A laser-armed Stryker manoeuvres during US Army testing at Fort Sill, Oklahoma. For NATO, the challenge is no longer directed energy technology, but rather its integration.

Bringing Directed Energy Weapons into Focus

Integrating Emerging Capabilities into NATO Air Defence

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For some, directed energy weapons (DEWs) represent the realisation of a 'Star Wars' vision of modern conflict, and a timely solution to proliferating air, missile, and drone threats.[1] For others, they represent the pinnacle of hype and an overstatement of the operational relevance of outdated technology.[2] The reality is that years of research and development (R&D) have unlocked a transformational capability, shifting the focus from technology maturation, testing, and experimentation towards operational deployment. Why, then, are DEWs generating such heated debate once again, and what can NATO do to maximise their utility?

The answer lies largely on the battlefields of Ukraine and the Middle East. Russia's war in Ukraine has catalysed rapid advances in uncrewed air systems (UAS), alongside industrial developments that enable them to be produced cheaply and at scale, overwhelming air defences and stretching stockpiles and production lines for kinetic interceptors.[3] Proponents therefore present DEWs as a low 'cost-per-effect'[4] solution to the challenges of saturation, cost asymmetry, and industrial sustainment in contemporary air defence, shifting the cost-exchange ratio of engagements against massed UAS in favour of the defender.[5] Whilst NATO efforts are primarily focused on DEWs' utility as counter-UAS (C-UAS) tools, the technology has much wider applications. These include not only short-range air defence (SHORAD) or counter-rocket, artillery, and mortars (C-RAM) missions closely aligned with C-UAS tasks, but also anti-satellite (ASAT) use cases, with threatening implications for strategic stability.[6]

Advances in Technology Readiness Levels (TRLs) confirm that DEW capabilities are maturing rapidly. Yet discussion too often focuses narrowly on the technology itself rather than the wider doctrine, organisation, training, materiel, leadership and education, personnel, facilities, and interoperability (DOTMLPFI) needed to field it effectively. This article addresses the role NATO can play in shaping DEW adoption through shared doctrine, standards, and integration.

Types of Directed Energy Weapons

Coherent adoption starts with clear definitions. 'Directed energy' is a contested term that different nations interpret to include a range of military applications. In its broadest sense, it captures many systems operating across the electromagnetic spectrum (EMS). Fundamentally, these systems rely on energy at specific wavelengths being directed to generate military effects, whether through deception, confusion, or kinetic intervention. This aligns with NATO and national-level policy and doctrine, which define effects more broadly than a simple 'hard kill'. 'Soft kill' effects, such as impairing sensors or reducing a target's capability, are often sufficient.[7] Australian doctrine, for example, frames Directed Energy as both an aspect and augmentation of electronic warfare (EW).[8] For NATO Allies, DEW technologies sit within this broader spectrum at the intersection of kinetic and EW capabilities. This sets the scene for the disaggregation of types of DEW, which focus largely, but not exclusively, on neutralisation of targets.

A 2025 RAND Europe study for the Ukrainian government classified and examined two principal categories of DEW from the perspective of C-UAS operations, offering a typology for NATO Allies.[9] High-energy lasers (HELs) emit a focused beam of photons (light, typically not in the visible spectrum). At low settings, these can 'dazzle' or blind a target's electro-optical sensors, including the human eye. At higher wattages,


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The US Navy demonstrates the Laser Weapon System (LaWS) HEL during operations in the Arabian Gulf.

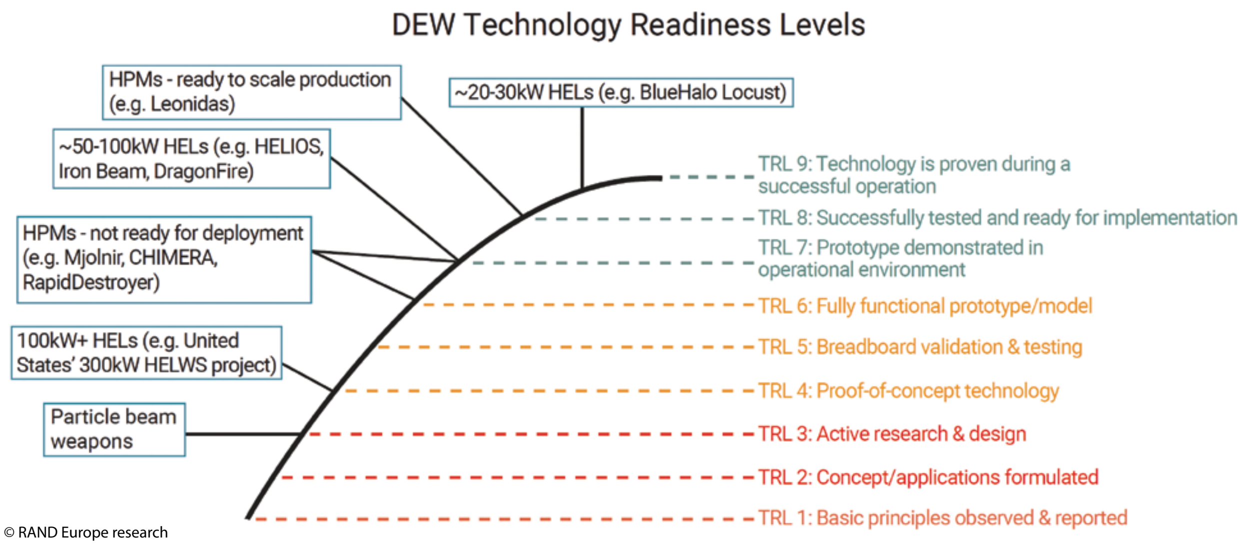

Figure 1: *Technology Readiness Levels of Selected DEWs.*

the laser burns through the targeted structure, for instance, the wing or body of a drone, causing it to crash. By contrast, high-power microwave (HPM) systems or radio frequency (RF) DEWs use concentrated pulses of energy to disrupt the electronics on board their target. Such systems can engage multiple targets simultaneously within a wider beamwidth, while lasers require greater accuracy to be effective.

While the current discourse on DEWs focuses largely on 'laser warfare', in practice DEWs have a more nuanced range of applications. As such, they are better considered by NATO Allies as emerging complementary elements of the EW toolkit rather than a new standalone effector option. Figure 1 provides an indicative assessment of TRLs across different types of DEWs based on open-source information. This reveals a patchwork of capability offerings, from the near-deployable through to those that remain largely conceptual.

Potential Applications and Benefits of DEWs

Development efforts commonly focus on DEWs' low cost-per-shot potential as C-UAS systems or as part of a wider layered approach to Integrated Air and Missile Defence (IAMD).[10] The Israeli Iron Beam concept will reportedly engage targets up to 10 km away using HEL technology, leveraging its high accuracy and rapid re-engagement against high-volume UAS threats.[11] Low-cost UAS such as the Iranian Shahed system are massed against exquisite, low-volume systems such as the PAC-3 interceptor, integral to the US Patriot missile system but reported to cost roughly $4M per interceptor.[12] The UK Ministry of Defence reports a cost-per-effect for its in-development DragonFire Laser DEW of only £10 per shot, or using a regular heater for just an hour.[13]

The Tactical High-power Operational Responder (THOR) at Kirtland Air Force Base ahead of its April 2023 counter-swarm demonstration. In contrast to a HEL's tightly focused beam, THOR's wide-beamwidth microwave pulses can disable multiple UAS near-simultaneously.

Proponents also emphasise the sustainment case for DEWs. Promotional materials often refer to unlimited magazine depths, in contrast to the interceptor replenishment bottleneck already noted.[14] Neither DEWs nor low-cost kinetic interceptors can fully replace exquisite systems such as PATRIOT, THAAD, or SAMP-T NG, but a high-low force mix may ease pressure on munitions production lines and keep NATO forces in the fight for longer.

Proponents typically cite other benefits, including high accuracy and the ability to deliver a range of scalable effects with a single system. This could include HELs fully disabling or simply blinding the sensors on a target, presenting a route for de-escalation in a crisis. This is a consideration that may cut across operational and strategic imperatives. Similarly, the US military has explored the potential of HPMs as scalable options for non-lethal crowd control, for instance during urban operations, or counter-insurgency missions.[15] In counterspace roles, DEWs offer a more controlled means of holding hostile space assets at risk than direct-ascent ASAT missiles, which generate clouds of debris that risk cascading collisions that render entire orbits unusable (the Kessler syndrome).[16]

Taken together, such attributes of DEWs could create a deterrent effect. Limiting the potency of attritable UAS or massed fires may shift that offence-defence balance further, reinforcing strategic stability.[17] Deterrence is in the eye of the beholder, and this potential is a key driver of investment, as with the $40B Drone Edge initiative announced at the 2026 Ankara Summit.[18]

Technical and Operational Limitations

DEWs have a potentially strong case as integral elements of the future IAMD toolkit, but they are not without limitations. These fall into two categories, mobility and employment, on top of which a plethora of policy and regulatory hurdles could hinder widespread adoption.[19]

First, the requirement for a suitable energy source constrains the mobility of future DEWs. Most large-scale HEL systems currently in development report requirements of between 20 and 100 kW, entailing substantial fixed energy support infrastructure.[20] Some of the newest programmes are even more power-hungry. In July 2026, the US Department of War awarded Lockheed Martin Aculight and nLIGHT Defense contracts to develop prototypes for a containerised Joint Laser Weapon System (JLWS) starting at 150 kW, with ambitions to scale to 500 kW.[21] This demand for increasingly large energy systems, potentially at MW rather than kW scales by the 2030s, drives system size, complexity, thermal management and reliability issues, and cost.[22] This demand therefore limits the operational flexibility and manoeuvrability of systems. The more powerful HELs are likely to remain static air defence nodes, vulnerable to attack and around which an enemy force may easily manoeuvre. That said, these systems could become smaller and more mobile over time. DEWs are also likely to generate signatures, making them easier for an adversary to find and fix, and limiting their use in fast-moving operational situations.

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Employment considerations will also impact adoption. Reported engagement ranges are limited to 10 km (though rising with elevation), and atmospheric limitations add to this constraint. Moisture, turbulence, or obscurants in the air can absorb, scatter, and defocus lasers, generating restrictions in conditions such as fog, rain, smoke, heavy dust, and humidity. HELs must be held on target during engagement, adding complications when engaging a fast-moving, small object or doing so from an unstable platform (such as a ship in heavy seas). This requires advanced stabilisation and target tracking integration. As lasers grow more powerful, they also cause more 'thermal blooming': the laser heats the air it passes through,

The DragonFire HEL fires during a trial at the UK Ministry of Defence Hebrides Range, January 2024, marking the UK's first high-power laser firing against aerial targets.

which in turn defocuses the beam and could reduce the laser's effectiveness. This is most problematic if engaging a target heading directly at the HEL system on a constant bearing. As such, HELs are limited to line-of-sight employment. HPMs, on the other hand, can deliver effects in a range of climatic conditions, but present a higher risk of adverse collateral effects to friendly forces. Countermeasures could harden targets or shield electronics against these effects, but this comes with increased costs. Together, these size, weight, and power (SWaP), employment, and support demands sit in tension with NATO's Agile Combat Employment (ACE) concept, which will likely focus early DEW deployment on protecting key installations and high-value assets.

Barriers to Capability Fielding and Integration

Beyond technological maturity considerations, the wider DOTMLPFI implications of DEWs will demand considerable focus from NATO defence planners. This means resolving issues such as a lack of doctrine and Tactics, Techniques, and Procedures (TTPs);[23] immature training for DEW employment; and issues with spectrum management, battlespace management, and the avoidance of fratricide. For example, HELs could affect other air assets, even satellites, behind their targets, while HPMs could affect all unshielded electronics along their beamwidth. It similarly means addressing the lack of adequate infrastructure, energy generation, storage, or transmission capacity and ensuring robust field maintenance solutions for novel and unproven high-tech systems.

This uncertainty extends into the true cost of DEWs as well. Defence customers must absorb high R&D and related costs while DEWs remain deployed in small numbers, skewing efforts to ascertain their true cost-per-effect. Open-source reports suggest that initial tranches of Israel's Iron Beam laser system could cost tens of millions of dollars per unit.[24] In November 2025, the UK Ministry of Defence placed a £316 million contract with MBDA to equip two Royal Navy Type 45 air warfare destroyers with DragonFire HELs from 2027.[25]

Until DEWs are ordered and deployed in much larger numbers, batch production will constrain economies of scale in manufacturing. It is equally unclear how industry suppliers will adapt their through-life support solutions and commercial models for DEWs. Maintaining DEWs does not produce the enduring revenue that replenishing traditional munitions does. As such, the full-lifecycle costs and long-term financial appeal to industry for DEW programmes remain uncertain, despite investment currently seen in the sector.[26]

A further consideration is the potential sensitivities with norms and standards on the ethical use of weapons systems. HELs can cause physical harm to persons, including permanent blindness, and intentional use of this type is banned under international law.[27] There is also concern about other inhumane use, such as HPMs for non-lethal anti-personnel or crowd control tools. Relatedly, national legislation and regulations covering everything from management of unsegmented airspace to health and safety can restrict safe testing of DEWs, as well as domestic peacetime deployment. For example, use of a US military C-UAS laser system on loan to Customs and Border Protection forced US officials to close El Paso International Airport in February 2026, disrupting civil aviation across Texas.[28]

Notably, Russian and Chinese discourse on DEWs typically does not focus on tactical applications in C-UAS roles, as in the West. Rather, it considers potential ASAT roles and the resultant threats to critical space infrastructure, including the space segment of nuclear command, control, and communications (NC3) or early warning systems.[29] This highlights a strategic dimension to DEW development and requires careful intent signalling to avoid unintended escalatory outcomes.

Overcoming these policy, legal, regulatory, and DOTMLPFI barriers could unlock DEWs' potential capability-enhancing role in the NATO force mix. Their benefits and limitations mean DEWs are no silver bullet, but they remain a useful addition to the IAMD toolkit. DEWs could form a key part of a layered architecture, integrating active and passive sensors, artificial intelligence (AI)- and cloud-enabled command and control (C2). Current kinetic interceptors should be augmented by affordable mass solutions, such as missile, drone, or gun systems, to counter low, slow, and cheap threats.[30] Further, DEWs could sit alongside Suppression/Destruction of Enemy Air Defence (SEAD/DEAD) and deep strike capabilities, undertaking counterforce missions and supporting not just NATO deterrence by denial but also deterrence by punishment.

Priorities for NATO

Given the outstanding issues surrounding DEWs, NATO's Science and Technology Organisation (NATO STO) has recently developed a Military Utility Readiness Framework (MURF) for DEWs. This framework aims to guide NATO Allies on how to mature DEWs across all defence lines of development.[31] NATO STO designed the approach with industry to embed whole-of-capability thinking from the outset, ensuring Allied nations reach 'mature user' standards before receiving DEWs into service. This MURF approach provides a template for future capability rollouts beyond DEWs.

Still, more remains to be done. Crucially, many of the priority actions apply not only to those NATO Allies already deploying or planning to deploy DEWs (France, Germany, the UK, and the US, in particular). Nations lagging in DEW development or procurement must prepare to operate alongside Allies that field the technology, just as all Allies should prepare for adversaries fielding DEWs of their own. This means work at both NATO and national levels to:

- Refine plans, doctrine, standards, training, and exercises to reflect developments in DEWs and their integration into wider IAMD. Practical examples could include ensuring the NATO Defence Planning Process (NDPP) and associated capability codes continue to evolve to reflect new technologies such as DEWs; including emerging DEW-related considerations into Allied Joint Publications, such as AJP 3-3 Allied Joint Doctrine for Air and Space Operations, and subsidiary documents; and updating the air and air defence elements of joint exercises to stress-test new approaches to managing Joint Engagement Zones (JEZs) and avoiding fratricide when layering DEWs into IAMD.[32]

- Update legislation, policy, and regulation, and ensure access to suitable ranges, to accelerate testing and maturation of DEW technology. This includes modernising approaches to air traffic management via fora such as EUROCONTROL, to reflect testing or operational use of DEWs;[33] ensuring civil-military coordination to avoid unplanned airspace closures, as with the El Paso incident, or unintended danger to satellites and space services;[34] and updating defence safety regulations or broader national health and safety legislation to include DEWs, as early adopters such as the UK military have recently done for HELs and HPMs. At the international level, existing arms control treaties do not directly address DEWs, though they do come under wider International Humanitarian Law;[35] NATO Allies should continue to influence global norms on DEW usage and any future instruments governing their deployment or use, both terrestrially and on orbit (for example, via agreements with adversaries to avoid the targeting of space assets involved in nuclear C2).[36]
- Share lessons learned from operational use of DEWs in contemporary conflicts, such as via NATO's Joint Analysis and Lessons Learned Centre (JALLC). Conduct intelligence gathering on evolving adversary DEW capabilities, concepts of operations, and countermeasures. Commission wargaming and academic research into evolving Russian and Chinese views on DEWs, including the strategic stability implications and inadvertent escalation risks around possible future Ballistic Missile Defence (BMD) or ASAT applications of DEW technology.[37]
- Invest in joint procurements to share costs and promote economies of scale (e.g. via the NATO Support and Procurement Agency, EU, or other groupings), building on recent initiatives such as the new NATO Front Door for Industry, or the $40 billion Drone Edge effort.[38] Promote interoperability and common standards, both for DEW systems themselves and for the Application Programming Interfaces (APIs) and software components that connect them to AI- and cloud-enabled C2. Develop robust supply chains, including for the critical raw materials used in energy technologies, building on existing NATO and European efforts.

DEWs are no longer science fiction. But they remain a source of fierce debate as they are hyped by some and derided by others. The prime barriers to realising DEWs' full potential within the NATO force mix lie not in the technology itself but in the challenges of integration within legacy structures, processes, and policy environments. Though no silver bullet, the maturation of DEWs offers a real opportunity to swing the offence-defence balance and cost-exchange ratio in IAMD in the defender's favour. Seizing that advantage, however, will demand the same focus that NATO brings to the technology itself: implementing the wider reforms needed to turn this once-fictional capability into an operational reality. ●

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