Naval port and large-scale maritime industrial site decarbonisation

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Synopsis

Addressing CO2 emissions is a challenge that every sector of society must rise to and overcome. Unlike the commercial sector, the Royal Navy are both owners and operators of both their ships AND ports, and therefore have an opportunity to deliver a coherent approach to tackling these challenges. Portsmouth, together with the other 2 UK Naval Bases in Plymouth and Scotland, are the largest consumers of energy in defence with highly similar outputs and therefore in a unique position to deliver the greatest benefits.

The paper will outline the existing approach to new ship programmes together with how their support base is being adapted. It will look ahead to the changing operational demands and predictions of how the National energy provision could be derived in the future. Constraints will be discussed, be they technical, fiscal, or societal, so that the real challenges are identified and options to address them developed. It will signpost to opportunities for closer collaboration with industry, local authorities and academia. It will also note the role of Central and other government departments in encouraging the necessary approaches and a potential for international engagement. An argument for addressing the range of issues will be matured into an example of a holistic solution for a complex military dockyard.

The expected findings of the paper will describe how an organisation's investment approval process should acknowledge the cost of carbon reduction, rather than just the fiscal advantages. Individual options will be critiqued, identifying the benefits and limitations. These will be combined into an indicative overall solution suite that, with the right motivations and what an organisation chooses to value, could be delivered as a coherent decarbonisation programme.

Keywords: Emissions; Carbon; Net Zero Carbon; Approvals; Ports, Investment.

Biographical Notes:

Lee Harrington is the Principal Infrastructure Engineer at Portsmouth Naval Base responsible for the overall material safety of the base and the design authority for new works. Previous roles have included working within navy acquisition, requirements management, leadership training and as a Naval Advisor in the Middle East.

Jeremy Bailey has just relinquished command of Portsmouth Naval Base where he oversaw a period of significantly increased operational output. He has a pedigree in Naval support, strategy and training and is a graduate of the Cabinet Office Project Leadership Programme and Royal College of Defence Studies. He has championed environmental sustainability throughout his career.

1. Introduction.

Naval Base Context. UK Naval Bases are substantial facilities which deliver the operational generation of Royal Naval ships and personnel; they represent the largest energy consuming sites in Defence. They support thousands of people and, as a result of Defence Estate Optimisation serve multiple users from Military Personnel, Industrial Partners (IPs) and their supply chains. Two of the three bases sit at the heart of cities, and the third in a devolved nation, and whilst Defence is a national issue, their impact on the local regional political landscape is important, especially in the drive to get to Net Zero. For the Royal Navy, the Naval Bases are managed separately from the Defence Infrastructure Organisation, and all 3 have recapitalisation programmes underway. Like most ports, they are in areas where National Grid provision is limited and under further pressure as the journey to Net Zero decarbonises the economy. Naval Bases have a long record of driving energy efficiency and carbon management, they have cold ironed warships since the early part of the 20th century. They must also operate within several constraints, from nuclear licensing and building heritage issues to vulnerabilities around sea level rises. Naval Bases represent challenging sites to decarbonise but are rich with opportunity to remove carbon from the Royal Navy's overall footprint. Historically Naval Bases have been the driving force behind many of the technological transitions that the Naval sector has experienced, and they remain potential seats for innovation of the present and future.

Ship acquisition and operations – factors that drive change. The Royal Navy is currently building 2 new classes of surface combatant warships - Type 26 and Type 31 Frigates. Both are conventionally powered, utilising a combination of gas turbine, generator and electric motor propulsion, with diesel as the primary fuel source. Both incorporate the use of exhaust emission reduction technologies as standard. On the horizon are further ship classes where the opportunity to go further is possible. Closest are the large Fleet Solid Support (FSS) ships to supply and sustain the fleet. FSS is the Maritime Net Zero Pathfinder for Environmental Sustainability. In their specification, the bid evaluation criteria places value on adaptability pathways for future fuels and propulsion systems and will incorporate energy saving devices as well as carbon management technologies at the start of life. It recognises that Naval shipping will likely be a follower of the commercial shipping sectors decision on future fuels. Future warships are going to be increasingly leaner-crewed but are unlikely, in the short to medium term, to make a significant step away from using diesel as the primary fuel source due to issues of power density, survivability and safety.

Considering how the Royal Navy of the future might operate opens the way for more rapid and positive changes. Autonomy, on, under and above the water is becoming an increasingly important and viable technology. The Royal Navy's Mine Hunting Capability programme uses small boats rather than ships to deliver the capability effect. These uncrewed surface vessels can be acquired more quickly and hence benefit from developing Technology Readiness Level (TRL) propulsion options, such as electric/hybrid, Hydrogen (H2), or biofuels. Indeed, the very fact that they are uncrewed removes the stringent personal safety consideration of a warship that makes these options increasingly viable. With much lower comparable Life Cycle Replacement (LCR) costs than the existing ships, the next generation of boats may be considered to be more readily replaceable than the existing capability.

The operating profiles and concept of operations are changing with technology and world geo-politics. The Royal Navy has a vision to 'Forward Deploy' vessels, so they operate from the geographic areas in which their capability and military effect is delivered. It already does this in specific areas where the transit times to and from the UK are alleviated, maintaining the in-theatre capability for longer. In doing so, crew rotations are flown out and the availability of local support and secure, reliable fuel bunkering is a key consideration.

Within the Naval Bases themselves, the auxiliary craft all tend to operate on diesel however, they are subject to shorter LCR periods and in some instances are operated by commercial IPs. Unless retro fit is possible in the near term, improvements will be linked to LCR incorporating biofuels and electric/hybrid solutions, dependent upon the proposals made and the cost of the replacement assets. The opportunity for use of H2 could be examined in parallel with these plans as part of the UK Clean Maritime Programme and UK Shipping Office for Reducing Emissions (UK SHORE).

The Naval Bases are the home ports to numerous ships and submarines all having different operating profiles, leading to a complex support-base requirement. For example, the introduction into service of the Queen Elizabeth Class (QEC) aircraft carriers in Portsmouth required an uplift in electrical power to support them when alongside for maintenance. With limited local capabilities within the city, a long lead time to upgrade the Distribution Network Operator (DNO) electrical supply and the timescale to make improvements unclear, the decision to commission an on-base Combined Heat and Power (CHP) Plant was necessary. The electrically-lead, but gas-powered, CHP has delivered the power requirements and resilience needed whilst introducing cost savings and additional efficiency opportunities. However, it has also hugely increased the Scope 1 gas emissions.

2. Developing the Vision.

The MOD accounts for around 50% of all government department emissions. Of the Navy's share, around 65% derive from Scope 1 emissions from ship and aircraft operations, leaving 35% accounted for from the bases, of which the 3 Naval Bases contribute the vast majority. Overall Tribase emissions are 19% for Scope 1 (Gas, Heating Oil, LPG), 27% for Scope 2 (Electricity) and 54% for Scope 3 (Supply Chain). Across all 3 bases there has been a 50% reduction in Scope 1 and 2 tCO_2 since 2014. The Bases remain the largest energy consumers in defence although the introduction of the CHP in Portsmouth is now skewing these figures due to the gas now being consumed. In 2020 Portsmouth Naval Base led a 3 Naval Base NZC Conference, the output was agreed that the Pan-Naval Base Carbon Management Vision is to become Net Zero Carbon (including the Enterprise Scope 3 supply chain) by 2040 and Net Zero Sinks of CO_2 by 2050, and that the Naval Bases adopt a 'World Leading' mindset in their approach to achieving the HM Government target of Net Zero Carbon by 2050. Figure 1 describes the progress achieved to date.

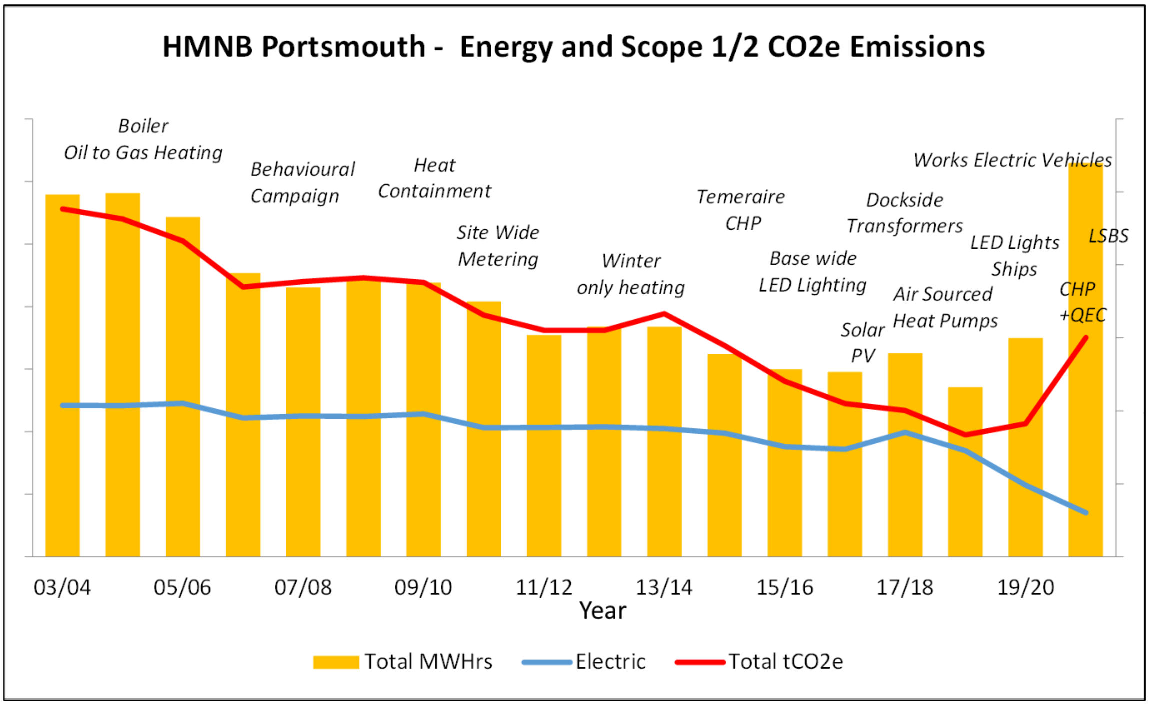

Figure 1: Progress Since 2004 to Date

3. Factors & Behaviour.

As with most wicked problems, careful and close collaboration is essential if substantial progress is to be made. It is clear that the UK Pan Government approach is hugely supportive in yielding the necessary catalysts for wide scale transformation, whilst maintaining the essential operational outputs that characterise this sector. The UK Government 10 Point Plan, coupled with the UK Maritime Strategy 2050 and the Clean Maritime Demonstration funding, are just two important examples of the clarity and supporting frameworks necessary to proceed. Within the UK Ports sector, the recent Innovation Network led by Innovate UK, supported by the Energy Systems and Connected Places Catapults, has cohered the sector and laid the problem set clearly out. Such networks foster the necessary collaboration to learn by doing and share insights and evidence to determine future strategies. Beyond this, international collaboration within the Defence sector is evident, either through NATO frameworks or multi-lateral working groups. Within MOD and the Royal Navy, Green Networks have been established to share best practice and harness the power of those change agents who are early adopters in the sector and are willing to make the difference.

Similarly, as the regional political drivers emerge, it is essential for Defence to work with other actors to set out its plans, to shape them according to the local needs, and to share their progress and opportunities with other organisations. In doing so, this creates opportunities horizontally across these relationships and enables more rapid progress to be made. MODs Climate Change and Sustainability Approach (Ref 1) describes in Epoch One the 12 initial actions to be undertaken by 2025. Set against the progress already made, the Naval Bases are actively engaged in each of these areas.

Motivations to act and levers to elicit change. There are many interrelated factors that combine to form the current and future ecosystem within which positive actions will be taken. Following extensive carbon baselining activities, carbon budgeting policy is now being formulated, recognising that the risk and subsequent mitigation can be used as a potential benefit for sustainability or decarbonisation activity, as carbon can now be priced into decision making.

At this stage, off balance sheet liability for the cost of carbon is an important comparator as it moves the conversation to a position where carbon can be quantified, like capability, time and money. Conducting sensitivity analysis to ascertain if, by valuing carbon, the options and ultimate decision changes, should now be investigated further as this new variable will have increasing importance within business cases. To date, target setting is focussed on just the MOD Estate and is based on Greening Government Commitments (Ref 2). Against the 2017/18 baseline, targets for a 10% reduction in Scope 1 emissions and a 30% overall target are under consideration to be achieved by 2024. Achieving targets relies on accurate data to set realistic goals that are measurable. Metering is pivotal in identifying the necessary dataset to be able to make informed decisions and to offer strong evidence within business cases. Budgeting and target setting must come with the necessary delegations. Similar to financial and safety delegations, Senior Leaders must be provided with the empowered levers to deliver the targets demanded of them so that the motivation to take increasing account of carbon is brought to the fore. This allows the existing balance of capability, time and money to be expanded to include carbon. Without such delegations, individuals will not be held to account in the delivery of carbon reduction and so will be neither empowered nor motivated to value its reduction in investment decisions.

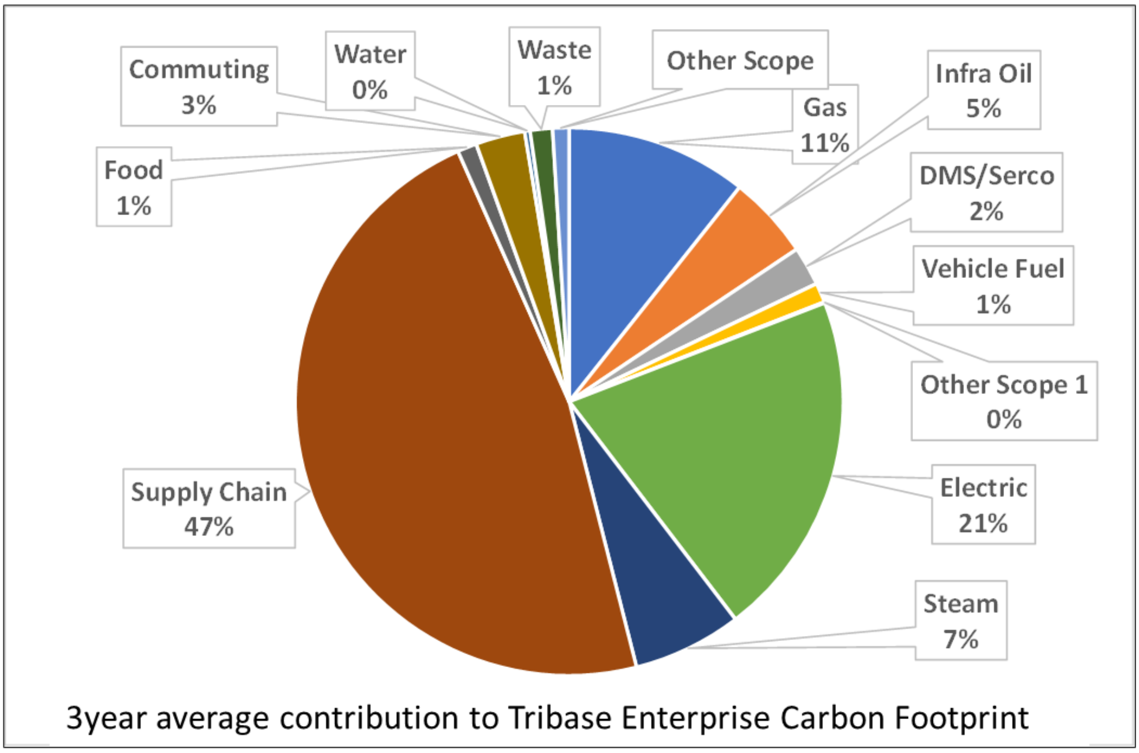

Figure 2: Tribase Carbon Baseline by Type.

The stimulation of innovation and development of TRLs is being encouraged through the availability of government financial assistance. Many of these schemes are focussed on the private sector with only MOD IPs able to apply. This presents a dichotomy, as the funding and effort is undertaken by the IPs, with all the benefits derived by MOD. With such a large contribution to emissions, governments' own departments should have open access to these funding routes to strengthen investment decision making. MOD guidance on business cases describes the approach to embedding sustainable procurement in the acquisition lifecycle and sustainable defence estate procurement. As shown in Figure 2, Scope 3 emission from the supply chain account for 47% of the Tribase emissions. Societal shifts and expectations for private companies to address their carbon and sustainability obligations will be the dominant motivator for the private sector to change – doing so addresses a major risk to future business. The MOD can further capitalise on this effect as, over time, the increased importance of Cardon Reduction Plans that a company must have to meet the pre-qualifying criteria to be considered for a MOD contract (presently over £5M) will be vital in encouraging and rewarding the desired behaviour. With the correct carbon reduction context as described above, contracting with the private sector should contain specific reduction targets that are cascaded down and the delivery of them assured through financial Key Performance Indicators (KPIs).

4. Technical Options.

The source of electricity in the National Grid is evolving as an increasing amount is generated by sustainable sources. Ports are often at the extremities of the distribution networks, but this may change as offshore wind, tidal, wave and sleeving power purchase agreements (e.g., from Norway) becomes more prevalent. Ports within cities such as Portsmouth and Plymouth must recognise that they form a major user within the local area, sometimes with limited supply. As an indicative example, Portsmouth have developed a 30-year forecast of options to achieve the vision to be a NZC sink by 2050. Figure 3 below indicates how different TRL options could be employed, the overall cost of which is calculated to be an additional £25M per annum.

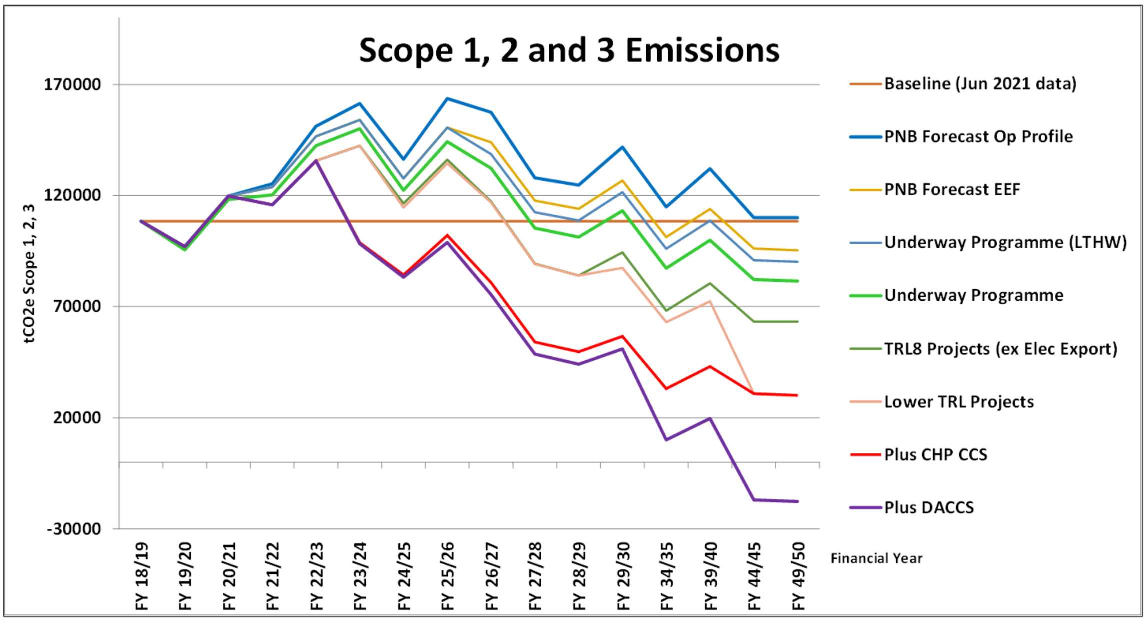

Figure 3: Carbon Reduction Option Profiles to Achieve NZC.

Combined Heat and Power. The Portsmouth gas-powered CHP and the Plymouth Energy from Waste (EfW) plant were both implemented to deliver a cost saving, provide additional electrical power and retain site resilience. However, they are now major contributors to on-site carbon. Maximising the efficiency of these plants is the first most realistic action to be taken, gaining maximum benefit from all waste heat. The introduction of any future electrical generation capability must be coherent with the produced emissions so that they are powered sustainably and/or have carbon reduction technologies embodied at build.

Carbon Capture & Storage (CC&S). This technology is at high TRL. They require a large footprint and come with their own energy demand. The extracted CO2 still needs to be transported to a long-term storage location, of which there are a limited few yet coming online. Shipping the extracted carbon to a point of permanent storage, either via road or sea, generates a carbon liability that is at odds with, and diminishes, the overall aim. The running and transport costs mean that CC&S has a significant Operating Cost (OPEX) throughout its life. CC&S themselves deliver no military capability other than significantly reducing emissions, making the investment decision for Capital Expenditure (CAPEX) in the present investment policy ecosystem a challenge.

Hydrogen (H2). A concept study to examine generation and use of green H2 for just base infrastructure use concluded that the Levelised Cost of Hydrogen (LCOH) per kWh is over 4 times the price of gas. Widening the scope of potential users to consider land and maritime transport brought this factor down considerably, suggesting that H2 use should be transport-lead as the LCOH per kWh is comparable to road diesel. The timing of this demand opening-up is driven by vehicle and vessel LCR, much of it several years away. Utilising H2 in this way is likely to require a more complex commercial model and increased collaboration. H2 can be blended with existing gas, but the emissions benefits are less than half of the blend percentage. Replacing the electrical generation engines with H2 fuelled prime movers would alleviate the need for large scale CC&S at significant CAPEX benefit but does require a large H2 supply that does not yet present a value for money proposition. A modest but scalable, green H2 production facility would provide the underpinning source to develop various use cases further. Although at a high TRL, the incentives to adopt H2 more prevalently are not yet aligning to stimulate more widespread use. In this sense, the bases could act as innovation leaders and facilitate an accelerated adoption of H2. In time, H2 shows much promise to supersede fossil fuels in many applications.

Low Carbon Heat Networks (LCHN). LCHNs, sometimes referred to as Low Temperate Hot Water networks, offer benefits in 2 areas. The bases have historically used steam to provide networked heating, many of which are nearing a LCR decision point. Moving away from burning fossil fuel to generate steam, with all its associated losses, is the first benefit. The second comes from utilising an existing source of waste heat to generate the hot water needed and be distributed in highly insulated pipework. This could come from many sources, but most obviously from the exhaust gasses and engine cooling medium used in the on-site electrical generation such as a CHP or EfW plant, which could also be supplemented by other sources to pre-heat water. By making maximum use of existing unharnessed waste heat, LCHNs are highly efficient and require modest additional electrical load, when compared to achieving the same effect from air or ground source heat pumps.

Direct Air Carbon Capture & Storage (DACCS). A developing TRL that is likely to become more prevalent. They are currently being developed in a modular manner and are both scalable and can be flexibly sited. If powered from a sustainable source such as PV, they are an option to be used as an 'offset' and to remove residual emissions to achieve targets. Like CC&S, the ultimate removal, transport, and long-term storage does come with a financial OPEX tail, but if they were located close to storage locations in a reverse 'offset sleeving' manner, then costs and further emissions would be minimised.

Air / Ground / Water Source Heat Pumps (A/G/WSHP). These can be used to supplement the future LCHNs where the buildings are geographically dislocated from connection to the networks and to replace existing gas boilers. Like DACCS, when powered from a sustainable source such as PV they offer a high TRL option but should be used sparingly as their overall load for a major site can be double that of a LCHN.

Wind. Now commonplace; however, the adoption of wind is somewhat hindered within the Naval Bases due to their city locations where the erection of turbines would be unacceptable – they are more suited to rural or offshore locations. They would need to be paired with an improved microgrid and battery storage to provide the required supply resilience.

Micro / *Small Module Reactor (M/SMR).* Scaled down nuclear development is underway and benefits from direct government investment into the nuclear sector as the UK seeks to diversify its energy sources. The low TRL means that they are some way off being a viable option for at least the next 5 years as the technical and regulatory challenges are explored further. Generating far more than the power required, the future Naval Bases could make a suitable and secure location for siting SMRs as they are next to the sea, close to large population densities and have much of the industrial infrastructure that could be utilised.

Photovoltaic (PV). This benefits from a high TRL and reducing costs. Locations on large industrial sites abound, as do the options to sleeve PV electricity from other MOD sites that have an excess of land. New buildings should include it as standard, as has happened in Portsmouth with the erection of the first carbon neutrally powered building in the Royal Navy. Increased adoption rates will make this a progressively important contributor to the overall electrical generation capacity.

Electric Vehicle (EV). Charging for EVs is increasing at a steady rate to service the electrification of MOD and IP owned vehicles that typically charge overnight. Maximum utility is being extracted by allowing private vehicle charging during the working day, allowing the individual decision to own an EV more attractive and contributing to the reduction in transport emissions. Servicing the increased electrical load must be considered in strategic planning.

Microgrids and Battery Energy Storage Systems (BESS). These form the backbone of the blended generating and storage solutions needed. Modernising the existing electrical systems is key to gaining the maximum benefit from the range of interconnected technologies and utilising them effectively. Delivered coherently with optimised power management from artificial intelligence they could deliver carbon and financial benefits.

Biofuel and Hydrotreated Vegetable Oil (HVO). Both should be a readily accessible option to replace diesel vehicles, standby generators and boats before they reach their natural LCR decision point. Provided it was obtained from a sustainable source, it would contribute to the direct reduction of Scope 1 emissions, but not other emissions for clean air targets, at around 20% additional cost.

Tidal. Despite being on the coast, apart from perhaps Plymouth on the river Tamar, the bases themselves are not favourably sited to make use of tidal options. Investigating sleeving opportunities from nearby tidal stream generating sites is recommended.

Geo-thermal. Such sources could be paired with LCHN and A/GSHPs to supplement or even deliver the full heating loads. They are high-TRL, however the geographic suitability and carbon assessment should be investigated further as part of feasibility studies.

Having discussed the various options above, an assessment and summary of the relative merits of each is in Table 1 to provide an indicative comparison.

Source	TRL	Relative CAPEX	Relative OPEX	Site Suitability	Desired Capability	Carbon Impact
CHP/EfW	H	££	£	H	H	H -ve
CC&S	H	££	££	H	L	H +ve
H2	M	££	£	H	H	H +ve
LCHN	H	£	£	H	H	H +ve
DACCS	M	£	£	M	L	L +ve
A/G/WSHP	H	£	£	M	H	H +ve
Wind	H	££	£	L	H	H +ve
M/SMR	L	£££	££	H	H	H +ve
PV	H	£	£	H	H	M +ve
EV	H	£	£	H	M	M +ve
Microgrids	H	££	£	H	H	H +ve
BESS	H	£	£	H	H	H +ve
Biofuels	H	£	£	H	H	H +ve
Tidal	M	££	£	L	H	H +ve
Geothermal	H	££	£	L	H	H +ve

Table 1: Relative Weighting and Assessment of the Technology Options.

5. Recommendations.

As has been described within this paper, the near-term challenges to overcome are predominantly behavioural, business, financial and policy driven. All defence sites should establish energy and carbon baselines, together with plans to achieve NZC targets. Sharing proven best practice, they must undertake all the readily available options now to limit energy usage and rapidly reduce carbon, as proven to work already. Some of this will generate savings however, making further influential carbon reductions will require additional funding allied with bold decisions. The existing approvals process of only valuing time, cost and capability is insufficient and must be updated. To gain approval for the further investments required, carbon as a commodity must be equally valued and the budgeting and approvals process re-cast to generate the correct incentives. Similarly, Defence Leaders must hold the carbon liability and be provided with the empowerment tools to be held to account to deliver the targets demanded. Government funding routes must be open to MOD and other government department CO2 emitters, enabling the public sector to lead by example and be strongly positioned to demand the private sector adapts accordingly. In tandem with the societal direction of travel, the MOD-contracted private sector must be set demanding NZC targets in the correct commercial framework. Technically, H2, renewables and SMRs should continue development and aim to become viable alternatives within the medium term. Considering the options available, Figure 4 is a holistic roadmap of the Scope 1 and 2 technical interventions that could be adopted within the next decade.

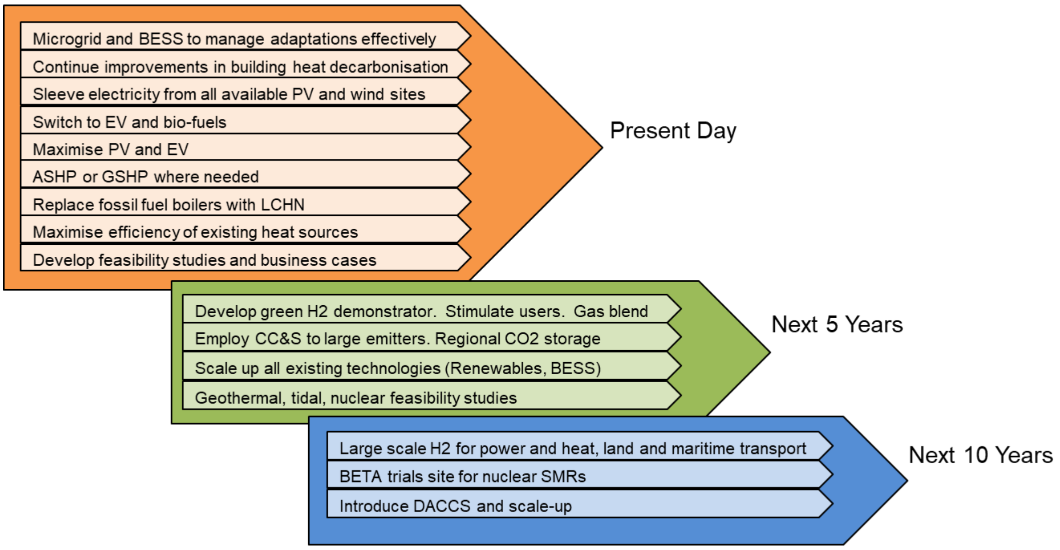

Figure 4: Indicative Options Roadmap for a Complex Industrial Port.

6. Conclusions.

The UK Naval Bases represent complex industrial sites which deliver critical outputs in support of Royal Navy Force Generation. Their role has constantly evolved in stride with the needs of the Navy and the Nation, and the demands in the 21st century will be no less; amongst these is an absolute requirement to adapt and mitigate the impact of climate change, including the need to drive towards NZC. To do this, they can take the opportunity to be market leading, demonstrate innovation in partnership with many, including industry, and potentially become early adopters of the solutions. Solving this problem is complex, but this paper has outlined a systematic, strategic and cost-effective approach to establishing a coherent approach to planning and investing in the wide range of interventions that will be required, including the need to underpin the investment decisions necessary for such interventions. Whilst some of the reduction will be made by wider actions, without direct and well managed direction, there is a risk that the Naval Bases will be unable to deliver their critical contribution without an increase in cost or the ability to offset their carbon consumption to remain within the UK legislative framework in 2050.

This paper has also demonstrated the potential technology and behavioural changes necessary to meet this challenge. It has revealed that Naval Bases represent a highly suitable capability to maximise the use of the government estate to develop and prove low TRL options, and the value this brings to communities beyond the boundary of the Naval Bases. In doing so, they have the potential to become catalysts for driving these changes, both within the Royal Navy, wider UK MOD and with allies and partners, together with other similar organisations that will need to make the transition to a low carbon economy and maintain outputs. In doing so, the authors have outlined that Naval Bases, and indeed Navies, need to commence the transition to a low carbon economy whilst preserving the ability to deliver their outputs. It is critical that the cost of carbon is now assimilated into strategic planning and prioritisation. In parallel, rapid development and delivery of adaptation and mitigation will be essential if the legal targets of 2050 are to be met. This will require Navies to be proactive, making timely investment decisions to avoid or minimise these future costs.

Acknowledgements.

The authors wish to thank the dedicated MOD and industry professionals who are contributing towards the NZC journey of the 3 Naval Bases.

The views expressed in this paper are those of the authors and do not necessarily represent the views and opinions of either the Royal Navy, MOD or Government.

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Glossary.

Air / Ground / Water Source Heat Pump	A/G/WSHP
Battery Energy Storage System	BESS
Carbon Capture and Storage	CC&S
Capital Expenditure	CAPEX
Combined Heat and Power	CHP
Direct Air Carbon Capture & Storage	DACCS
Distribution Network Operator	DNO
Electric Vehicle	EV
Energy from Waste	EfW
Fleet Solid Support	FSS
Ground Source Heat Pump	GSHP
Hydrogen	H2
Hydrotreated Vegetable Oil	HVO
Industry Partners	IP
Key Performance Indicators	KPIs
Levelised Cost of Hydrogen	LCOH
Life Cycle Replacement	LCR
Low Carbon Heat Network	LCHN
Low Temperate Hot Water	LTHW
Micro / Small Module Reactor	M/SMR

Net Zero Carbon	NZC
Operating Cost	OPEX
Photovoltaic	PV
Queen Elizabeth Class	QEC
Scope 1	Gas, heating oil, fossil fuels, LPG
Scope 2	Electricity
Scope 3	Supply Chain
Tonne of Carbon Dioxide	tCO2
UK Shipping Office for Reducing Emissions	UK SHORE