Defence: Sustainability as a Competitive Advantage

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Executive summary

Climate change presents a systemic challenge to society. This challenge is driving an unprecedented sustainable technology revolution. Participating in this revolution has the potential to improve the agility, resilience and capability of our armed forces. Failure to adopt changes in sustainable technology could leave our armed forces, weaker, less agile, less resilient and less capable than our adversaries.

In 2023, colleagues from AECOM, BAE Systems, Frazer-Nash, the Royal United Services Institute (RUSI), and the Defence Science and Technology Laboratory (Dstl) committed to work in partnership to deliver a series of roundtable events with support from the Directorate for Climate Change and Environment (MOD). These events sought to address the details of a common issue: how can the defence sector overcome the affordability/ incentivisation gaps which limit the uptake of scientific and technological solutions typically described as 'Climate Change and Sustainability' (CC&S) products. They brought together leading innovators and academics across multiple institutions; the conclusions of which are summarised here.

The defence industry has some unique challenges in considering CC&S products. First and foremost is the perception that CC&S represents an additional cost and comes at detriment to operational capability; the primary purpose of defence. Furthermore, the exacting nature of defence equipment means long term development and commissioning cycles inhibit the options for rapid change and alteration. The requirement for certainty, reliance and dependency also restrict experimentation with new technology resulting in the defence industry more frequently being a fast follower in integration of emerging technological solutions (though at times there can be safety or legal reasons for this).

Conversely, the points made above create the argument for why the defence sector needs to address CC&S aspects in military capability planning now, as options to adapt further down the line could be more costly and disruptive. The potential impacts of climate change on current and future operating scenarios are increasingly understood, as is the general transition away from fossil fuels. Both factors require the defence sector to be thinking now about climate change adaptation and its implications for products and capability and the requirement for energy resilience and security both in platforms and across infrastructure and bases.

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The group consensus followed a number of core themes:

1. Communicate Value of Sustainability in Business Terms

Currently, CC&S issues are addressed separately from operational discussions, limiting the sector's ability to leverage and integrate the optimum solutions. Despite this challenge, the defence sector now has growing evidence and experience to overcome some of these obstacles.

It is important to ensure that the value of CC&S is communicated in terms of capability. Typically, sustainability is presented from a 'green' perspective and identifies the benefits to the environment. This does not create the imperative for 'why now' or communicate potential to benefit operations. We, therefore need to present CC&S in the business language that resonates with our customers – resilience, energy security, operational effectiveness and energy transition. These efforts will typically be associated with reduced emissions and lower environmental impact but these benefits are realised as an outcome rather than the primary intent.

The language we use also needs to reflect business requirements. We need to be clear on the value and positive impact of a sustainable solution; and, in addition to expressing this in terms of capability, there should also be the business and economic case. This is where applying the longer term, whole life-cost model and costs of adaptation should be brought to bear.

2. Ensure fit for the future & clarify the cost of delaying decisions

The term used by NATO to describe the risk posed by ongoing climate change is 'threat multiplier'. This encompasses both the potential physical impacts upon natural environments (e.g., temperature, flood, drought etc.); and the geopolitical consequences to consider implications for future operational capability and security. NATO released the Secretary General's annual Climate Change and Security Impact Assessment on 9 July 2024 (NATO, 2024) within which there is a strong emphasis on the need for energy security, resilience and adaptation: matching the terminology being utilised by MOD.

The MOD has a need to consider the potential needs and design of the force in 20 and 30 years, (rather than traditional five- or ten-year cycles), and the assets that the future force will and won't require., All the effects of climate change are not yet appropriately embedded within planning processes. This could compromise MODs understanding of the utility or potential redundancy of essential products in different contexts.

Since commercial technology development often evolves faster than government time-scales, there is a need for clarity on the route by which industry and academia can better contribute to identifying and characterising the requirements of future operational capability.

As we support this development of the future force mix, it is our responsibility to address the consideration of sustainability in these solutions. We should be highlighting the impact of delaying investment in specific technologies, or where not investing could restrict future capability and have possible cost implications.

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3. The role of the 'Sustainability Team' is to enable informed change

The need for agility will become more apparent as MOD enters Epoch Two of the Climate Change and Sustainability Strategic Approach (MOD, 2021), which requires upscaled implementation of solutions proven to help defence adapt to the effects of climate change during Epoch One.

Our role as the sustainability experts is in supporting the defence community in addressing the impact of climate change. The challenges of rapid technology uptake are not unique to our domain, however (we as the sustainability community) need to work together to create the case for change that will inform the decision makers.

In conclusion, the consensus of the group is that we need to change WHAT we do by changing HOW we do things. By changing our narrative from 'greening defence' to 'How we sustain defence capability in a changed climate' we will be able to advise on the advantages of, and build the case for, adopting novel solutions with environmental benefits.

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1. Introduction

In 2023, colleagues from AECOM, BAE Systems, Frazer-Nash, the Royal United Services Institute (RUSI), and the Defence Science and Technology Laboratory (Dstl) committed to work in partnership to deliver a series of roundtable events with support from the Directorate of Climate Change and Environment (CCE) within MOD.

These events sought to address a common issue for defence Climate Change and Sustainability (CC&S) practitioners: how to overcome affordability/ incentivisation barriers affecting the uptake of solutions typically described as CC&S products. The roundtable discussions offered the opportunity to learn from recent experiences, drawing upon a broad knowledge base from industry and academia (see Appendix 1 for detail).

Climate Change and Sustainability are both broad topics with numerous sub-themes. Therefore, the group sought to work through various facets of a single problem to understand where defence is already delivering results, and to identify actions that could enable defence CC&S practitioners to achieve greater impact.

The discussions revealed a shift in the culture of CC&S practice in the defence sector. The operational benefits of solutions are now presented first, before the wider environmental impacts are acknowledged and communicated. This helps counter the perception that climate change and decarbonisation can be a distraction from defence's warfighting focus.

Industry is already creating products that are more environmentally responsible than their predecessors in alignment with their values, and often their shareholders. CC&S practitioners can help MOD to capture these benefits by ensuring products are presented for their impact upon operational efficiency, resilience or agility, with wider benefits also communicated.

Climate Change in the Defence Context

Climate change presents a systemic challenge for society. The physical world we live in is changing, and presenting more extreme weather ranges and associated emergency events. At the same time, there is great technological change underway as society and industry are pursuing decarbonisation and alternatives to fossil fuels; increasingly prioritising sustainability.

These transitions will shape how defence operates, but also the security risks that it will be tasked to manage. The decisions made today will determine how easily our forces can adapt to operating in the conditions of tomorrow.

Without taking action, there is a risk that carbon-reliant systems could become entrenched within future force designs, especially in logistics support, affecting capabilities, budgets and operational licenses.

This underscores the need for the CC&S community to confidently explain the mission-relevant aspects of climate solutions, and to capture the broader benefits of implemented solutions.

Many of the technological solutions are developing outside the defence sector, and there is potential for MOD to gain operational and environmental benefits by adopting them. Yet, the 'climate challenge' is often seen as something that will be urgent in the UK, but is not currently a tangible, or confronting threat.

Currently, MOD procurement frameworks don't provide the most productive space to capture non-monetised benefits – such as reduced emissions and improved energy security. Nor do they recognise the potential for one-off investments to yield multi-year savings and ease wider budgetary pressures

The UK defence sector has a long history of adopting civilian technologies for military operations or militarising existing technologies to navigate complex or challenging physical environments. Yet in recent decades, there has been a shift from defence-first innovation to defence adopting/adapting commercial technologies.

There remains a broad lack of understanding as to how climate technologies can enhance the operability of defence. The speed of technological development exacerbates this problem.

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Embedding Climate Change into Defence Practice

Often, CC&S conversations feel separate from operational discussions, limiting MODs ability to leverage the best available solutions. There is a need to ensure that CC&S focuses (e.g. resilience, sustainability of supply, energy security) are aligned with efforts to secure operational advantage, and that successes realised are communicated.

The relevance of CC&S to defence is well recognised, with MOD and NATO publishing a range of relevant strategy documents and educational resources in recent years (MOD, 2021, Strategic Command, 2022, NATO, 2024, Dstl, 2024), providing valuable narratives as to why climate change matters to defence.

The Defence Operational Energy Strategy is a great example of how CC&S narratives can be effectively communicated in the traditional defence operational language (MOD, 2023).

Defence CC&S practitioners have typically attempted to straddle the language used by wider society to describe climate threats and solutions with defence language. However, the recent shift towards operational language appears to be delivering enhanced results and should be adopted more broadly to help MOD achieve its ambitions.

Despite these challenges, the defence sector now has increasing evidence and experience to overcome some of these obstacles.

Already, there are solutions that can shorten logistics supply chains, reducing costs, and reducing security risks for deployed personnel, all while significantly cutting emissions from production and deployment. However, more needs to be done to communicate how CC&S solutions can offer enhanced operational results compared with their predecessors.

Purpose

The event series sought to focus on actionable conversations about climate change, facilitating focused in-depth conversations over an extended period (six months).

Participants were invited from industry and academia (including think-tanks) to share their views on how climate change and sustainability practitioners in the defence sector can overcome financial and incentive barriers that limit engagement with CC&S solutions.

The event series presented a rare opportunity for government, industry and academia to reflect upon the requirements to turn the 'so what' narrative, into a 'how to' approach, identifying opportunities for collaborative action which can enable MOD to develop a more agile, resilient and adaptive force.

This paper documents the shifting approach observed amongst CC&S practitioners towards an intentional operational framing of CC&S solutions, an approach endorsed by the organising committee.

It provides examples of infrastructure and capabilities projects that have a proven ability to respond to operational requirements, whilst also delivering carbon or environmental effects. Case studies later in the report provide further detail as to the operational benefits that can be achieved whilst also realising significant climate benefits, namely reduced emissions.

The report also presents a range of actions that could be undertaken by defence focused CC&S practitioners aiming to increase the quality of advice available to MOD to help to overcome financial and incentivisation barriers.

The Roundtables & Methodology

The group planned a series of four events that delved into different aspects of the overarching theme of overcoming financial/incentive barriers for CC&S solutions.

As set out in Table 1 each event was designed around a sub-theme and featured two discussion sessions designed to enable detailed conversations around problems and solutions.

Methodology

Each discussion session was guided by a chair from the planning group. Notes were taken by group members during each event. Upon the conclusion of the event series, the notes were collated and processed to create a list of all suggestion actions or case studies highlighted during the eight sessions.

Over 100 actions were raised across the events, and this data was processed to create the final actions presented in section 6. The remaining notes helped to form the basis of sections 3 and 4 which focus on defence infrastructure and capabilities. Case studies were selected which reinforced the core takeaways of the events: CC&S solutions can respond to operational requirements, and reduced emissions can be achieved as a result of responding to these requirements without reinventing the defence machine.

Above: The events were hosted in the RUSI Library in London, between October 2023 – March 2024. Credit: Chris Jones, RUSI © shared with consent of those featured.

The report draft was 'challenged' by a small number of attendees, along with a group of industry and academic experts, who were asked to provide feedback on whether the report was aligned with their experience and understanding. Feedback was provided through written comment and verbal discussion, and was used to refine the report. This process was implemented to ensure that the report findings do reflect the general position of the defence CC&S community.

	EVENT & TOPIC	SESSION 1 FOCUS	SESSION 2 FOCUS
1	**Incentivising climate adaptation & mitigation**	Mitigation	Adaptation
2	**Tangible cost benefit analysis (CBA)**	Strategic outlines for business cases	Making CBA work for the future
3	**From innovation to implementation**	Learning from experience	Future collaboration
4	**Future technology landscapes**	Working within ongoing transitions	Future technology landscapes

Table 1: table of events delivered and themes discussed

3. Infrastructure

The Challenge

This section focuses on the opportunities that lie within defence infrastructure associated with deployments and non-routine operations, i.e. bases and supporting infrastructure, as opposed to permanent accommodation.

Although home bases and deployed bases can differ substantially in their requirements and risks, solutions already exist which can offer UK defence a competitive advantage in both contexts.

Additionally, infrastructure presents the opportunity to look at examples beyond the UK (and even beyond defence) to consider how the pursuit of operational effectiveness is enabling a reduced carbon footprint. Some of the leading examples have been framed by their resilience benefits.

In 2020, a United Nations (UN) report stated that building climate resilience involves 'all actors (governments, communities and businesses) having the capacity to anticipate climate risks and hazards, absorb shocks and stresses, and reshape and transport development pathways in the longer term' (UN, 2020).

In this context, to improve climate resilience, there is a need to assess how climate change will create new, or alter current risks, and take steps to better manage these risks (The Centre for Climate and Energy Solutions).

The challenge is to find ways of explaining and reporting which work within existing frameworks to enable defence to capture more results without 'reinventing the wheel'. It is also critical to help MOD understand how solutions which may not initially appear mission-critical can in fact improve the security or efficiency of operations or address medium-or long-term risks which typically extend beyond the traditional five-to-ten-year planning cycles.

The defence operational estate offers an excellent place to build confidence in these skillsets, given the breadth of case studies and examples which can be drawn upon as evidence of success within and beyond defence. Even where projects have been pursued primarily for decarbonisation benefits, operational efficiency and resilience has improved.

MOD bases within the UK face a range of climate-related risks, including rising sea levels threatening naval bases, rising temperatures affecting airfield runway requirements, and potential storm damage to firing ranges.

Further afield, RAF Akrotiri in Cyprus has been considered at risk from the effects of wind and coastal erosion for over a decade (MOD Defence and Climate Change Inquiry, 2022; Lucy Blue, 2018; J.F.P. Galvin, 2014). Some MOD bases require updating to improve efficiencies, whilst others still have unrealised opportunities to build upon existing standards.

UK defence must also consider the requirements for the infrastructure it will take in support of future operations, planning for current and future climate risks in the countries where the UK is likely to operate.

Therefore, mitigating climate risk in defence infrastructure and exploiting associated opportunities is essential to ensure that future deployments can be sustained within their operating environments.

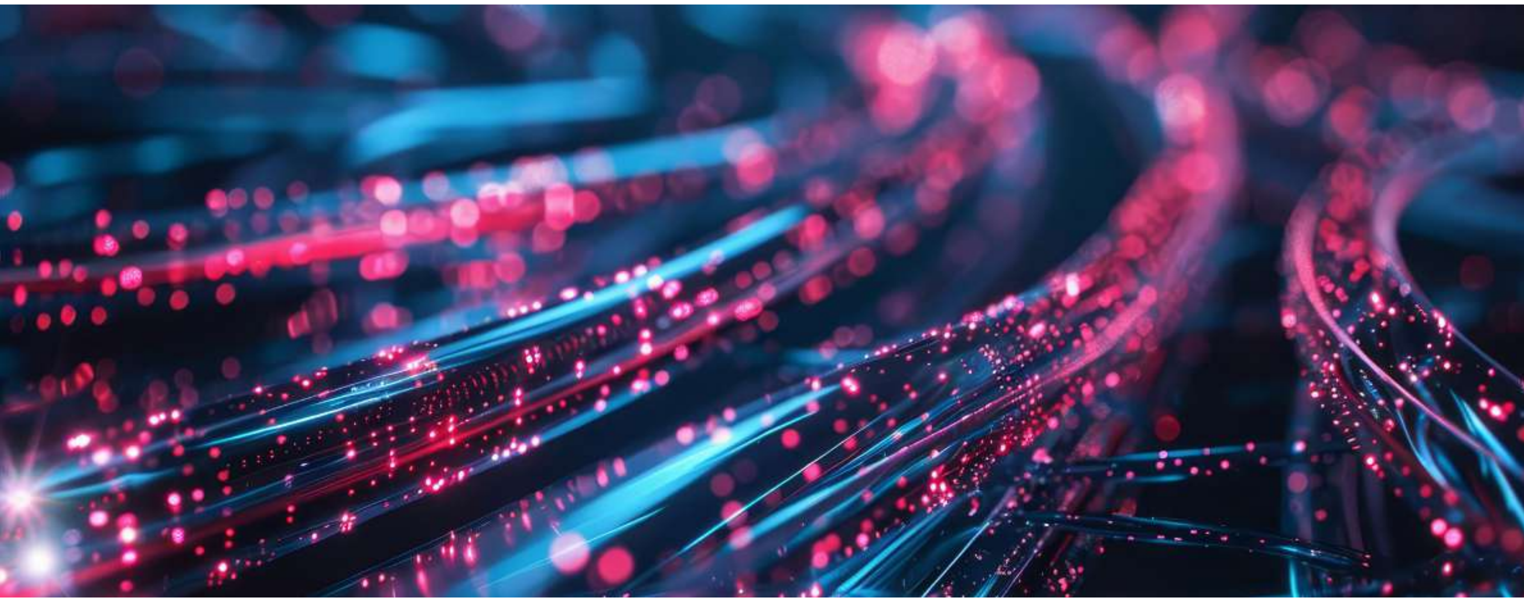
Adapting bases to such significant risks will be an expensive endeavour, and as such, it's likely that the required works will transcend traditional defence planning cycles. In some cases, bases may need to be entirely relocated. MOD requires support to understand the practical responses which will mitigate or even eradicate climate risks to fixed bases.

Energy resilience is a crucial focus area for MOD, helping it adopt technologies that address both traditional operational risks and wider climate-related risks.

A US Presidential Policy Directive described energy resilience as the ability of energy systems to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions (U.S. Office of the Press Secretary, 2013).

The war in Afghanistan (2001-2021) saw UK Defence's logistics supply chain pressured by fuel demands, and MOD budgets heavily affected by price shocks to the fuel market due to the demand increase associated with the war. Yet the ability to transition defence capabilities from traditional fuels is both complex and costly – as shall be explored in the subsequent section.

This necessitates a reduction in fuel and energy consumption in other areas associated with operations to protect the logistics function and national finances.



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Solutions

One simple approach is to analyse inefficiencies in fuel purchasing to identify opportunities for streamlined expenditure. Such aims can also be achieved by incorporating – or 'militarising' – the use of technologies designed for their CC&S benefits because of the operational advantage they offer in a defence context.

In 2023, newspapers reported Ukraine's use of microgrids on the battlefield, deploying the technology to power communication systems and power the systems that run artillery units and tactical operation centres (Microgrid Knowledge, 2023).

In January 2024, the U.S. Army announced the results of operational trials of a microgrid system at Fort Liberty (US Army, 2024).

Exercises had tested the ability of the AMMPS 120kW microgrid system to power the 528th Field Hospital, which is currently fuelled by 100kW generators. Exercises tested the ability to power 56-bed and 92-bed configurations, demonstrating the effectiveness of microgrid technologies in meeting operational requirements.

More recently, the US DOD has invested in commercial geothermal technologies, recognising the opportunity to generate power which could sustain an operation in the event of either cyberattack or fuel-supply disruption, offering security advantages in both home and deployed contexts.

The news and analysis website Defense One reported that the transition away from oil helps the US to ensure that it does not offer an 'economic boost' to a potential adversary through fuel purchasing (Defense One, 2024).

Geothermal technologies are not weather dependent, increasing the potential for their use in a defence context. Geothermal power plants are considered a ‘greener’ source of energy, with life cycle emissions reportedly four times lower than solar PV technology, and between 6-20 times lower than natural gas, also consuming less water on average than traditional power generation technologies (Open Access Government, 2023).

This highlights the ability to pursue both competitive advantage and advantage denial in an operational context, whilst also realising significant reductions in defence emissions without additional effort.

There remains an opportunity to explore how UK defence can sustain operations beyond energy production by using generated energy as an asset. Energy produced could be transferred or even sold to national grids.

Such capacity could enable MOD to contribute to the energy security of UK society, to contribute to stabilisation or humanitarian focused operations in conflict or climate affected zones, or to offer support to the host nation of an overseas operating base.

Additionally, defence purchases of climate-relevant technologies could strengthen geopolitical relationships by adding value to the resources of partner nations and contributing to their industrialisation (European Union External Action, 2023). The UK could also offer energy production and storage technologies to allied nations to support their own national defence (in circumstances where the UK is not a combatant nation).

McKinsey reported in 2021 that a typical base could support its annual electricity demand with 40-50 acres of solar panels (McKinsey, 2021). This is equivalent to the roof area of a mid-size site. Whilst it could be argued that this creates an increased strike risk for defence bases, they are already a strike risk, and this option would not increase the footprint of the existing base.

However, it reduces the risk of strike to additional structures associated with fuel storage or transport, which could help to increase the human security of operations as a secondary consequence.

Solar panels have already been trialled and proven within traditional built environments, meaning data and lessons learned are already available. Solar technologies for more niche military environments – such as air hanger roofs – are being developed to enhance the option for solar applications in a defence context.

These examples underscore the opportunity for MOD to develop greater independence of power generation, from energy extraction/creation through to energy access. Methodologies also exist which can help to identify solutions.

Circular economy methodologies allow MOD to assess a product’s value and efficiency from concept to disposal – potentially identifying investments that quickly pay off through greater efficiency of use.

Systems thinking can help MOD to better understand how energy systems and existing technologies will interact with one another.

One project which combines these approaches is the ViTAL Living Lab at RAF Leeming, led by Newcastle University (Newcastle University, 2021), which explores the applications for sustainable energy and carbon reduction solutions on an RAF base.

Infrastructure to support electrified platforms is also a necessary consideration for MOD. Whilst some platforms and equipment across the domains may continue to rely on traditional energy sources for the foreseeable future, the quantity and nature of electrified capabilities is already in flux.

Project LURCHER supported the experimental electrification of British Army Land Rover Defenders. If adopted for operational use, bases must be able to sustain their use, requiring the ability to supply power. Producing this power at – or near – the point of use will reduce the need to transport conventional fuels into theatre, helping to protect the security of supply.

The use of unmanned aerial vehicles (UAVs) has expanded significantly in the war in Ukraine, highlighting a range of opportunities for the UK.

In the context of reconnaissance, the use of an electric UAV instead of a traditional patrol unit within a conventional vehicle could significantly reduce operational emissions associated with such activities, improving human security by reducing the need to task personnel with conducting these duties in person.

Although the landscape of opportunities remains vast, there remain a range of risks which should inform MOD thinking, due to their ability to compromise defence operations. Some 'green' technologies have supply chains which are heavily controlled by foreign nations, from extraction of materials to manufacture and supply.

Academia and industry can help MOD to manage these risks by analysing market capacity and identifying risks for current and future supply.

The requirement for MOD infrastructure to operate in increasingly severe temperatures presents numerous challenges. Civil society has developed a plethora of technologies which are already demonstrating the ability to offer operational advantage in a military context. UK defence does not need to reinvent the wheel to reap the benefits of these technologies now.

The operational case has already been demonstrated in many instances, and industry has helped defence to recognise to additional benefits resulting from investments made across defence estates, such as reduced emissions.

Resilient infrastructure is crucial for sustaining all MOD operations. Therefore, its functionality – even in the most extreme of environments – cannot be compromised. Defence infrastructure offers an area full of quick wins, with the potential to deliver long-term benefits within and beyond MOD as a result of business as usual.

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4. Platforms & Equipment

The Challenge

In 2021, Lieutenant General Nugee wrote that the character of warfare is changing fast, as is the climate (MOD, 2021). Consequently, defence must adapt how it operates, what it operates with, and how it prepares for demands upon its services.

Because of the unique nature of defence (namely warfighting, humanitarian disaster relief, and capacity building), the operational capability of platforms and equipment will always be top priority for MOD.

Approximately 70% of the military carbon footprint is estimated to be associated with the use of mobile assets or platforms (Roland Berger, 2023).

A significant proportion of defence emissions remain attributable to the use of aviation fuel, with this amounting to nearly 35% of MOD's total emissions in 2019/20 (Defence Aviation Net Zero Strategy, 2023).

These statistics indicate the magnitude of the challenge for UK defence to adapt to a future state where fossil fuels are widely unavailable, cost prohibitive or incompatible with allies' systems. Whilst MOD cannot control the market's ability to create alternative fuels, there are a range of existing technologies which offer operational advantage and also deliver reductions in emissions.

There is a common misperception that decarbonising defence platforms and equipment compromises operational capability.

However, group discussions highlighted numerous examples where reduced emissions resulted from technological advancements or operational requirements. For instance, simulation and synthetic training enable platform fuel efficiency improvements and increased use of in-situ power generation for operational logistics.

Many of the technologies and methodologies discussed have proven effective in addressing long-standing challenges associated with transporting fuel to the front line; a task which is costly and creates vulnerabilities – as was starkly demonstrated during the Afghanistan War (RUSI 2024 – 'Retaining the Hard-Won Lessons of Britain's Afghan War', publication pending). More recently, the primacy of logistics during operations has been well reported during the ongoing Russia-Ukraine conflict (Ronald Ti and Christopher Kinsey, 2023; Jack Watling et al., 2024).

Reducing the logistics supply chain will enhance operational resilience, reduce human security risks and protect defence operations from fuel market price shocks. Emissions could be reduced as a result of reducing the supply chain and should be reported. In an era shaped by a need to do more with less, CC&S practitioners must improve their ability to communicate solutions that boost operational resilience and efficiency to deliver effect.

There are a range of technologies, beneficial to CC&S, which can respond to the problems of today, such as the size of the logistics supply chain. But, already, defence leaders are having to make decisions about equipment and platforms that may still be in use in twenty- or thirty-years' time.

This means that it is essential for the community to support defence to understand what the future operating environment may look like. Taking the examples of Italy and Iraq presented the NATO 2023 Climate Change and Security Impact Assessment (NATO, 2023); temperature projections indicate heats which may result in serious changes to engineering requirements, and may even exceed the safe working limits of equipment and platforms.

Therefore, it is critical that defence is informed about the ranges within which capabilities will be used within their planned lifecycles when making decisions today to maintain operational effectiveness.

Solutions

The global transition away from fossil fuels has presented another challenge for defence, forcing a creative approach to innovation and capabilities planning. As previously described, RAF use of aviation fuels represents the largest source of MOD emissions. The RAF has signalled its intent to be net zero by 2040 (RAF, 2021) with a focus on using sustainable and synthetic fuels for aircraft, upgrading equipment with hydrogen and electric alternatives, and developing electric aircraft.

As part of this, a successful flight of a microlight aircraft, powered by synthetic UL91 gasoline was undertaken in 2021. All these activities are prefaced by the requirement to maintain operational effectiveness. However, it is recognised that the volumes of sustainable aviation fuels (SAF) required both for the commercial and military sectors do not currently exist.

There is significant work ongoing across the sector to enable the use of SAF in air platforms, such as the November 2022 test flight of an Airbus Voyager powered by 100% SAF (MOD, 2022), and a subsequent trial in April 2023 where a Voyager powered by a 43% SAF blend refuelled four Eurofighter Typhoon fighter jets (Airbus, 2023).

MOD is already working to establish a routine procurement pathway for SAF as a means to realise the Defence Aviation Net Zero Strategy (MOD, 2023). The Department for Transport's work to support the development of a 2025 SAF mandate may help to enable industry.

However, defence will need to continue to work closely with producers to ensure that they stay ahead of wider market demands to ensure that the physical volumes required can be procured. This speaks to the NATO recommendation to experience an "Energy Transition by Design" (NATO, 2023).

The Eurofighter Typhoon (produced by a consortium led by Airbus, BAE Systems and Leonardo) is now powered by electric battery ground power units, replacing diesel systems to reduce running costs by 80% whilst reducing emissions by more than 90% (BAE Systems, 2022).

The Dassault Aviation Envoy IV CC Mk1 was purchased to replace the British Aerospace 146 (known as Bae 146) to fulfil the Command Support Air Transport (CSAT) function of providing timely and discreet transport of high priority personnel and mission critical freight to, from or within operational areas (RAF).

The medium-sized aircraft will produce fewer emissions than the larger BAE 146 or similar-sized aircraft, with a fleet supported by synthetic training facilities to reduce live training requirements and associated emissions.

The developing Boeing E-7 Wedgetail aircraft will replace the E-3 Sentry fleet, providing the next generation of the RAF's Airborne Early Warning Capability with a Northrop Grumman active electronically-scanned radar (DE&S, 2023).

The Wedgetail is designed to fill a capability gap, but unlike its predecessor, it does not use Sulphur Hexafluoride (SF_6) as an insulating medium to 'prevent electric flashovers in the hollow conductors of the antennae' (Department of Energy & Climate Change, 2014).

The Wedgetail limits the emission of SF_6 during ascension and potential system leakages, reducing the operational impact upon the environment without compromise to the military effect.

In the maritime domain, the Royal Navy (RN) is seeking to adopt a mindset of modular ship design, within which engines can be interchangeable – as opposed to the tradition of building the hull around the engine. A range of CC&S solutions have also been adopted, with trials continuing to exploit the potential for energy resilient, interoperable fleets.

In June 2024, the BAE-produced patrol ship HMS Tamar completed an exercise with the US and Australian Navies; within which HMS Tamar berthed alongside USS Emery S Land, joined by HMAS Leeuwin on the outboard side before making connections that enabled the ships to receive fuel, water and electricity from USS Emery S Land (Royal Navy, 2024).

This exercise demonstrated a potential to expand operations by reducing resupply requirements, and enhancing access to maintenance or engineering works during operations. At DSEI, 2023, ISL spoke about the importance of climate change and sustainability and announced that the RN with industry partners will conduct a shipboard demonstration of sustainable fuel.

In the land domain, developments are now advancing our understanding of the potential for hybrid and electric armoured vehicles.

The aforementioned Project LURCHER has enabled the Armoured Trials and Development Unit (ATDU) to work with Electrogenic and Babcock International to develop tactical electrified vehicles.

Land Rover Defenders were adapted to reduce thermal and acoustic signatures, improving downhill safety and increasing straight line speed, with the benefits of increased exportable power and reduced emissions.

Though the civilian commercial market is typically embracing all-electric vehicles, their utility in the defence context remains contested. A study by the US National Academy of Sciences, Engineering and Medicines has concluded that full electrification is "not practical for a majority of battlefield vehicles now nor in the foreseeable future" (National Academies of Sciences, Engineering, and Medicine, 2021). Project Lurcher may challenge some of these assumptions, although alternatives to full electrification also exist.

Hybrid Electric Drive (HED) vehicles offer a relevant solution for a multi-domain operating environment. These vehicles are powered by an internal combustion engine, an electric motor(s), and an energy storage system such as batteries.

This means they don't need extensive charging infrastructure on the battlefield, as they charge while in use and rely on the existing fuel supply infrastructure. HED vehicles can improve range and fuel economy, provide electrical power for enhanced C4ISR capabilities, and reduce overall lifecycle costs (BAE Systems). A further benefit of operating in hybrid mode is increased stealth and reduced thermal footprint.

BAE Systems has been testing the integration of HED technologies into existing Bradley Fighting Vehicles within the Combat Vehicle Power and Energy architecture and mobility capabilities development program.

This work is being executed under a prototype agreement from the U.S. Army's Rapid Capabilities and Critical Technologies Office to increase vehicle efficiency and boost power generation to support integration of future technologies and greater mobility for combat vehicles on the battlefield.

Military benefits aside, HED vehicles may potentially provide better protection against fuel price shocks during wartime and generally help reduce fuel spending.

The use of drones as military aircraft in Ukraine represents yet another twist to the ever-changing character of war.

Military and civilian designed drones have been deployed in a range of ways. Drone use has become more lethal, enabling improved reconnaissance and reducing kill chains, i.e. the identified structure of an attack (Kristen D. Thompson, 2024).

When used for reconnaissance purposes, they reduce the need for personnel to physically travel to or within the relevant territory, improving human security with the benefit of reduced emissions. They can also offer similar benefits in a humanitarian assistance and disaster relief (HADR) context.

As such, drones may play an increasing role in navigating extreme environments which may present health risks to UK personnel, but may be tolerable to an adjusted enemy.

Associated with platforms use, synthetic environments training offers armed forces the opportunity to improve familiarity with platforms and terrains from convenient locations without the use of fuels.

Synthetic environments can complement in-platform training by enabling repetition or allowing the user to build confidence in complex manoeuvres or extreme environments without encountering risks to personal safety.

Environments can be modeled to envision future scenarios that might seem unfeasible today, such as the case studies of Italy and Iraq presented by NATO. These models can help personnel identify potential future risks before they develop, allowing industry to generate methods to adapt to such conditions.

There are a broad range of initiatives across defence equipment which are helping defence to deliver the required military effect in theatre whilst reducing the impact of the products manufacture upon the environment. For example, BAE Systems is developing NATO compliant lead-free rounds with a lighter weight, meaning less emissions will be emitted during their transport (BAE Systems).

The absence of lead will protect the environment and human health from lead contamination. Other lead-free cartridges are available, made from recyclable materials like zinc, tin, and aluminium, ensuring that disposal and battlefield clearance are both efficient and responsible.

Researchers at the University of Sheffield are working on a remotely-operated robotic system, MediTel, which will enable trained medics to provide immediate diagnostic services on the battlefield and conduct observations where timely in-person support is not available.

MediTel aims to minimise the risks to military personnel on the frontline and address the need to “reduce decommissioning activities carried out by humans in hazardous environments.” This innovation could “revolutionise our ability to access contaminated areas that are unsafe or impossible for humans to enter” (DASA, Dstl and NDA, 2023).

Small robotics systems can be powered without fossil fuels, reducing emissions associated with use, and reduce or remove the requirement for larger vehicles to move medical staff within the theatre, reducing emissions associated with transport and use, and minimising human security risks to medical staff.

Not all CC&S products will offer cost saving benefits, e.g. it is difficult to improve the sustainability of radio product, so their purchase will not be viable. However in some cases, products are cheaper, or similarly expensive, yet deliver benefits aligned with operational and net zero strategies.

The products presented do not encompass all solutions available. The number of products with proven CC&S benefits that are already in service is significant, and the opportunity to communicate the impact of existing technologies and the potential for future technologies remains vast.

Image credit: Adobe Stock | #216485912

5. Next Steps & Opportunities

As previously described, the roundtable series enabled eight discussion sessions across four events.

The core takeaway from the event was that there has been a shift in language and approach within the defence CC&S community, moving away from green possibilities to a focus on more traditional business language around operational capability and resilience.

This report has provided a range of examples as to how this approach has already been successful in practice.

For industry and academia, this does not represent a change to how business or research is done, but rather how it is framed in the defence context.

In recognition of this shift, roundtable participants helped to identify ways in which defence CC&S practitioners can respond to financial and incentivisation barriers commonly experienced.

This section features the actions that the organising committee believe can best enable MOD to benefit from CC&S expertise, and enable CC&S practitioners to align with wider operational practice.

Four core themes emerged within the actions which are: publishing core stories, the cost of not changing, collaboration and agility. This section describes these themes and the related suggestions for actions or works which could help to create the evidence base or conditions for MOD to overcome barriers identified. These actions are neither tasked nor funded, but highlight practical opportunities for works which could help to initiate positive change, and who might be best placed to undertake them.

Publishing core stories

There is a need to publish more core stories and case studies that can describe the benefits of CC&S technologies in a defence operational context, or quantify the impact of delaying investment in different products and solutions. Creating these resources will increase the evidence available to defence decision makers.

	PROBLEM	RECOMMENDED ACTION	SUITED TO
1	**MOD requires access to case studies which can contextualise the risks and opportunities that climate change presents to operations.**	**a)** Academia & Industry should seek to create and publish more case studies which explain climate risks and benefits within an operational context. **b)** MOD & Dstl should explore appropriate processes to capture case studies produced, e.g. an annual call for case studies to support a UK register of case studies or creation of an evidence-base for access via MODNet to facilitate access for personnel.	**a)** Academia & Industry **b)** MOD
2	**More research is required to understand positive and negative tipping points.**	**a)** Academia & Industry should conduct research which can help the sector to build confidence in interrogating, quantifying and/or communicating the consequences of action or inaction and any associated second or third order consequences. Research should be supported by outputs which can help to operationalise results, e.g. vignettes or scenarios, workshops or wargames.	Academia & Industry

Table 2. Recommended actions to support the publication of core stories.

The cost of not changing

There is a need to explain the position that CC&S technologies can help to achieve operational advantage, and to communicate the impact of not capturing the opportunity that these technologies present, including upstream and indirect impacts. The following actions describe activities which could help MOD to understand potential implications of not investing in a product or service, and which may enable learning from stakeholders or other sectors.

	PROBLEM	RECOMMENDED ACTION	SUITED TO
3	**It can be difficult to communicate the effects of choosing to not invest in a product or solution.**	**a)** Industry and academia should seek to expand the evidence base by publishing case studies, which can contextualise or quantify the impact of delaying investment in specific technologies, or of choosing not to invest.	Academia & Industry
4	**MOD needs support to quantify current and future costs associated with climate risks. Also, support to understand the return on investment for solutions.**	**a)** Academia and industry can support MOD and Dstl through research and activities which may help to improve the balance of investment insights. Activities which increase access to non-governmental risk frameworks and methodologies may add value.	Academia & Industry

Table 3. Recommended actions to explore the cost of not changing.

Image credit: Adobe Stock | #478133647

Collaboration

The defence CC&S sector is already working collaboratively, delivering joint projects and activities. The following actions describe projects and outputs which will support wider MOD activity associated with future scenario planning.

	PROBLEM	RECOMMENDED ACTION	SUITED TO
5	**MOD must consider force design and requirements for the next 20 and 30 years. Any related work must reflect the effects of climate change upon the force and their operating environment.**	**a)** MOD should investigate ways to improve engagement with relevant external experts during future scenario planning. It should consider where climate scenarios can enable decision makers to engage with/mitigate relevant threats to operations. Industry and academia should seek to deliver activities which can help decision makers to build confidence in embedding climate into future-focused scenarios.	Academia, Industry & MOD
6	**Academic research indicates that future temperatures will exceed operating ranges for defence capabilities and infrastructure.**	**a)** Academia, industry and Dstl can support MOD by working to increase the availability of future temperature models. **b)** Industry and MOD can collaborate to review methodologies and timelines for testing, evaluation and verification of platform, equipment or infrastructure performance to maximise future resilience.	**a)** Academia, Industry, MOD & Partners Across Government **b)** Industry & MOD
7	**Industry often looks to MOD for a steer as to which solutions it intends to invest in to inform future production. Yet MOD requires improved awareness of the solutions available to provide this.**	**a)** Research and activities which support improved awareness of what new/emerging technologies do, what they will replace and what new ways of working they enable. Activities which explore technological integration will enhance understandings further.	Academia, Industry & MOD

Table 4. Recommended actions to support enhanced collaboration.

Image credit: Adobe Stock | #205559004

Agility

CC&S practitioners are well placed to help MOD to understand future technology requirements, and the support required to enable the industrial supply chain. The listed actions may help to create the evidence base and awareness required to interrogate futures-based scenarios, and better enable MOD to capture the right technologies at the pace of requirement.

	PROBLEM	RECOMMENDED ACTION	SUITED TO
8	**The way that MOD works is not aligned with the cultures and expectations of investors who fund SME's, making it difficult to fund and sustain SME projects.**	**a)** The community has an opportunity to explore how MOD can work more closely with UK SME's and Primes through creating a mutually supportive process or ecosystem. **b)** Investors and SMEs could collaborate to explore the potential to design technology for use across multiple sectors, reducing reliance on defence funding and take up without affecting scalability.	**a)** Academia & Industry **b)** Industry
9	**Technology often evolves faster than government timescales. Support is required to identify technologies, materials, components which may become redundant during their service lifetime.**	**a)** Work is required to improve awareness of new technologies and initiatives in the CC&S space, and to communicate which technologies may become redundant as a result of their use.	Academia, Industry & MOD
10	**His Majesty's Treasury had evolved process for other sectors (e.g. construction) to reflect emergent priorities. There may be similar opportunities for MOD.**	**a)** Academia and industry should conduct research which helps MOD to understand how HMT process/adaptions to process have 'un-locked' barriers in different sectors; and the opportunities for MOD to achieve similar results to enable the purchase of CC&S technologies which offer sustainability or resilience benefits to military operations.	Academia, Industry & Cross-Government
11	**MOD has an opportunity to develop a climate security informed Vulnerability Threat Assessment, or similar risk-based register.**	**a)** Industry and academia should conduct research or activities which can help to identify an existing framework or process that could be expanded or replicated to reflect climate security risks.	Academia & Industry

Table 5. Recommended actions to support enhanced agility.

Image credit: Adobe Stock | #840049440

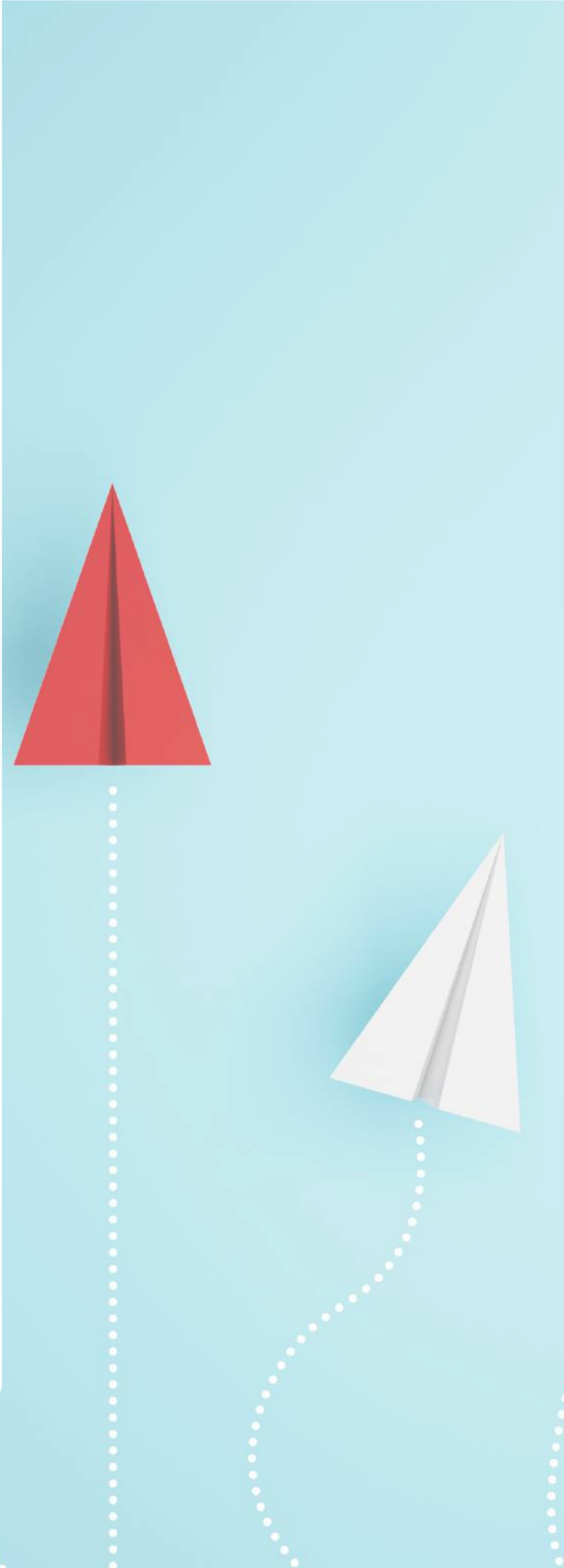
Summary

The opportunities presented are not the result of substantial or academic research, but rather the result of four conversations. However, they do reflect the experiences of CC&S practitioners who have experience of working through the barriers already identified. The featured actions provide a steer as to works which could be undertaken to help UK defence to overcome these barriers and capture more results in pursuit of operational advantage. The actions presented are not exhaustive.

The need for agility will become more apparent as MOD enters epoch two of the Climate Change and Sustainability Strategic Approach ('minimising and fitting for the future 2026 - 2035), which mandates a commitment to exploiting and developing existing technologies at greater scale, and determining use cases for emerging technologies. The actions identified in this report have the potential to support defence's transition to epoch 2.

Some of the actions are also aligned with recommendations 2, 3, 4 and 5 of the House of Commons Defence Committee 2023 Defence and Climate Change Report (House of Commons Defence Committee, 2023).

The takeaways and opportunities for action offer a steer as to how CC&S practitioners can focus efforts and support MOD to realise strategic goals and wider commitments.



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6. Conclusions

The roundtable series offered an opportunity to explore a range of issues relating to overcoming the barriers limiting the uptake of climate change and sustainability solutions in a defence context. There was recognition that the language and lexicon in use across NATO and MOD is one of adaptation, energy security and climate resilience.

Moreover, where CC&S technologies are being used, it is where they can deliver operational benefits. Thus, the best way to upscale and progress the impact already realised, is for CC&S professionals to improve understanding of where CC&S can enable operational effectiveness and integrate these considerations into traditional operational conversations and processes.

To reiterate, this pivot of language does not negate the importance of decarbonisation. Rather, it recognises the need to integrate it within 'business as usual' as it exists across MOD.

UK defence can be limited by finances and planning cycles. Sustainable technologies have potential to support and enable the sustainment and efficiency of military operations. Therefore, there is a need for Defence to better understand where adapting can offer financial rewards, or prevent financial loss.

This means that in the short term, colleagues working in industry or academia should invest efforts into evaluating and presenting the technologies which have the ability to offer operational advantage, whilst also realising wider benefits which could be captured by CCE.

MOD colleagues can support by asking industry partners to identify environmental benefits of a project or programme, escalating relevant results to CCE through the appropriate channels.

The roundtables also enabled the development of actions describing a range of ideas that could be adopted by the CC&S community to help advance MODs ability to respond to the threats presented by climate change, and how to quantify the wider benefits. The results of such actions may help MOD to respond to cultural and financial barriers recognised across the series.

MOD is nearing the end of epoch one of the Climate Change and Sustainability Strategic Approach. Epoch two, beginning in 2026, requires the scaling up of efforts to implement CC&S solutions across MOD.

This report has highlighted a range of technologies and projects with potential to help inform this uplift. The case studies presented further demonstrate the breadth of possibilities and reinforce the position that CC&S benefits can be achieved by responding to traditional defence operational requirements. Further examples of relevant projects are available within the NATO Compendium of Best Practice (NATO 2022).

The work presented in this report is not exhaustive. The range of projects already completed is too broad to capture, and the opportunity landscape remains too vast to attempt to summarise.

The roundtable discussions represent a mere snapshot of an ongoing continuum of work. However, the value of the report is the confirmation of a new common consensus between government, industry and academia.

Whilst it would be impossible to reflect the views of every relevant institution; the findings of the report broadly reflects the position of a range of institutions which are active in the defence CC&S sector (see Appendix 1), and provides signal as to which actions or works could be undertaken across the community to ensure the operational resilience of UK defence.

CASE STUDY 1 | Infrastructure

Image credit: Adobe Stock | #353544954

AECOM & BAE | Decarbonisation of Air & Maritime Estates

Project title: AECOM & BAE Defence Portfolio Decarbonisation Strategy

Overview: AECOM worked with BAE Systems to develop a decarbonisation roadmap for each of their establishments across the UK. For the Air Sites, a decarbonisation pathway in line with Science Based Targets initiative (SBTi) requirements was developed.

This prioritised the projects with the shortest return on investment and synchronised with others to coordinate with lifecycle replacement programmes. Recommended solutions included a combination of energy efficiency projects including: improved insulation; replacement of x plant with improved controls; high efficiency air source heat pumps for electrification of heat; power generation projects including solar PV generation and battery storage; and infrastructure projects including a new heat network and heat recovery plant. The ability to generate onsite power increased the energy security of the sites, reducing operational costs due to more efficient use of energy. Operational carbon emissions reduced by 50% as a result.

Non-air sites included Land and Maritime bases, Ports and Submarines, and a fabric first approach was adopted. Whereby, the extent of retrofit possible was evaluated first to assess where existing facilities could improve their energy performance. A subsequent assessment reviewed the best solutions to decarbonise the residual heat requirement, considering the knock on impact for supporting electrical infrastructure. The lack of existing grid capacity often resulted in the recommendation of alternative fuels (e.g., biofuels) to provide clean heat to the facilities. Sharing of both heat and excess peak electrical generation with adjacent facilities significantly improved the financial viability of the proposals, overcoming a typical barrier for progress for low carbon technologies. The wide range of activities undertaken improved the resilience of the sites, and has enabled long-term reductions in expenditure.

Keywords: *reduced emissions, cost savings, improved energy security, resilience, efficiency*

Measure Type: *adaptation, mitigation*

BAE SYSTEMS

AECOM

Above: AECOM worked with BAE Systems to develop a decarbonisation roadmap for each of their establishments across the UK. Image credit: AECOM and BAE ©

Cardno-AECOM | Pacific Joint Venture

Project Title: Cardno GS-AECOM Pacific Joint Venture

Overview: As part of the Cardno-AECOM Pacific (CAP) Joint Venture (JV) AECOM undertook a suite of engineering and environmental planning studies in support of current and future resiliency requirements at the Pacific Missile Range Facility (PMRF) in Kauai, Hawaii. The studies centered around the development of an Installation Energy Roadmap (IER), a structured and effective approach to selecting, prioritizing, sequencing, and implementing energy projects and programs that will result in stronger long-term installation energy and resiliency posture.

The studies informed the development of an IER and Installation Energy Plan Summary (IEPS) for PMRF. The IER incorporates input from mission owners, installation planners, engineers, and other key stakeholders. The studies also incorporated a review of the critical energy infrastructure and capital projects proposed as a result of the IER for vulnerability and risk to sea level rise given the installations immediate proximity to the Pacific Ocean. The sea level rise vulnerability and risk assessment include adaptation strategies to further support the installation's energy resiliency.

The Pacific Missile Range Facility incorporates a 14 MW solar facility paired with a 70 MWh battery energy storage system. PMRF is on track to achieve a net-zero carbon emissions Navy base (for Scope 1 and 2) by 2035. This is largely due to four key steps that PMRF is taking: leverage Renewable Energy potential; reducing use of backup generators by developing a more reliable grid; electrification of fleet vehicles; carbon off-setting through sequestration and maintaining sustainable carbon sinks of forests, grasslands, and wetlands within the PMRF boundaries. The studies highlight how decarbonisation and resilience are entwined and can potentially be mutually supporting. They are not the same but many of the solutions to one also benefit the other.

Keywords: *resilience, efficiency, reduced emissions, improved energy security, cost savings*

Measure Type: *adaptation, mitigation*

Above: US DOD's Pacific Missile Range Facility includes a 14 MW solar facility paired with a 70 MWh battery energy storage system.
Image credit: Cardno and AECOM ©

QinetiQ | Naval Fuels Analysis

Project Title: QinetiQ Marine, Air, Land Fuel capability investigation

Overview: QinetiQ conducted an in-depth analysis of UK Royal Navy oil fuel depots and associated infrastructure options to assess potential operational impacts. This process identified capital investment savings of £166 million while still delivering the desired capability.

UK Defence Oil Fuel Depots provide fuel to meet the routine and contingent requirements of Defence. The depots have been configured and installed over a number of decades to support a range of vessels, vehicles, aircraft and ground fuel use. QinetiQ undertook a Capability Investigation to evaluate the future requirement and options for fuel storage in the UK and overseas and identified opportunity to optimise fuel storage, reducing investment and achieving the required capability.

It endorsed current and future maritime fuel demand figures; provided understanding of how and why fuel demand evolves over time; identified interdependencies between fuel supply, demand, transportation and storage; and gave an understanding of current and future options, risks and benefits. The study was conducted to meet capability, efficiency and financial goals. Reducing fuel purchased and stored has an additional benefit of reducing carbon emissions, as does reduction in any unnecessary travel between fuel depos. Future studies would benefit from quantifying emissions alongside financial and capability metrics.

Keywords: *efficiency, cost-savings, reduced emissions, energy security*

Measure Type: *adaptation, mitigation*

Above: Aircraft carrier HMS Prince of Wales conducting Replenishment at Sea (RAS) with RFA Tidesurge during NATO Exercise Steadfast Defender. © LPhot Stuart Dickson, UK Crown Copyright 2024. Image credit: QinetiQ ©

Rolls-Royce | Microgrids Project for Strat Com

Project Title: Rolls-Royce Defence Micro-Grids

Overview: Decentral Energy Solutions ('Micro-Grids' or microgrids) are an alternative setup for energy provision 'from the grid' for customers with special requirements towards resiliency, sustainability and cost-efficiency. A Rolls-Royce mtu microgrid solution has been installed at Symmetry Park Biggleswade, promising to deliver 2MW of reliable power to the side 99.9% of the time.

The microgrid system has integrated Combined Heat & Power (CHP) plants, battery storage containers and standby generators. The setup also enables the integration of renewable energy sources like wind and solar while maintaining highest levels of security of supply, especially in locations where grid connection is not stable or even not given at the point in time. Each microgrid component is controlled by a central smart microgrid control system; able to identify load requirements, calculate the most efficient distribution of power and deploy sufficient assets while keeping reserve power that reduce dependency on national grid supplies and/or in island mode off-grid. The system is supported with maintenance and web-based monitoring services.

Electricity can not only be imported from the grid but also made available to the grid as an operating reserve, delivering additional revenue streams and by that supporting grid stability/ resilience and further enabling installation of volatile renewable energy sources like wind and solar. Micro-grids are easily updated, enabling integration of new components, e.g. small modular reactor (SMR) technology or micro-nuclear. It can already accommodate sustainable fuels such as hydrotreated vegetable oils (HVO fuel), Biogas and Hydrogen. They are increasingly used in U.S. military bases, including Fort Bliss, Los Alamitos and Fort Hunter Liggett, offering security of supply, flexibility, resilience and cost efficiency.

Keywords: *Flexibility, resilience, efficiency, reduced emissions, cost savings, improved energy security*

Measure Type: *adaptation, mitigation*

Above: Rolls-Royce mtu Micro-Grid, Symmetry Park, Biggleswade UK. Image credit: Rolls-Royce ©

Above: Installation of 2100 meter deep CeraPhiWell with energy centre in North Yorkshire to produce 3.9 GWth per annum. Image credit: Ceraphi Energy ©

CeraPhi | Geothermal Systems

Project Title: CeraPhiWell Energy Extraction System

Overview: The CeraPhiWell deep geothermal system pumps cold water down a well, heats it using geothermal heat and then pumps the hot water to the surface. It can be used for numerous purposes (e.g., heat, cold or energy provision) depending on the temperature of the water accessed. It offers a noiseless, resilient and maintenance-free source of heat, and (if drilled deep enough) it is ideal to replace existing generators or plants. This can reduce logistic resupply requirement and enable a reduced maintenance team, freeing up these valuable resources for elsewhere.

It offers predictable supply, providing energy security to operations, and is ideal in circumstances where either the energy provision has been destroyed or where the austere base is not connected, allowing the base to be self-sufficient in heat/cooling or power. The easy-to-transport equipment can be used where there are existing wells that can be repurposed for geothermal, or new drill holes can be dug. With a minimal physical footprint, the well can be easily hidden once established. The CeraPhiTru mobile energy centre (a container) ensures instant access to cooling or heating when attached. The lifecycle of the wells extends beyond most operational timelines, so can be left to the host nation to support national infrastructure with minimal training requirements. It is also easily extracted to deny an enemy access.

The reported return on investment for permanent bases is significant, with low maintenance requirements. It is able to support deployed austere self-sufficient bases with a need for a semi-permanent energy source, and could also be used to support humanitarian refugee camps or areas. Compared with the energy infrastructure used to support Camp Bastion, the Ceraphi system offers immediate and ongoing cost savings, reduces the need for resupply missions which place the troop lives at risk, and releases combat support personnel to other mission critical tasks.

Keywords: *reduced emissions, improved energy security, self-sufficiency, flexibility, resilience, cost savings*

Measure Type: *adaptation, mitigation*

Newcastle University | ViTAL Living Lab RAF Leeming

Project Title: Newcastle University ViTAL Living Lab

Overview: Launched in 2021, the ViTAL Living Lab project was funded by the Defence Innovation Fund to conduct high risk, high gain experimentation of decarbonising technologies and solutions to support the RAF's journey towards Net Zero. The project brings together personnel at RAF Leeming and academics at Newcastle University to test solutions in a defence context. Newcastle academics worked with RAFX, an RAF innovation hub based at RAF Leeming, to deliver six diverse experiments including: 1) Carbon Accounting; 2) Solar Technologies; 3) Soil Carbon Capture; 4) Geothermal Energy for Heating; 5) Sustainable Ground Transport and 6) Life Cycle Costing and Assessment.

Baselining of the main sources of emissions has enabled the development of an integrated roadmap for RAF Leeming, supported by a prospective life cycle assessment methodology. The solutions offer the ability to mitigate energy and supply chain security risks to ensure operations can be sustained in an emergency scenario, offering reassurance to decision-makers. Alternatives to ground mounted solar panels have been identified, increasing the potential for self-sufficiency of electrical power. Soil carbon capture methods offer the potential to reduce emissions on and around operational infrastructure, offsetting currently unavoidable emissions elsewhere. Low-cost imaging technologies can support the identification of optimal drilling sites to support geothermal systems to heat/cool bases. In additional to electrifying the fleet using Electric Vehicles (EVs) Hydrogen offers a promising alternative for green fleet vehicles

These experiments have enabled the RAF to explore how renewable technologies and power sources can improve efficiency and sustainability across operations, including base and forward operations. The ability of these solutions to deliver operational results has been proven, and upscale to support military operations is possible.

Keywords: *efficiency, reduced emissions, improved energy security, resilience, cost savings*

Measure Type*: adaptation, mitigation*

Above: Photo of scientists working on collecting soil samples at RAF Leeming as part of the Soil Carbon Capture experiment, ViTAL Living Lab. Image credit: Newcastle University ©

CASE STUDY 2 | Capabilities

Image credit: Adobe Stock | NuPenDekDee | #353544954

BAE & AIRBUS | Typhoon Decarbonisation

Project Title: Oxford Economics Analysis of Eurofighter Typhoon Decarbonisation

Overview: The impact of the Eurofighter Typhoon programme on the UK Economy' is an independent report written in 2022 by Oxford Economics (Typhoon | BAE Systems). The report highlights the Royal Air Force (RAF) commitments to achieving net zero carbon emissions by 2040 and reducing the environmental footprint of the fleet of more than 100 Typhoon jets through increased use of "synthetic" training simulators is one element of this strategy. The RAF is aiming for 80% of its' training to be synthetic by 2040.

Building on current capability, BAE Systems' engineers will provide high-fidelity simulators which will allow Typhoon pilots of the future to develop their skills to secure our skies for decades to come. The synthetic environment we are developing will allow RAF pilots to train together on Typhoon and become the first plug in to Gladiator, a single synthetic environment which will be the digital backbone across air, land, sea and space.

IN 2020, BAE Systems' team of training experts delivered more than 9,000 training events from the synthetic facilities that it currently operates at the RAF's Typhoon main operating bases, representing nearly 13,000 flying hours conducted virtually. The company has estimated that every synthetic flight saves 9.6 tonnes of carbon, and that substituting live training with synthetic training has so far saved about 75 million litres of aviation fuel—equivalent to 184,000 tonnes of carbon.

Keywords: *reduced emissions, efficiency, flexibility, sustainability, cost savings*

Measure Type: *adaptation, mitigation*

BAE SYSTEMS
AIRBUS

Above: The development of the Typhoon aircraft illustrates the dynamic evolution of cutting-edge combat aircraft.
Image credit: BAE Systems and AIRBUS ©

MBDA/QinetiQ/Leonardo Dragonfire high energy laser systems

Above: DragonFire laser firing at an aerial target during Dstl trials at MOD Hebrides. Image credit: Dstl / Crown ©.

Project title: MBDA, QinetiQ and Leonardo DragonFire

Overview: DragonFire is a Laser Directed Energy Weapon (LDEW) demonstrator. DragonFire boasts the ability to deliver a high power laser over significant ranges in varied weather conditions, with pinpoint accuracy for tracking and pointing. LDEW systems are of significant interest to defence because they are expected to provide military useful effect at reduced costs when compare to other weapon systems.

Having demonstrated that the technology is credible, there is a defence push to solve system integration challenges and place the capability in the hands of the user. LDEW systems emit precisely targeted light; this means that there is less likelihood of collateral damage, and no possibility of unexploded ordnance (except if an enemy weapon is targeted).

LDEW can complement conventional defensive capabilities, but can reduce the need for forces to use alternative forms of ammunition, providing an option which can respond to mass requirements and ensure in-theatre resource efficiency. Depending on the power of the system, LDEW are expected to be effective against a wide range of threats from unmanned aerial vehicles (UAV) to Anti-ship missiles.

Whilst the power used by the systems is not insignificant, it could in theory be generated by sustainable means. The logistic chain for LDEW is short compared with many weapon systems, meaning fewer emissions will be emitted as a result of transportation. Further trials will aim to reduce the systems size, weight and power requirements, which will reduce pressures upon defence logistics operations and ensure fewer emissions are emitted as a result of DragonFire transport and use.

Keywords: *efficiency, cost savings, efficiency, reduced emissions, resilience*

Measure Type: *mitigation*

General Dynamics Land Systems AbramsX

Project Title: AbramsX Hybrid Tank

Overview: The AbramsX technology demonstrator was introduced in 2022 to showcase innovations that could be incorporated into the next generation of main battle tanks. It features a hybrid-electric drive propulsion system, increasing fuel efficiency by 50% compared with its predecessor, reducing the need for resupply. With a weight of 60-tons, it is roughly 12 tons lighter than existing Abrams tanks, though the option to increase armour remains. Its smaller size and lighter weight could improve the ability to cross bridges and enter strategic passageways. The reduction in weight also offers potential to reduce the logistics burden associated with transport to and from theatre.

It enhances survivability with lower thermal and acoustic signatures. This enables silent watch capability, and some silent mobility. Its unmanned turret reduces the crew from four soldiers to three.

The AbramsX is designed to support continuous modernization. Onboard AI-driven command and control systems offer the ability to communicate with, and even launch, UAVs whilst in motion; and early warning systems to alert the crew to long-range threats, enhancing lethality and survivability.

Keywords: *reduced emissions, mitigation, adaptation, improved energy security, efficiency*

Measure Type: *adaptation, mitigation*

Above: General Dynamics Land Systems unveiled the AbramsX technology demonstrator at the 2022 Association of the United States Army (AUSA) exhibition. Image credit: General Dynamics Land Systems ©.

Frazer-Nash | Synthetic Environments

Project Title: Frazer-Nash SPEAR Synthetic Environment

Overview: Frazer-Nash worked with Dstl to develop a detailed and realistic simulation environment to test and evaluate concept robotic autonomous systems. Modellers constructed functioning 3D representations of concept vehicles and their associated mission systems. This included drivetrains, weapons systems, sensors and unmanned air and ground vehicles. Ground platform dynamics were also modelled from the ground-up, representing suspension systems and tyre interactions with the environment explicitly.

A representation of a crew station based on existing Generic Vehicle Architecture (GVA) guidelines was developed, allowing the exploration of how future operators would interact with the new technologies. This included visual feeds, shared battlefield management information and remote control of autonomous assets. As a complete package, this enabled the visualisation and real-time evaluation of novel technologies and the capabilities that they could provide. Furthermore, concept vehicles could be iteratively prototyped, refined and tested by assessing concept performance across numerous simulated war-gaming scenarios in a range of physical environments.

The vision behind SPEAR is to use the Synthetic Environment (SE) to form the first step in testing new military capabilities. This will reduce the cost during the experimentation phase and shorten the time to bring new equipment into service. The experimentation in the SE could also be used to test new technologies that may improve efficiency or reduce the reliance on current fossil fuel platforms, including integration of alternative power sources or with allied systems.

Keywords: *efficiency, cost efficiency, energy security, resilience, reduced emissions*

Measure Type: *adaptation, mitigation*

Above: Frazer-Nash developed high fidelity models of Future Ground Combat Systems to be tested in a representative Synthetic Environment to assess technology developments and improve future ground combat capability. Image credit: Frazer-Nash ©.

APPENDIX 1 | Roundtable Series Delivery Team & Participants

Image credit: Adobe Stock | Generative AI | #76911621

Appendix 1: Roundtable Series Delivery Team & Participants

This report was written by members of the planning committee from AECOM, BAE, Dstl, Frazer-Nash and RUSI, and refined with the support of participating CCE staff. It is published as a Dstl asset with the consent of all organizing parties.

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