hotter than hydrocarbons), particularly if in an active war zone, which can be detrimental if shot down, causing catastrophic explosions and reducing the likelihood of pilot survival.

Research and development will be required to determine new sustainable materials that can withstand this heat without damaging equipment.

The MOD would be a very promising initial customer for the UK hydrogen industry and help overcome many of the key challenges anticipated. The application of hydrogen technology in Defence would likely filter into civil use (together with people familiar with using it) leading to a greener UK.

CONCLUSION

Hydrogen is here.
The application of hydrogen technology (and hybrid powered systems) must be targeted, such that Defence benefits and military capability is enhanced.

The So What?
Need to understand more about hydrogen technology and how to exploit it. Should I use hydrogen as fuel or use hydrogen-power to make fuel? Use digital techniques to explain how, where and when hydrogen technology delivers best value over time. Create a Defence Energy Environment (Transition) Road Map.

Get going!
Partner with industry and academia, undertake small hydrogen technology projects, learn fast and scale. Develop the confidence and know-how around hydrogen. Forecast when hydrogen technology becomes an enduring, dependable source of energy and applied in the target areas selected.

Investment
Hydrogen production, storage, transportation, distribution has significant cost and lead times. Consider how to express benefits, risk and opportunity in ways that Government can appreciate. Consider the cross-sector benefits and export potential as well as sustainability (social, economic and environmental) benefits. All become a valuable parts of the case for investment.

Innovation headline
'MOD becomes global leader in hydrogen technology. Catapults UK industry, technologies, standards, policy, qualifications and skills to new levels'.

We feel the event was a real success and highlighted the diversity of interest in this topic. It revealed examples of pioneering progress and for some how little we really understand.

DE&S - FCG (Operational Energy) finds itself surrounded by relatively new and long-term programmes such as QE Class, F-35 and A400 but with Future Programmes such as Type 26, Type 31, FCAS on the horizon (with alternative energy demands). The latter will operate in a significantly changed technology, security, threat and climatic environment, than the former.

Change is taking place. By 2035 a single fuels policy may well become a single point of failure? Hydrogen technology is a likely component of the future defence energy environment, just need to find out how. We hope this event and report has helped.