2026 NDIA MICHIGAN CHAPTER
GROUND VEHICLE SYSTEMS ENGINEERING
AND TECHNOLOGY SYMPOSIUM
***MSPV* TECHNICAL SESSION**
AUGUST 11-13, 2026 - NOVI, MICHIGAN

PARAMETRIC SCREENING OF HYBRID POWERTRAIN ARCHITECTURES FOR HIGH-ENERGY LASER VEHICLES: APPLICATION TO FOXHOUND AND BOXER

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ABSTRACT

The US Army and several NATO allies have committed funds for directed energy weapons including high energy lasers (HEL), which require substantial electrical power. Silent Mobility and Silent Watch requirements mandate hybridization, which also provides the electrical capacity needed for a HEL.

This paper introduces a HEL framework of classes A-E based on target types and fluence physics. It estimates installed HEL mass and power demand by class, and applies rapid powertrain screening to hypothetical hybrid variants of the UK vehicles Foxhound and Boxer. Results show that HELs up to Class B (60 kW) and D (300 kW) laser output can be supported with minimal powertrain modifications by Foxhound and Boxer respectively, and upgrades to support Class C (150 kW) and E (500 kW) are containable within the payload of each vehicle. A rapid methodology is presented to determine what powertrain architecture is needed to support a given HEL.

Citation: R. Tull de Salis, “Parametric Screening of Hybrid Powertrain Architectures for High-Energy Laser Vehicles: Application to Foxhound and Boxer,” *In Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium* (GVSETS), NDIA, Novi, MI, Aug. 11–13, 2026.

1. INTRODUCTION

Directed energy weapons (DEW) in high energy laser form (HEL) offer a compelling answer to the rise of aerial drone warfare: a marginal cost per engagement, an unlimited magazine, and a sustained engagement rate far exceeding that of missile systems [1]. HELs are, however, heavy, and their electrical power requirements exceed what existing vehicle platforms can supply without extensive modification. Future platforms are likely to feature diesel-electric hybrid powertrains to deliver Silent Watch and Silent Mobility, and will therefore include the inverter and generator subsystems needed to supply HEL power. The challenge addressed here is planning such a platform at concept stage.

The U.S. Army has invested substantially in vehicle-mounted HEL systems, including the 50 kW DE M-SHORAD (Directed Energy Maneuver Short-Range Air Defense) on the

Stryker and the 300 kW-class IFPC-HEL program [2]. The UK's 2025 Strategic Defence Review committed nearly £1 billion to directed energy capability [3]; the Ministry of Defence has since ordered DragonFire laser systems for the Royal Navy [4] and demonstrated a Radio Frequency Directed Energy Weapon against drone swarms [5]. In June 2025 DE&S issued a market engagement notice for vehicle-mounted HEL, with a budget of £20 million and a deployment requirement within twelve months of contract award [6]. Outside NATO, vehicle-mounted HEL programs in the 30–100 kW class are in advanced development; the Chinese Silent Hunter ground system is reported at a TRL (Technology Readiness Level) of 7–8 [1].

A HEL fires in bursts of several seconds, after which a thermal recovery period must elapse before the next engagement, as accumulated waste heat is dissipated. CRS Report R46925 [2] identifies this thermal constraint as the dominant rate-limiting factor for sustained HEL operations, but no formal framework for characterizing it appears in published literature. The Sustained Firing Fraction (SFF) is introduced here as the maximum sustainable ratio of firing time to total time.

The average power demand, together with HEL system installed mass, defines two significant constraints that any candidate powertrain must satisfy. Both quantities vary with HEL parameters that are unlikely to be frozen at the vehicle concept stage, making powertrain design for a HEL platform a multi-dimensional problem.

Published simulations of military hybrid powertrains rely on high-fidelity tools such as ADVISOR, PSAT, and Autonomie, which require detailed engine maps and component data [7],[8]. The approach presented here, based on powersize.tech [9], requires only limited vehicle parameters that are available at concept stage, and screens HEL classes against multiple platforms simultaneously.

All data in this paper are drawn from publicly available sources, and the same methodology could be refined with access to program-specific information.

2. TACTICAL WHEELED VEHICLE PLATFORMS

The British Army operates a range of protected tactical wheeled vehicles that might serve as hosts for vehicle-mounted HEL systems. Foxhound and Boxer are selected as the two primary analysis platforms; they represent opposite extremes of the UK Army's protected wheeled vehicle fleet in payload and engine power, and are used as bases for hypothetical future hybrid platforms. Both use conventional diesel powertrains today, fueled by JP-8 military diesel. Other candidate platforms that were considered are described in [10].

Foxhound LPPV. The Foxhound Light Protected Patrol Vehicle (LPPV), has a gross vehicle mass (GVM) of 7,500 kg and a stated maximum payload of approximately 2,000 kg. It is powered by a Steyr M16-Monoblock diesel engine rated at 160 kW [11]. It is the smallest British Army vehicle that might support a functional HEL [12],[13].

Boxer MIV 8×8. The Boxer Mechanized Infantry Vehicle (MIV) is the British Army's new protected 8×8 wheeled vehicle, with 623 vehicles on order under a £2.8 billion contract [14],[15],[16]. It has a gross vehicle weight of 38,500 kg and is powered by an MTU diesel rated at 600 kW. A common drive module carries interchangeable mission modules, leaving a payload of 15,000 kg. A dedicated HEL mission module would be the natural integration method for a Boxer-based laser system, isolating the weapon's power conditioning, thermal management, and energy storage within a self-contained unit that can use power from the drive module's powertrain. The German Bundeswehr has ordered 19 Rheinmetall Skyranger 30 HEL systems, with a stated near-term output target of 50 kW, on Boxer chassis [17].

Table 1: Platform payload for HEL system integration. [11],[12],[13],[16]

Parameter	Foxhound LPPV	Boxer MIV
Gross Vehicle Weight max. (kg)	7,500	38,500
Payload capacity (kg)	2,000	15,000

3. HEL SYSTEM: CLASSIFICATION AND CHARACTERIZATION

3.1. HEL Technology

High-power microwave (HPM) / radio frequency DEW (RFDEW) and millimeter-wave active denial (ADS), have modest electrical demands and present no hybrid powertrain architecture challenge [18]; this paper focuses exclusively on high-energy laser (HEL) systems.

High-Energy Laser (HEL) Systems

Figure 1 shows a HEL system mounted on a Stryker 8x8 vehicle. HEL systems generate the output beam by using electrical power to generate photons via a pump diode array, driving a fiber laser or solid-state gain medium. The waste heat (60 to 70 percent of input power) must be absorbed in the short term by thermal inertia and phase change material (PCM), requiring dedicated mass, and then rejected by a cooling system, which both adds weight and consumes power [19],[20],[1]. The cooling system must keep the HEL components at a temperature close to ambient and reject heat to ambient also, which for military equipment is specified up to 49 deg C atmospheric temperature, so chiller equipment is required. The load occurs in bursts of several seconds, punctuated by short re-engagement intervals and longer thermal recovery periods.

The key vehicle-mounted HEL systems that have been demonstrated are listed in Table 2.

Figure 1: *Directed Energy Maneuver Short-Range Air Defense (DE M-SHORAD) 50 kW-class laser weapon system mounted on a Stryker A1 8×8 armored vehicle.*

Table 2: Reference HEL systems. HELIOS is a shipboard system. Range figures are for hard-kill engagements against UAS targets where reported in open sources; n/r = not reported.

System	Platform	Output	Range	Ref
Raytheon HELWS	Wolfhound; JLTV	15 kW	~3 km	[21]
US Army E-HEL	JLTV (US Army, future)	10–20 kW	req. 4 km	[39]
AMP-HEL / LOCUST	JLTV (US Army)	20 kW	n/r	[23]
Rheinmetall Skyranger 30	Boxer 8×8; Pandur EVO	20 kW	n/r	[17]
Lockheed Martin ATHENA	Ground demonstrator (US)	30 kW	n/r	[24]
India DRDO Mk-II(A)	Ground mobile (India)	30 kW	~3.5 km	[38]
Raytheon DE M-SHORAD	Stryker A1 8×8 (US Army)	50 kW	n/r	[2],[25]
LM HELIOS Mk 5	USS Preble DDG-88	60 kW	n/r	[26],[27]
UK DragonFire	Land / Royal Navy (UK)	~100 kW	~1 km	[4]
Dynetics / Leidos HEL-TVD	FMTV M1083 6×6	100 kW	n/r	[2]
DARPA HELLADS	Aircraft (MQ-9 class)	150 kW	n/r	[28],[29]
US Army HEL / Valkyrie	Semi-fixed site	>250 kW	n/r	[2]

3.2. HEL Subsystem Architecture

The DEWS MOSA RA (Directed Energy Weapon System, Modular Open Systems Approach Reference Architecture), [30] defines the open-standard module taxonomy for HEL systems, with the four dominant consumers being the DE Source, Power and Thermal Management System (PTMS), Beam Director, and Power Conditioning module; the full taxonomy and power allocation are given in [10, Table A1].

Thermal Management

The PTMS is the heaviest subsystem for ground-based HEL systems, and consumes the most power. At current wall-plug efficiencies, 60% to 70% of the laser input power is rejected as waste heat during each engagement. Ground vehicles cannot exploit the ram-air cooling and low temperature air available to aircraft, so the PTMS must actively store and reject this heat through a liquid cooling loop and heat exchanger, augmented by phase-change thermal storage materials for burst absorption [31]. The mass of the PTMS depends on waste heat rejected, which depends on Wall Plug Efficiency (WPE), the ratio of the output power of the laser beam to the electrical power required to run the HEL system during firing. WPE values exceeding 50% have been reported under lab conditions, but if PTMS and other parts of a fully installed mobile system are included, then the reported values are much lower, around 35% at best.

3.3. Performance Classification

No standard taxonomy of HEL weapon classes by output power and target type exists in publicly available literature, beyond informal references such as "the 50 kW class". The classification proposed here is derived in three stages. First, the fluence-to-kill thresholds that characterize each target category are taken from Zohuri [32] and tabulated in Tables A6 and A7 in [10], together with the progressive energy loss from atmospheric absorption, beam quality, and target surface reflectance. Second, these thresholds are compared against open-source program evidence, comprising the known output powers of systems that have been physically demonstrated to defeat each target type. Third, class boundaries are drawn at qualitative steps in capability, i.e. power levels at which new categories of target become defeatable.

The five-class framework is summarized in Table 3; the program references and defeat mechanisms for each class are given there. The derivation for each step is given in Tables A5–A7 in [10].

Ground vehicle engagement scenarios are assumed to be at or below the output power of Class E (500 kW). As shown in Table 2, the maximum engagement range demonstrated by any ground-based HEL system in the open literature is approximately 3.5–5 km. Ballistic missile boost-phase intercept is the only task requiring over 500 kW, but it would require sustained beam propagation and precision aiming over distances orders of magnitude greater; this is impractical on grounds of beam aiming and atmospheric propagation, so it is outside the scope of ground vehicle HEL systems [32],[2]. No ground vehicle engagement scenario identified in the open literature requires laser output exceeding 500 kW. Therefore, if a vehicle platform can support a HEL up to Class E, that represents the full power requirement for a ground-based system.

Table 3: HEL Performance Classification: Classes A–E.

Class	Output Power (kW)	Primary Target Set	Defeat Mechanism
A	**20**	Optical sensors / IR seekers; Group 1–2 UAS (Unmanned Aerial System)	Photonic overload of detector array (sensors); composite avionics / airframe charring (UAS)
B	**60**	Group 3 UAS; one-way attack drones (Shahed-136 class); mortar rounds (81–120 mm)	Composite structural failure by delamination or burn-through (UAS). Steel body and propellant heating (mortar).
C	**150**	122 mm rockets; unprotected cruise missiles; fuel system ignition on armored vehicles	Steel body structural defeat; propellant / fuel ignition; sustained ablation of light armor
D	**300**	Hardened RAM; cruise missiles with ablative coatings; rotary-wing aircraft	Sustained ablation through surface countermeasure; rotary-wing structural kill via rotor head and fuel system aimpoints
E	**500**	Manned fixed-wing aircraft; supersonic cruise missiles with heavy ablative coatings.	Deep structural kill by sustained ablation through thick metal skin at extended dwell (20–30 s); fuel system, control surfaces.

3.4. HEL Efficiency

Role of Efficiency. Wall-plug efficiency (WPE) governs both the electrical power for a given laser output when firing, and the associated power consumed by the PTMS and other HEL subsystems. A higher WPE reduces the installed mass as well as the power demand of the HEL.

Laser-Only versus Installed Efficiency. Laboratory measurements typically meter only the laser head and pump diode supply; chiller, compressors, pumps, and heat exchangers draw from a separate circuit [31], along with computer controls and other supporting subsystems, and are excluded. In a military vehicle installation, installed WPE equals optical output divided by the combined demand of laser and supporting systems. This boundary difference explains why field values of 30–33% lie substantially below laboratory peaks of 50–56%. Full data sources are given in Table A2 in [10].

Reported WPE data. Compiled data (Figure 2; full table in [10, Table A2]) shows laser-only WPE reaching 50–56% under laboratory conditions [33], with a 60 kW system demonstrated at >43% [34]. The installed equivalent, which includes PTMS, is approximately 33% [35]. No improvement trend over time is apparent in the installed data.

3.5. Specific Mass

Figure 3 plots published laser source specific mass against year; values span 4.0–5.0 kg/kW across all power classes and years, with no improvement trend. A laser source specific mass of 4–5 kg/kW is therefore adopted as a fixed baseline. Full data sources are in [10, Table A8].

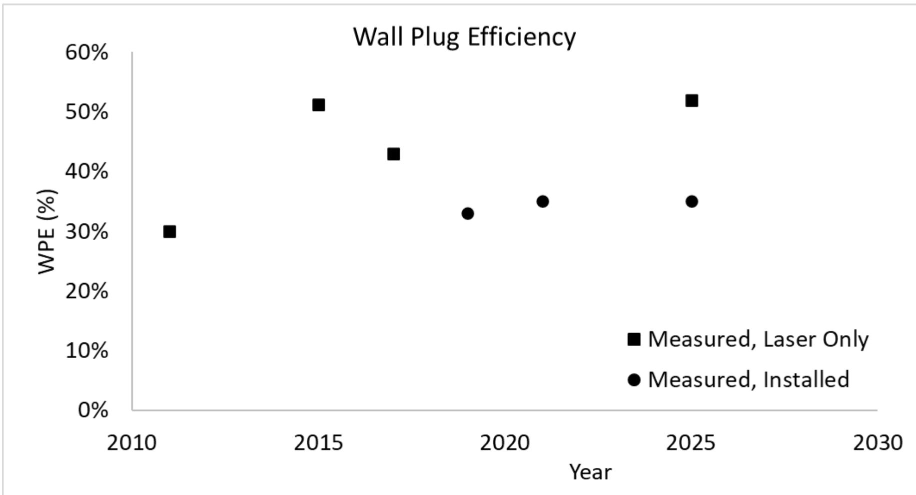

Figure 2: *Wall Plug Efficiency (output power / input power, %)*

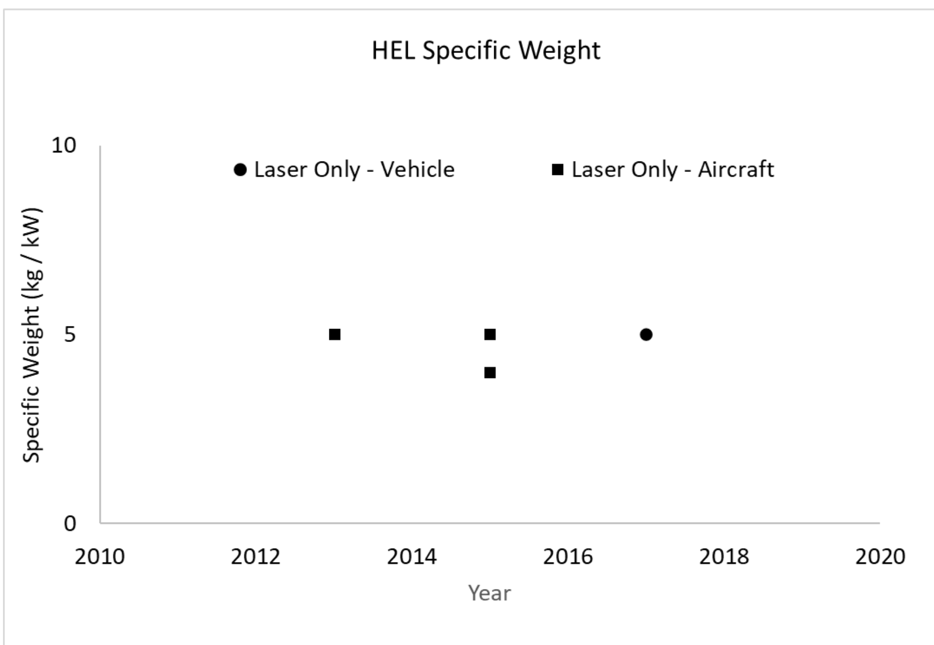

Figure 3: *HEL Specific Mass (kg/kW)*

3.6. Engagement Cycle Definition

A HEL system operates in a repeating three-phase engagement cycle.

• Engagement phase: Laser fires at target. A high power peak is drawn, and the laser output power during firing is the nominal output power describing the system. The required duration depends on target type, range, atmospheric conditions and laser power class, and presumably continues until the intended damage is visually confirmed, so is variable from shot to shot.

• Re-acquire phase: Beam slews to next target.

• Thermal recovery phase: PTMS dissipates accumulated waste heat.

The large-capacity generator and inverter of a hybrid powertrain, already sized for Silent Watch and Silent Mobility, serve equally well to power a HEL, and the battery provides a stable DC bus that simplifies the laser driver electronics. Given the laser output power, the WPE, and the SFF, the average vehicle electrical demand during sustained engagement can be calculated, and the powertrain sized accordingly using powersize.tech as described in Section 4.

3.7. Sustained Firing Fraction

The SFF (sustained firing fraction) is the fraction of total engagement cycle time during which the laser is firing. It is determined by the thermal recovery characteristics of the HEL. As these characteristics are not publicly reported, the analysis adopts two bounding values of SFF.

Upper bound: SFF = 83 percent. Derivation: DragonFire field test data from the UK MoD reports defeat of a target travelling at 650 km/h with a dwell time of approximately 10 seconds [4],[22]. CRS Report R46925 [2] states that beam director slew time between targets is of the order of several seconds; 2 seconds is adopted as a representative lower bound on slew time. Setting thermal recovery time to zero, the physical ceiling, achievable only if the PTMS can reject waste heat as fast as it is generated, gives SFF as 10 seconds out of 12, or 83 percent.

Adopted value and lower bound: SFF = 50 percent, on tactical utility grounds: a weapon system that spends more than half its engagement cycle time in thermal recovery seems unlikely to maintain a useful engagement rate against a sustained aerial threat. SFF = 50 percent is therefore treated as the practical floor for a tactically effective system. The value of SFF may be adjusted when the methodology of this paper is applied, so an error in the selected value would not invalidate the analysis method.

3.8. Smoothing the Power Demand

The power demand of the HEL is illustrated in Figure 4, for a HEL of class A, comprising alternating loads for firing and recovery. The large battery of a hybrid powertrain may be considered suitable for accommodating the demand peaks, but in practice this might force an oversized battery, simply because charging rate should be limited to preserve battery durability. Ultracapacitors offer a much cheaper and lighter solution. By comparison with batteries, they lack energy density (kWh/kg) but excel in power density (kW/kg). The period of alternation is suitable for the use of ultracapacitors to smooth out the power demand to an average value during operation. For example, a commercially available ultracapacitor module from Skeleton Technologies is advertised with power capacity 504 kW and energy capacity 225 Wh, and it weighs 35 kg [36]. If such ultracapacitors are used to smooth out the power draw for a Class A HEL, as illustrated in Figure 4, the charging and discharging power would be approximately 24 kW for 3 seconds, with a total energy storage of 20 Wh. For a class E HEL, the values would be approximately 500 kW for 15 seconds, giving 417 Wh, containable with two ultracapacitor modules weighing only 70 kg, a negligible added weight by comparison with the payloads of the two vehicles. Ultracapacitors work between a wider range of voltages than batteries, so a DC-DC converter is also required. A HEL system is assumed to use ultracapacitors, so that the vehicle need supply only the average power required during engagement, not the peak.

3.9. Electrical Power Demand

The total vehicle electrical demand is the sum of five component groups, listed in Table 4. Of these, the laser chain, the chiller, and the coolant pumps, scale with laser output power and dominate at all but the lowest power class. Two are fixed regardless of laser power class: the beam director drive load (which scales weakly with aperture size) and the fixed loads (acquisition, tracking, and pointing sensors, fire control computer, and communications). Table A3 in [10] defines each component's behavior, worked example values, and the assumptions underlying the model.

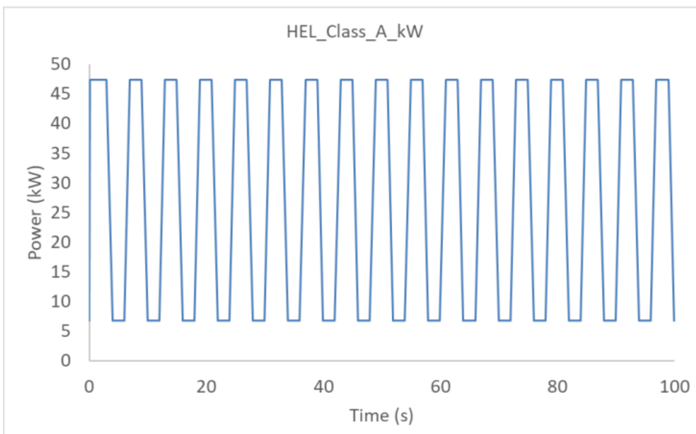

Figure 4: *Power demand for HEL system. Alternating firing and thermal recovery, for SFF = 50%. This power demand can be smoothed to a near-constant average value, by the use of ultracapacitors.*

The chiller COP (Coefficient of Performance) is adopted as 3.7, derived from Carnot analysis at the system operating temperatures and cross-validated against published vapor-compression data; the full derivation is in [10, Table A7].

During the firing phase, the dominant loads are the laser and the chiller. During the non-firing phase (beam director slewing between targets, or thermal recovery), the laser is off but the chiller continues to run at full load to discharge the phase-change material (PCM) thermal store that absorbed the burst waste heat.

The average vehicle electrical demand is the weighted sum of the firing-phase and non-firing-phase demands, weighted by the SFF and smoothed by ultracapacitors, as described in Section 3.7.

Table 4: DEW subsystem specific mass at 100 kW output. Further details in Table A9 in [10].

Subsystem	**kg/kW (low)**	**kg/kW (high)**
DE Source (laser, pump diodes, SBC, output optics to BD aperture)	4.4	5.0
Thermal Management / PTMS (liquid loop, pump, HX, PCM, HX)	2.0	2.8
Beam Director (steerable telescope, gimbal, ruggedized MIL-STD-810)	2.0	4.0
ATP (Acquisition, Tracking and Pointing) Sensors (EO/IR tracker, radar cue receiver, processor)	0.5	1.5
Platform Integration (mounts, EMI (Electromagnetic Interference) shielding, harness, connectors, armored housing)	0.5	1.5
EPS (Electrical Power System) / Power Conditioning (DC-DC converter, EMI filter, isolation transformer)	0.5	1.0
Fire Control and Track Manager (ruggedized processor and I/O)	0.2	0.5
Beam Transport (internal fiber, DE Source to BD aperture)	0.1	0.2
TOTAL	**10.2**	**16.5**

3.10. Installed System WPE and Results

The installed system wall-plug efficiency is the ratio of average laser output to average vehicle bus demand, integrated over the full engagement cycle. The installed WPE is always substantially lower than the laser-only WPE of 50 percent, because the chiller and fixed loads draw power throughout the cycle while the laser produces output only during the firing phase. At low power classes the fixed loads are significant;

at Class C and above the chiller dominates, and the system WPE converges to a stable value determined by thermodynamic analysis. Table 5 gives numerical results for all DEW classes at SFF = 50%.

Table 5: Electrical Power Demand and System WPE by HEL Class.

Class	Laser output (kW)	Firing-phase demand(kW)	Average demand at SFF=50% (kW)	System WPE at SFF=50% (%)
A	20	48	27	36.8%
B	60	134	73	41.2%
C	150	328	176	42.5%
D	300	652	348	43.1%
E	500	1,084	579	43.2%

3.11. Chiller Specific Mass

The PTMS comprises several heavy components: the vapor-compression refrigeration circuit (compressor, condenser coil, expansion valve, and evaporator at the laser head), a phase-change material (PCM) thermal store that absorbs burst waste heat during the engagement phase, liquid coolant circuit plumbing and manifolds, condenser fans or liquid-to-air heat exchangers, and an electronic controller.

The chiller must reject the average waste heat over the full engagement cycle. The PCM thermal store absorbs burst waste heat during firing; the chiller then operates during the non-firing thermal recovery phase to drain the store. The required chiller thermal capacity is therefore not the instantaneous peak waste heat rate but the cycle-average rejection rate. For a laser of output power P_L at wall-plug efficiency WPE, the required average chiller thermal capacity $\mathbf{P_C}$ is given by equation (1):

$$\mathbf{P_C = P_L \times SFF \times (1 - WPE) / WPE} \quad (1)$$

No open-source specific mass figure has been identified for a military DEW PTMS refrigeration circuit at this capacity and operating temperature.

The chiller circuit specific mass is bounded between 4 and 5.5 kg/kW(thermal) using three reference points (aircraft galley, automotive R-134a circuit, bus rooftop unit); the derivation is given in [10, Table A9]. All three operate at a temperature lift of approximately 40 K, matching the DEW case.

3.12. Installed System Mass by Class

Table 6 gives the resulting specific mass range and total installed mass range for each HEL class. Values are plotted in Figure 5.

The mass table and the electrical demand table together define the two constraints that a candidate hybrid powertrain must satisfy simultaneously. The powertrain addition must remain within the platform payload budget after the HEL system mass is allocated. The powertrain's engine, generator and inverter must be capable of sustaining the average electrical demand at the selected SFF.

Table 6: Estimated installed HEL system mass range by class.

Class	Laser output (kW)	Average Power Draw, During Engagement (kW)	Total installed mass range (kg)
A	20	27	358–580
B	60	73	732–1,184
C	150	177	1,328–2,149
D	300	349	2,083–3,374
E	500	578	2,900 – 4,700

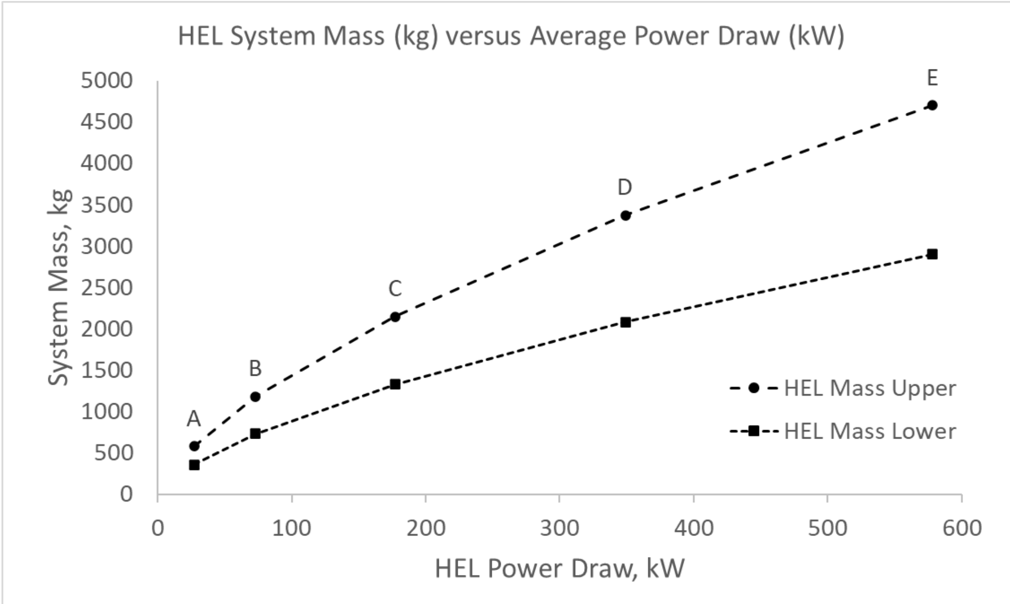

Figure 5: *HEL System Mass (kg) versus Operational Power Draw (kW).*

4. ANALYSIS METHODOLOGY

4.1. Mission Profile CEMP-H combined with HEL Power Draw

The CEMP-H (Central European Mission Profile – Hybrid Tactical Vehicles), a 24-hour charge-neutral mission cycle for hybrid tactical wheeled vehicles, is defined in [37]; it comprises nine phases including a five-hour Silent Watch period, a two-hour Silent Mobility patrol, a one-hour weapons-engagement phase, and base-rest Export Power periods. Vehicle-specific parameters for both platforms are given in [37, Tables 2 and 3].

4.2. powersize.tech Screening Method

powersize.tech 1.0 (Power Size Technologies Ltd) is a rapid parametric powertrain screening tool designed for concept-stage architectural decisions. Unlike high-fidelity tools such as ADVISOR, PSAT, and Autonomie, which require detailed brake specific fuel consumption (BSFC) maps, component efficiency tables, and calibrated models, powersize.tech requires only the limited vehicle parameters that are typically available from open-source program documents at the concept stage [9]. These inputs comprise vehicle mass, rolling resistance, aerodynamic drag, frontal area, maximum speed, and the electrical loads and Export Power requirements of the CEMP-H mission cycle.

The tool converts the CEMP-H speed-time profile into a wheel-power demand using the standard longitudinal road load equation, adds auxiliary electrical and Export Power loads phase by phase, and generates a power-time trace for the full 24-hour cycle. From this trace it determines the minimum engine power and battery capacity needed to complete the cycle charge-neutrally, applying a minimum state of charge (SOC) floor of 20%.

Component sizing follows a sequential efficiency cascade. For a series hybrid, the chain runs: engine → motor generator unit

(MGU) → rectifier → inverter → traction motor → driveline, with each stage derated by a component-class efficiency drawn from powersize.tech's internal parameter database, which aggregates published efficiency characteristics across drivetrain component classes [9]. The resulting component power ratings, masses, and estimated costs are tabulated automatically; the component mass values in Tables 7 and 8 of this paper are the direct outputs of this process.

The average HEL electrical demand from Table 5 is added as a continuous DC load during the one-hour engagement phase of the CEMP-H, and the DC-DC converter is resized accordingly. Engine power is constrained to be no lower than the current platform specification (160 kW for Foxhound, 600 kW for Boxer), on the assumption that unpublished operational requirements justify those ratings; only HEL classes that exceed this ceiling require an engine uprate.

The series hybrid was selected as the evaluation architecture for both platforms. It completely decouples the engine operating point from the HEL load and the traction demand, allowing each to be optimized independently. The parallel hybrid was also sized in [37] and is shown in Tables 7 and 8 as a reference baseline; the series architecture adds mass and cost but provides the electrical separation needed for HEL integration. A step-by-step setup procedure and open-access Excel workbooks supporting this methodology are provided in [37].

5. RESULTS

Figure 6 shows the powertrain architecture for a parallel hybrid, generated by powersize.tech, and Figure 7 shows a series hybrid. The baseline powertrain in both cases is ICE (Internal Combustion Engine). The bottom output in each diagram is the electrical supply to the HEL system. The series architecture was selected for both Foxhound and Boxer. Tables 7 and 8 show how the power specifications of the powertrains increase, along with the weight, as the vehicle is hybridized and HEL is added. Figures 8 and 9 illustrate the results. The engine power is kept no lower than that currently deployed for each platform, with the result that little or no power increase is required except for the highest class of HEL considered for each platform.

Foxhound is evaluated against Classes A–C only, respecting its payload limit; Boxer is evaluated against Classes C–E.

A minimum payload of 240 kg should remain, for a driver and a gunner: 120 kg is allowed per person, comprising 85 kg soldier body mass (95th percentile NATO male), 15 kg combat body armor, and 20 kg personal weapon, ammunition and equipment. This is an engineering estimate that is consistent with planning figures used in UK MoD vehicle procurement.

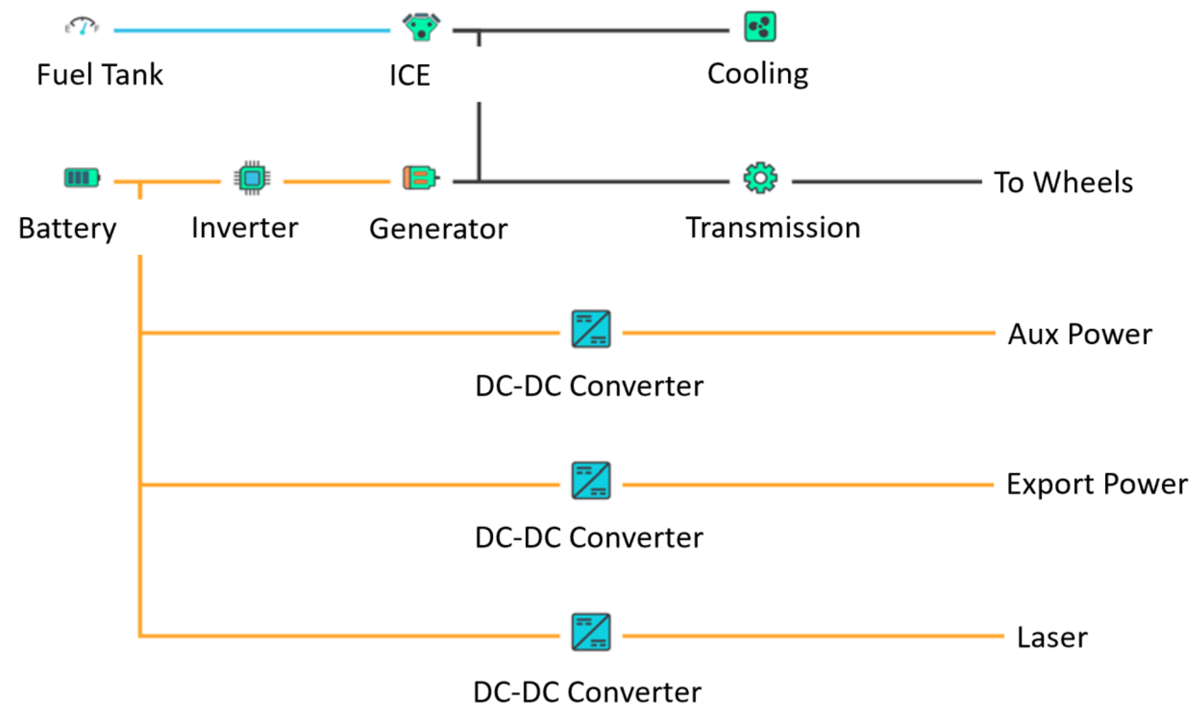

Figure 6: *Parallel-Hybrid Architecture with HEL Power Output*

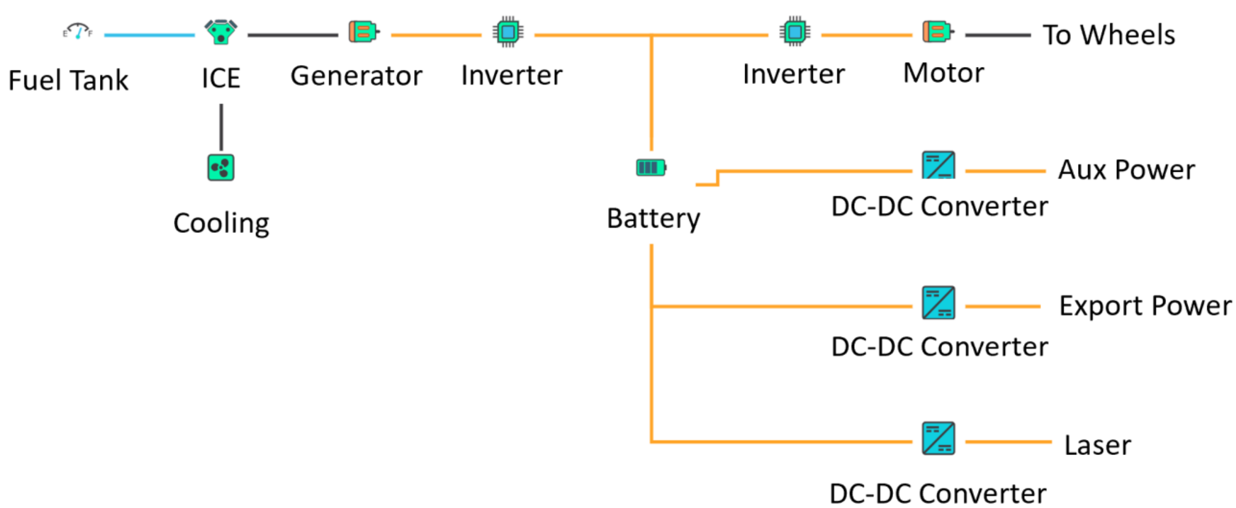

Figure 7: *Series-Hybrid Architecture with HEL Power Output*

Table 7: powersize.tech specifications and mass for Foxhound in ICE (Internal Combustion Engine), hybrid and HEL configurations.

		ICE Only	Parallel Hybrid	Series Hybrid	Series with HEL Class A	Series with HEL Class B	Series with HEL Class C
ICE	kW	160	160	160	160	165	228
MGU (Motor Generator Unit)	kW		152	152	152	152	203
Rectifier	kW			146	146	146	195
Inverter	kW		140	140	140	140	140
Motor + Gearing	kW			133	133	133	133
Transmission	kW		144				
DCDC Converter	kW		42	42	42	87	195
Battery	kWh		65	65	65	65	65
Fuel Tank mass	kg	244	222	252	253	252	252
Powertrain Mass	kg	781	1625	1907	1915	1922	2196
P/T Mass Added	kg			Base (0)	8	15	289
HEL mass (lower)	kg				358	732	1328
Payload	kg			2000	1634	1253	383

Table 8: powersize.tech specifications and mass for Boxer in ICE, hybrid and HEL configurations.

		ICE Only	Parallel Hybrid	Series Hybrid	Series with HEL Class C	Series with HEL Class D	Series with HEL Class E
ICE	kW	600	600	600	600	600	704
MGU	kW		570	570	570	570	669
Rectifier	kW			547	547	547	642
Inverter			525	525	525	525	525
Motor + Gearing	kW			499	499	499	499
Transmission	kW		542				
DCDC Converters	kW		83	83	205	385	623
Battery	kWh		210	210	210	210	210
Fuel Tank mass	kg	742	616	766	766	766	766
Powertrain Mass	kg	2679	5183	6604	6659	6719	7223
P/T Mass Added	kg			Base (0)	55	115	619
HEL mass (lower)	kg				1328	2083	2900
Payload	kg			15000	13617	12802	11482

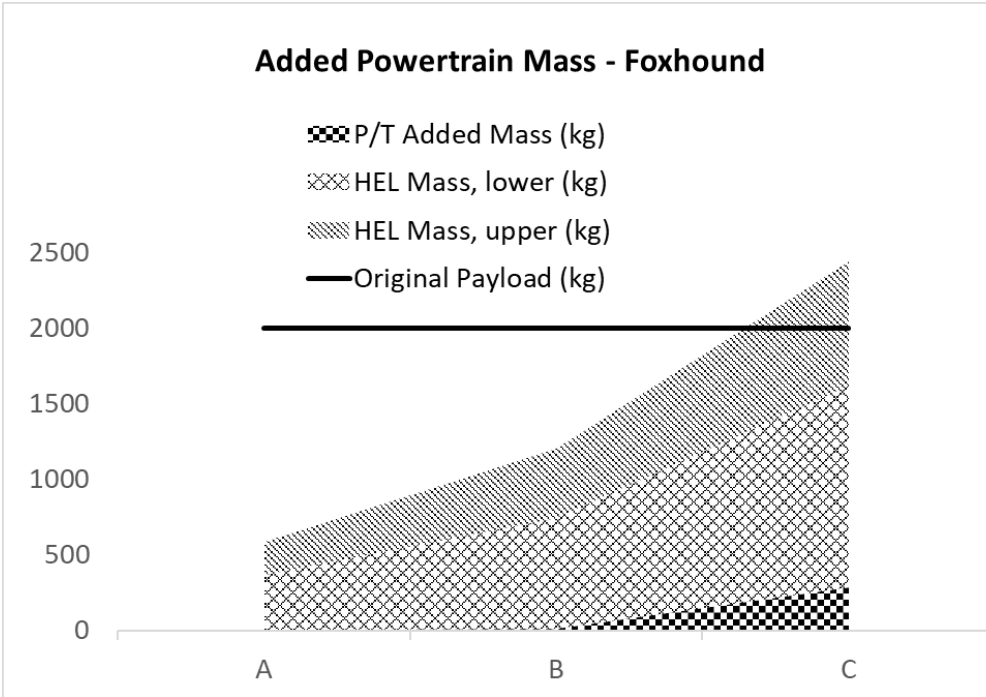

Figure 8: *System Mass (kg) versus HEL Class – Foxhound*

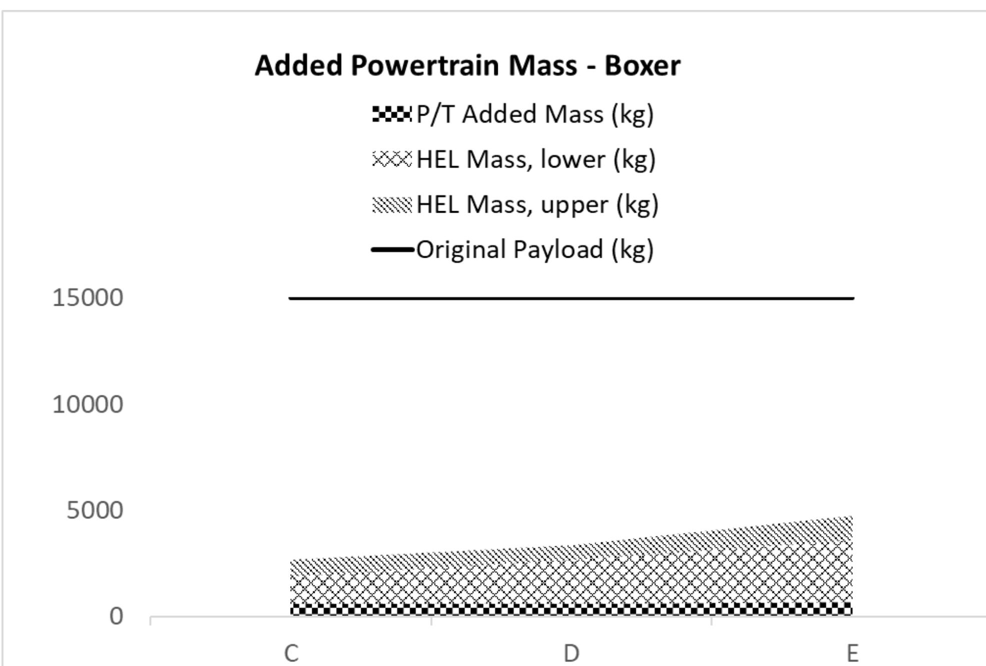

Figure 9: *System Mass (kg) versus HEL Class – Boxer*

6. DISCUSSION

The chief obstacles to mounting a HEL on a vehicle platform are the power requirement and the system weight. Both are illustrated in Figure 5, for HEL classes A-E. The power requirement can also drive a mass increase in the powertrain, adding to the complexity of the matching task.

The Foxhound and Boxer hybrid powertrains proposed in [37] are already equipped to provide significant electrical power, via substantial generators and inverters sized for the requirements of the CEMP-H mission profile. Tables 7-8, and Figures 8-9, show that the necessary enlargement of the Foxhound powertrain components for HEL is minimal for Class A-B, and likewise for Boxer with Class C-D. Only the highest classes for each vehicle (C and E) mandate significant powertrain upgrades, which are containable within the payload capacity of each vehicle. This holds for all cases except Foxhound with the Class C HEL, which is feasible only if the HEL system mass is closer to the lower estimate than to the higher.

The series hybrid platform offers a further advantage. A standalone vehicle HEL EPS (Electrical Power System) must power the laser driver, typically requiring a dedicated diesel generator, AC bus, rectifier, and power conditioning unit. On a series hybrid platform, the traction battery and stabilized high-voltage DC bus are already present as standard features of the drivetrain. The HEL EPS therefore reduces to a single DC-DC converter and EMI (Electromagnetic Interference) filter, eliminating the AC front-end entirely. The EPS specific mass adopted in Table 4 is therefore 0.5–1.0 kg/kW rather than the 1.0–2.0 kg/kW typical of a standalone EPS. The saving scales with power class and is therefore most valuable for Classes C–E. This synergy makes the series hybrid the preferred host architecture for a vehicle-mounted HEL, confirming that hybridization for Silent Watch and Silent Mobility prepares the platform for HEL integration at relatively low incremental cost. The batteries sized in [37] for Silent Watch and Silent Mobility (65 kWh for Foxhound, 210 kWh for Boxer) are also sufficient in both power and energy capacity to support HEL deployment for a limited time with the engine off.

The ICE power requirements for HEL Class C and Class E increase to 228 kW (Foxhound) and 704 kW (Boxer), both of which are obtainable with commercially available engines. If, however, engines of sufficient power cannot be obtained, several measures could reduce the requirement:

1. Reduce the SFF below 50%.
2. Reduce the size of the laser cooling system to provide full SFF at a lower ambient temperature than the assumed 49 deg C, and accept de-rating of SFF at higher temperatures.
3. Seek improved WPE from the laser system.
4. Reduce the target output power (150 kW, 500 kW) for Classes C and/or E.

The weight of the powertrain is already increased substantially with the first step (hybridization) before HEL is added, as the system is sized to provide Silent Watch, Silent Mobility and Export Power, as explained in the companion paper. [37] For the addition of a HEL, the series hybrid is assumed as baseline rather than the parallel hybrid, despite being heavier, because the series hybrid completely detaches the engine operating point from the demands of the HEL and the traction drive, so they can operate independently. The series-hybridization step itself adds 1126 kg to the Foxhound per Table 7, but it is assumed that weight savings will be achieved elsewhere in the case of such a major redesign, deliberately preserving the original payload of 2,000 kg as a program target, as is the usual practice with commercial vehicles. (The 7,500kg GVM of the Foxhound cannot be increased, as higher GVMs require a different driving license for operators in Europe and the UK.)

The last rows of Tables 7-8 track the remaining payload as HEL hardware is added, with the series hybrid as baseline, and Figures 8-9 illustrate it.

Table 7 shows that the addition of a Class A or Class B HEL to the Foxhound vehicle has very little effect on the specifications of the hybrid powertrain, confirming that hybridization partially prepares the vehicle for HEL. The step up to Class C almost doubles the required engine power, but this is containable with only a further 274 kg added to the powertrain weight.

The Boxer has a payload of 15,000 kg. Figure 9 shows that this is far more than required to accommodate even the Class E laser.

7. CONCLUSIONS

Matching a HEL system to a vehicle platform at concept stage is a multi-dimensional problem: power demand and installed mass both vary with HEL parameters that are unlikely to be frozen early in a program, and the power demand itself can trigger further mass increases in the powertrain additional to those of the hybridization step. The methodology presented here allows these interactions to be analyzed rapidly, and requires no specialist simulation expertise; powersize.tech screens multiple HEL power classes against multiple platforms simultaneously, requiring only limited vehicle data that is readily available at concept stage.

Five HEL classes (A–E) are defined by target type and laser output up to 500 kW, covering the full range of land-based applications. Power demand and installed mass scale from Class A to E, and are compared with platform payloads. Applying powersize.tech to the CEMP-H mission profile for Foxhound and Boxer shows that each platform can accommodate specific HEL classes within its payload and engine power envelope, with only Class C and E respectively requiring engine uprates.

The Foxhound platform in series hybrid form could support a HEL class A-B with very little modification to the powertrain, assuming that it was already specified to deliver Silent Watch and Silent Mobility functions according to the CEMP-H mission profile. Class C is also attainable if the engine power is increased. A Boxer series hybrid platform could support a HEL up to class D in respect of both weight and engine power, and even up to class E at 500 kW laser output, given an engine uprate to 704 kW.

8. REFERENCES

[1] Karkadakattil, A., "Laser-Based Directed Energy Weapons: Technological Capabilities, Material Interaction, and Strategic Deployment Pathways," *Defense Science Review*, No. 21, 2025 (received Dec. 2025; accepted Jan. 2026). DOI: https://doi.org/10.37055/pno/216776 (accessed March 9, 2026).

[2] Congressional Research Service, "Department of Defense Directed Energy Weapons: Background and Issues for Congress," CRS Report R46925, updated 2024.

[3] UK Strategic Defence Review, March 2025, HM Government, London. (Report: SDR directed energy investment, ~£1 billion commitment)

[4] UK Ministry of Defence, "DragonFire directed energy weapon: £10 per shot laser capability", MoD press release, November 2025. Available at: https://www.gov.uk

[5] UK Ministry of Defence, "British Army successfully tests new drone-destroying laser", MoD press release, December 2024. Available at: https://www.gov.uk/government/news/british-army-successfully-tests-new-drone-destroying-laser

[6] UK Defence Equipment and Support (DE&S), "Preliminary Market Engagement Notice: Land Laser Directed Energy Weapon (LDEW)", FMC-StratProgs-CWDEW-Group@mod.gov.uk, 13 June 2025.

[7] Silvas, E.; Hofman, T.; Murgovski, N.; Etman, L.F.P.; Steinbuch, M. Review of Optimization Strategies for System-Level Design in Hybrid Electric Vehicles. *IEEE Transactions on Vehicular Technology*, 2017, 66(1), 57–70. DOI: 10.1109/TVT.2016.2547897 (accessed March 18, 2026).

[8] Kramer, D.M.; Parker, G.G. Current State of Military Hybrid Vehicle Development. Int. J. Electric Hybrid Veh. 2011, 3, 369–387. https://doi.org/10.1504/IJEHV.2011.044373.

[9] R. Tull de Salis, "Rapid Evaluation of Off-Highway Powertrain Architectures," *World Electr. Veh. J.*, vol. 16, no. 12, p. 671, Dec. 2025, doi: 10.3390/wevj16120671.

[10] R. Tull de Salis, "Parametric Screening of Hybrid Powertrain Architectures for High-Energy Laser Vehicles: Application to Foxhound and Boxer," Zenodo preprint, Mar. 2026. DOI: https://doi.org/10.5281/zenodo.19113766

[11] Wikipedia contributors, "Ocelot (vehicle)," *Wikipedia*, last modified November 2025. Available: https://en.wikipedia.org/wiki/Ocelot_(vehicle) (accessed 12 March 2026).

[12] GlobalData / Army Technology, "Foxhound Light Protected Patrol Vehicle (LPPV), UK," *Army Technology*, updated January 2026. Available: https://www.army-technology.com/projects/ocelot-lppv/ (accessed Mar. 11, 2026).

[13] Morrison, B., "Armour Focus: Foxhound LPPV Pt 3," *Joint Forces News*, Dec. 2022. Available: https://www.joint-forces.com/features/18750-armour-focus-foxhound-lppv-pt-3 (accessed Mar. 11, 2026).

[14] Rheinmetall BAE Systems Land (RBSL), "UK Boxer MIV program update", Telford, January 2024. Available at: https://www.rheinmetall.com/en/media/news-watch/news/2024/01/2024-01-23-rheinmetall-boxer-miv-update

[15] European Security & Defence, "UK Boxer Program Moves Ahead", Vol. 21, September 2022.

[16] RBSL / Rolls Royce, "MTU 8V 199 TS21 engine selected for UK Boxer MIV",

RBSL press release, 3 August 2022. (600 kW rating)

[17] Rheinmetall AG, "The Skyranger 30 HEL — Rheinmetall's hybrid solution for threat-commensurate, modern mobile air defence," press release, 4 February 2022. Available: https://www.rheinmetall.com/en/media/news-watch/news/2022/2022-02-04_the-skyranger-30-hel (accessed 12 March 2026).

[18] Office of Naval Research, "Directed Energy Weapons: High Power Microwaves," ONR Division 353, 2022. URL: https://www.onr.navy.mil/organization/departments/code-35/division-353/directed-energy-weapons-high-power-microwaves (accessed March 3, 2026).

[19] P. Dussinger, "Thermal Management for Directed Energy Weapons," *Mobility Engineering Technology* (SAE Media Group), September 2020. Available: https://www.mobilityengineeringtech.com/component/content/article/37608-thermal-management-for-directed-energy-weapons (accessed 12 March 2026).

[20] P. Ritt, D. Pellicone, and H. Pearlman (Advanced Cooling Technologies, Inc.), "Compact Thermal Management Solutions for Mobile Laser Weapon Systems," *Mobility Engineering Technology* (SAE Media Group), 2015. Available: https://www.mobilityengineeringtech.com/component/content/article/23128-compact-thermal-management-solutions-for-mobile-laser-weapon-systems (accessed 12 March 2026).

[21] Defence Equipment and Support / Raytheon UK, "Raytheon HELWS completes live-firing with British Army", December 2024. Reported in: European Security & Defence, Vol. 23, December 2024.

[22] Navy Lookout, "DragonFire – pathway to a Laser Directed Energy Weapon for the Royal Navy?" March 2024. URL: https://www.navylookout.com/dragonfire-pathway-to-a-laser-directed-energy-weapon-for-royal-navy/ (accessed March 2026).

[23] AeroVironment, Inc., "AV Delivers JLTV-Mounted LOCUST Laser Weapon Systems to U.S. Army," press release, Arlington, VA, Dec. 18, 2025 Available: https://investor.avinc.com/news-releases/news-release-details/av-delivers-jltv-mounted-locust-laser-weapon- systems-us-army (accessed Mar. 2026).

[24] Lockheed Martin Corporation, "Turning Up the Heat: Latest Evolution of Lockheed Martin Laser Weapon System Stops Truck in Field Test," press release, 3 March 2015. Available: https://news.lockheedmartin.com/2015-03-03-Turning-Up-the-Heat-Latest-Evolution-of-Lockheed-Martin-Laser-Weapon-System-Stops-Truck-in-Field-Test (accessed March 13, 2026).

[25] US Army / Congressional Research Service, "U.S. Army Maneuver Short-Range Air Defense (M-SHORAD) System," CRS In Focus IF12397, updated 2025. Available: https://www.congress.gov/crs-product/IF12397

[26] Lockheed Martin Corporation, "Lockheed Martin Delivers Integrated Multi-Mission Laser Weapon System to the Navy," press release, 18 Aug. 2022. Available: https://news.lockheedmartin.com/2022-08-18-Lockheed-Martin-Delivers-Integrated-Multi-Mission-Laser-Weapon-System-to-the-Navy (accessed Mar. 17, 2026).

[27] Trevithick, J. (2026, Feb. 3). "USS Preble Used HELIOS Laser To Zap Four Drones In Expanding Testing." The War Zone. twz.com/sea/uss-preble-used-helios-laser-to-zap-four-drones-in-expanding-testing (Accessed Mar. 2026).

[28] DARPA. (2015). "HELLADS: High Energy Liquid Laser Area Defense System."

Program overview. darpa.mil (Accessed Mar. 2026).

[29] General Atomics Aeronautical Systems, Inc. (2015, May 21). "HELLADS Laser Completes Development." Press release. Available: https://www.ga.com/hellads-laser-completes-development (accessed Mar. 11, 2026).

[30] W. Roscello et al. (The MITRE Corporation / OUSD(R&E)), "An Overview of the Directed Energy Weapon Systems Modular Open Systems Approach Reference Architecture (DEWS MOSA RA)," NDIA Ground Vehicle Systems Engineering and Technology Symposium (GVSETS) 2022, Distribution A: Approved for Public Release. Available: https://ndia.dtic.mil/wp-content/uploads/2022/systems/Wed_24609_Roscelloe.pdf

[31] J. Vetrovec and R. Rice, "Thermal Management System for Solid-State High-Energy Laser," in *Proc. 15th Annual Solid-State and Diode Laser Technology Review*, Directed Energy Professional Society, 2002. https://www.researchgate.net/publication/244987464 (accessed 12 March 2026)

[32] Zohuri, B. (2016). Directed Energy Weapons: Physics of High Energy Lasers (HEL). Springer International Publishing, Cham. ISBN 978-3-319-31289-7. (Fluence-to-kill thresholds, Sections A and C of tables.)

[33] Witte, U. et al. (Laserline GmbH), "Multi-10kW diode laser systems with wall-plug efficiency greater than 50%," *Proc. SPIE 13345, High-Power Diode Laser Technology XXIII*, 133450H, 21 Mar. 2025. DOI: https://doi.org/10.1117/12.3048960 (accessed March 9, 2026).

[34] Lockheed Martin Corporation, "Lockheed Martin to Deliver World Record Setting 60kW Laser to U.S. Army," press release, 16 Mar. 2017. Available: https://news.lockheedmartin.com/2017-03-16-Lockheed-Martin-to-Deliver-World-Record-Setting-60kW-Laser-to-U-S-Army (accessed March 9, 2026).

[35] LaGrone, S., "Navy to Field High Energy Laser Weapon, Laser Dazzler on Ships This Year," *USNI News*, 30 May 2019. Available: https://news.usni.org/2019/05/30/navy-to-field-high-energy-laser-weapon-laser-dazzler-on-ships-this-year (accessed March 9, 2026).

[36] Skeleton Technologies GmbH, "SkelMod 162V62F Ultracapacitor Module," Product Datasheet, Doc. No. 01-DS-240124-SKELMOD-162V62F-1D, January 2024. Available: https://www.skeletontech.com/hubfs/Data_sheets/Modules/DS-SKELMOD-162V62F-240124.pdf (accessed March 17, 2026).

[37] R. Tull de Salis, "A Standardised Mission Profile and Rapid Architecture Screening Methodology for Hybrid-Electric Tactical Wheeled Vehicles," Zenodo, Mar. 2026. DOI: https://doi.org/10.5281/zenodo.19113638

[38] DRDO / CHESS, "India Demonstrates Laser Weapon Capability, Joins Elite Global Club," *News on Air* (All India Radio / Prasar Bharati), 13 Apr. 2025. Available: https://www.newsonair.gov.in/india-demonstrates-laser-weapon-capability-joins-elite-global-club/ (accessed March 2026).

[39] D. Mehta, "Give 'Em E-HEL: Army Seeks Industry Ideas for Counter-Drone Laser Systems," *Breaking Defense*, 3 Nov. 2025. Available: https://breakingdefense.com/2025/11/give-em-e-hel-army-seeks-industry-ideas-for-counter-drone-laser-systems/ (accessed Mar. 2026).

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10. ACKNOWLEDGMENT

This work was funded by Power Size Technologies Ltd. During the preparation of this manuscript, the author used AI-assisted tools (Claude, Anthropic; ChatGPT, OpenAI) for research assistance, data preparation, formatting compliance, drafting support, and error detection. All content was reviewed, edited, and verified by the author, who takes full responsibility for the accuracy and integrity of the published work.

11. ACRONYMS

ADS	Active Denial System
ATP	Acquisition, Tracking and Pointing
CEMP-H	Central European Mission Profile – Hybrid Tactical Vehicles
COP	Coefficient of Performance
CRS	Congressional Research Service
DC	Direct Current
DCDC	Direct Current to Direct Current (converter)
DE	Directed Energy
DEW	Directed Energy Weapon
DEWS	Directed Energy Weapon System
EMI	Electromagnetic Interference
EO/IR	Electro-Optical/Infrared
EPS	Electrical Power System
FMTV	Family of Medium Tactical Vehicles
GVM	Gross Vehicle Mass
HEL	High Energy Laser
HELLADS	High Energy Liquid Laser Area Defense System
HELIOS	High Energy Laser with Integrated Optical-dazzler and Surveillance
HELWS	High Energy Laser Weapon System
HPM	High-Power Microwave
ICE	Internal Combustion Engine
IFPC	Indirect Fire Protection Capability
JLTV	Joint Light Tactical Vehicle
JP-8	Jet Propellant 8
LPPV	Light Protected Patrol Vehicle
MGU	Motor Generator Unit
MIL-STD	Military Standard
MIV	Mechanized Infantry Vehicle
MOSA	Modular Open Systems Approach
M-SHORAD	Maneuver Short-Range Air Defense
NATO	North Atlantic Treaty Organisation
OUSD(R&E)	Office of the Under Secretary of Defense for Research and Engineering
PCM	Phase Change Material
PTMS	Power and Thermal Management System
RAM	Rocket, Artillery and Mortar
RFDEW	Radio Frequency Directed Energy Weapon
SBC	Spectral Beam Combining
SFF	Sustained Firing Fraction
TRL	Technology Readiness Level
UAS	Unmanned Aerial System
WPE	Wall Plug Efficiency