



Annexes and source register

Advanced Munitions Outlook 2026, version 5.0 — companion volume. Annexes A to G carry the supporting detail for the paper, referenced inline from it. The source register that follows numbers every source in citation order, so a superscript anywhere in the paper resolves directly to an entry here.

A Annex A — Insensitive munitions: adoption in detail

Supporting detail for Section 2.4 and Figure 2, so the crossover model can be checked against the instruments themselves.

THE CLAUSES THAT DECIDE MARKET EFFECT

NATION	THE CLAUSE THAT MATTERS
United Kingdom	New acquisitions should be procured to comply; project teams should remain proactive in reviewing in-service munitions for improvement opportunities. The test is reasonableness and tolerability rather than absolute compliance, and no implementation date is stated. Version 2.0 of February 2026 restructured the code without adding either ^{14, 15}
Canada	Applies to all ammunition and explosives used by the department and the armed forces — the widest scope of any instrument reviewed — but exempted stock predating 2004 scheduled for replacement before 2020. That exemption has lapsed, making Canada the one country whose instrument now nominally reaches its fielded inventory ¹⁶
United States	Statutory direction to ensure, so far as practicable, that munitions under development or procurement remain safe when subjected to unplanned stimuli, supported by joint-service programmes and formal hazard-test standards. Exemptions cover current-inventory small arms without high-explosive fill, and cartridge- and propellant-actuated devices ¹³
Italy, Norway, Australia	Italy grades three levels and is the only instrument reviewed making a specific test — heavy fragment impact — compulsory. Norway requires all procurement to demonstrate compliance with the NATO standard, with an operational-necessity exemption at the highest hazard division. Australia makes assessment mandatory within the safety case, so far as reasonably practicable, on new acquisitions only ¹³

EUROPEAN NATURES NOW IN PRODUCTION ON INSENSITIVE FILLS

NATURE	COUNTRY	FILL ROUTE	STATUS
LU211-M and successor	France	Melt-cast, non-TNT base explosive	Classified under the national scheme in 1999; mass production at La Chapelle Saint-Ursin ^{82, 83, 87}
DM121	Germany	Cast-cured polymer-bonded, filled at Sorgues in France	Series production from late 2016 ⁸⁶
Vulcano 155 and 127	Italy	Polymer-bonded	Second-best reaction category across the test set; in production ⁸⁸
ROWANEX-filled	United	Cast-cured	Demonstrated 2006 in 105mm, 4.5-inch and

NATURE	COUNTRY	FILL ROUTE	STATUS
demonstrators	Kingdom		155mm; survived 60,000 g across more than a hundred rounds; not taken to series ⁹⁸
M795 with insensitive fill	United States	Melt-pour	Approved July 2010; predominantly but not exclusively adopted — the Marine Corps retained the TNT version and the Army called TNT the primary fill in November 2024 ^{124, 125}

B Annex B — The range ladder: supporting data

Supporting detail for Section 1 and Figure 1, covering the items not carried in the table at 1.1.

ITEM	FIGURE	BASIS
M107 legacy shell	14.6 km at charge 7 on the older cannon; 18.1 km at charge 8 on the standard cannon. The shape limits it, so a longer barrel adds little	¹³⁸ — sourced
M795 extended-range development version	Specified at 26.5–28.5 km on 39 calibres and 34–36 on 52. Never fielded	¹³⁸ — sourced
Rheinmetall extended-range charge	About +60 m/s over the standard charge at 21 °C; 950 m/s with a conventional shell on 52 calibres and 1,013 with a velocity-enhanced one; +7,000 to +7,500 m of range; temperature-independent propellant tested from –46 °C to +63 °C; stated to cost the barrel the same as a mid-zone charge rather than a top charge	⁵ — sourced, manufacturer-published
Modular charge system	810 m/s mean muzzle velocity on five modules in a 39-calibre gun against 945 on six in a 52-calibre gun; up to 54 km with extended-range shells; qualified across –46 °C to +63 °C; over 1.5 million modules produced	⁴ — sourced . The five-versus-six module explanation is derived ⁶
Boeing / Nammo ramjet	Record for the longest indirect-fire test of a ramjet-powered artillery projectile, October 2023, from a 58-calibre development gun. No range figure appears in the primary release. The next phase adds a precision guidance section	²⁵ — sourced . The widely repeated 150 km is projected and carried by trade press
Tiberius Sceptre pricing	\$52,000 a round at a thousand-round batch, explicitly excluding payload, fuel and fuze; \$40,000–42,000 projected in volume. Separately the company publishes a cost per target destroyed of about \$175,000–\$206,000, against comparisons it draws at \$720,000 for a guided round and \$840,000 for conventional high explosive	^{117, 118} — sourced, company-stated . The two figures measure different things and must not be compared with each other
Payload fraction	M795: 46.7 kg round carrying 10.8 kg of fill, about 23%. Guided Excalibur: 48 kg carrying 5.4 kg, about 11% — roughly half the payload fraction surrendered for two to three times the range	^{28, 29} — the first pair sourced , the second secondary; the comparison is derived
Guided-round unit cost	Published figures for the American guided round range from \$68,000 to \$258,777 depending on year and source; the highest is	²⁹ — secondary . Not a basis for a cost ratio without a primary budget

ITEM	FIGURE	BASIS
	a procurement average across 7,474 rounds in one year	document

c Annex C — The chemistry, and how the costs were worked out

Written for a reader evaluating Sections 2 and 3 without a background in energetic materials, and showing the arithmetic behind every estimated figure so it can be argued with. It contains no formulations, ratios, synthesis routes or process parameters.

THE TWO ENERGETIC PRODUCTS IN A ROUND

The fill is the high explosive inside the projectile body. The traditional Western route is melt-pour: a carrier explosive is melted, other solids are mixed into it, and the mixture is poured into the body and allowed to set. TNT was the carrier for a century because it melts at a convenient temperature. The alternatives are cast-curing, where the explosive is held in a polymer that sets chemically, and pressing, where it is compacted into the body as a solid.

The charge is the propellant outside the projectile, in the gun chamber, that accelerates it. In a modern modular system it is a set of interchangeable combustible units — more units, more velocity, more range. Conventional charges are built on nitrocellulose. A composite charge would hold a nitramine explosive in a polymer binder instead.

WHY THE BINDER QUESTION DECIDES THE ECONOMICS

Two kinds of binder are used. An inert binder holds the mixture together and contributes nothing energetic; it is an ordinary industrial polymer. An energetic binder such as GAP contributes energy as well, which is why it appears in every theoretical case for composite charges — published work calculates force constants up to about 1,487 joules per gramme at combustion temperatures conventional chemistry cannot reach at that energy⁹⁷. The commercial difference between the two is very large, and it is the reason the inert route is the realistic first step.

ITEM	FIGURE	HOW IT WAS ARRIVED AT
Inert polymer binder, bulk grade	\$5-10 per kilogramme	Derived. The world market is reported at \$150-270m a year across three studies, on a volume of roughly 30-40 kt. \$216m against 30-40 kt gives \$5.4-7.2/kg. Cross-check: a specialty polymer typically sells at four to seven times its monomer, and butadiene traded at \$0.76-1.58/kg in August 2026, giving \$3-11/kg. The two methods agree ^{110, 111}
Energetic azide binder	\$300-1,500 per kilogramme	Estimated. Its precursor is a commodity at \$1.70-1.90/kg ¹¹² , so the cost is entirely in processing. Production runs at tonne scale in licensed energetic plant against ten-thousand-tonne scale for the inert binder; standard scale economics give a factor of ten to thirty on fixed cost alone, before the hazard-rated plant premium. This supports the working assumption that it is an order of magnitude or more above the inert binder, and it is the reason no fielded propellant uses one
Energetics plant capital intensity	About €140,000 per annual tonne	Derived from a sourced pair. €350m at Aschau to raise propellant powder output by about 2,500 tonnes a year ¹¹⁶ . Roughly ten times the intensity of the polymer plants that feed it — which is the single most useful ratio in this annex for anyone sizing a proposition

ITEM	FIGURE	HOW IT WAS ARRIVED AT
Ammonia per tonne of energetic output	0.5-0.8 tonnes	Derived. Ammonium nitrate carries 0.35 t of nitrogen per tonne, all from ammonia, giving 0.43 t of ammonia per tonne; nitric acid takes about 0.27. An operation running two to three tonnes of nitric acid per tonne of product therefore needs 0.5-0.8 t of ammonia per tonne
European ammonia cost disadvantage	\$230-250 per tonne	Derived. Ammonia takes 33-36 units of gas per tonne. European gas averaged \$10.40 per unit in 2024 against \$2-4 in the United States; a \$7 gap across 33-36 units gives \$231-252 ¹¹⁴
Small ammonia plant, 20-50 kt/yr	\$35-110m	Derived. Published capital intensity for small ammonia plants is \$1,700-2,250 per annual tonne, close to world-scale intensity rather than punitively above it ¹¹⁵

D Annex D — Charge modules and combustible cases

Supporting detail for Section 4.6, and for the six-module mechanism behind the ranges in Section 1.

A modular charge system replaces bagged charges with interchangeable combustible units, so range is set by how many are loaded. The same projectile therefore reaches materially different ranges on different charge families: the published figures are 810 metres per second mean muzzle velocity on five modules in a 39-calibre gun against 945 on six in a 52-calibre gun, with up to 54 kilometres available on extended-range shells⁴. The commercial consequence is exact. A buyer can hold a fully qualified extended-range projectile and still be range-limited by the charge family it was sold, and that is not a projectile defect. Projectile and charge must be quoted as a matched pair or the range claim is unsupportable.

Why platform design is now setting propellant demand. Every new self-propelled gun in the current record is designed around a six-module load, and BAE's re-barrelled M109 would migrate a large part of the Western 39-calibre fleet into the same regime^{23, 24}. Charge demand is therefore being set by platform decisions taken now rather than by round consumption — and Europe's largest single announced charge-module addition is about six per cent of what the floor implies at six modules a round.

SUPPLIER	POSITION	STATUS
Nitrochemie Aschau (Rheinmetall)	Powder, combustible components and charge assembly on one site. Baseline 1,700 tonnes of powder and 300,000 modules a year, rising to over 4,200 tonnes and over 1.7 million modules at full rate; €350m within a €500m site programme and €650m group-wide; workforce from 800 to about 1,400	Foundation laid July 2026; gradual production from 2027, full capacity 2028 ^{3, 116} — sourced
VEGA (Poland)	Next-generation combustible cases for NATO modular charges, developed with the national armament technology institute. Existing line in 60-120mm mortar containers. Claims an operating band of -50 °C to +70 °C, over ten years of storage stability, smokeless combustion with minimal barrel residue and a positive energy contribution	Announced July 2026; commercial entry stated for 2027; no capacity published; all claims company-stated ahead of first showing ^{40, 41} — low-to-medium confidence
Base-bleed motors	A separately scarce category, because base bleed bolts on as an interchangeable module rather than being integral to the body ²⁰ . One	^{80, 81} — medium confidence; contracted rather than

SUPPLIER	POSITION	STATUS
	US supplier was awarded \$24m in August 2026, with contracted output rising from about 336 tonnes a year to 1,400 and nothing produced before summer 2027, under an exclusive arrangement with a prime	demonstrated

E Annex E — Process technology: the installed base

Supporting detail for Section 4.5. The argument rests on machines that exist and can be named.

SITE	INSTALLATION	CONFIDENCE
McAlester Army Ammunition Plant, Oklahoma	A 55-gallon-class acoustic mixer serving a 5.5-acre multi-purpose loading facility for near-net-shape polymer-bonded loading; about \$4m through Army contracting; final installation announced May 2024. A smaller predecessor unit is credited by the vendor with over \$20m of savings	High on the installation; vendor savings claims are marketing ^{34, 35}
US Navy energetics centre, Maryland	A smaller acoustic mixer replacing conventional vertical mixing on a warhead filling line; about \$1m of annual saving on one line for a two-and-a-half-year payback, a reduced footprint, and nothing mechanical in contact with the explosive	Medium-high ³⁸
BAE Systems Glascoed, Wales	Bench-scale acoustic mixers for polymer-bonded explosive; BAE claims roughly a twenty per cent increase in explosive power, reduced mixing time and reduced waste, with production scale-up stated as the intent	Medium-high — pilot rather than production ³⁶
STV Group, Polička, Czechia	Single-spindle screw-extrusion filling machine on solid explosive, launched August 2023, extended from 122mm to 81mm, 120mm and 155mm; 56,000–150,000 pieces a year depending on calibre; a second unit intended	High ³²

Three qualifications apply. The documented ladder runs from bench units through about 36 kilogrammes to about 400 kilogrammes a batch, and it is a British ladder as well as an American one — but the British rung is a pilot, and a pilot is not production. Adoption is tracked by NATO's munitions safety centre, which has run repeated technical meetings on the safety implications, so a national safety authority will have views³⁹. And the vendors do not publish: acoustic mixing, screw extrusion and nitrocellulose plant construction are each supplied by very few firms, none of which discloses an order book. No new production-scale acoustic mixing installation was announced anywhere in 2026. The proxies that do work are planning and environmental permits, which name a process before the plant is built; recruitment for named process-engineering skills; and the vendors' own installation announcements, which lag but do appear. Direct enquiry closes the remainder and is the cheapest market intelligence available in this sector.

F Annex F — The standing judgements of Outlook 01

Outlook 01 of July 2026 remains the standing baseline, and its thirty-million-round floor is the denominator used throughout this paper. Its seven judgements are carried forward with the position at the end of August 2026.

	JUDGEMENT	POSITION
KJ1	European rearmament is structural, not a spike tied to Ukraine	Confirmed, high. The NATO Ankara declaration and its €70bn pledge with a 2027 equivalence clause ¹
KJ2	The binding constraint has moved from shell bodies to explosives and to filling and assembly	Confirmed and corrected. The constraint is real but sits at the charge rather than at filling — see 4.1. A Spanish permit authorising 22,500 tonnes a year of inert components, and stating that explosive charge is never produced or loaded on the site, remains the cleanest illustration of the split ⁵⁵ . Explosives is not one lane: propellant, nitramines and charge assembly are not equally constrained ¹⁹⁷
KJ3	Europe's TNT and nitramine base is critically narrow through at least 2028–29	Confirmed and now quantified. NATO-accessible TNT supports 0.9–1.5m rounds a year today and 2.8–4.5m by 2029 if all five projects land ¹⁹⁸
KJ4	The bottleneck finding is robust to the reserve assumption	Confirmed, and sharpened. The \$469m Texas plant makes shell bodies, and its failure is attributed to flow-forming process capability against the steel specification rather than to conversion ^{64, 182, 183} . The stage arithmetic at 4.1 locates the bottleneck at the charge
KJ5	Precursor dependencies are an unpriced single point of failure	Confirmed, raised. And extended a level upstream at 3.3 — hexamine, formaldehyde and toluene were missing from the map
KJ6	A second wave of private and public-private capacity is highly likely to be required	Confirmed, high. Flat capital spending against rising order books ² ; over eighty per cent rejected on the first European energetics call ⁴⁴ ; government guidance stating venture capital is expected to carry the majority ⁹
KJ7	Demand survives a ceasefire	Confirmed at the contracted layer. The uncontracted coalition layer is exposed to member-state electoral politics on a six-to-eighteen-month cycle, independently of the war's status

G Annex G — Assumptions and confidence register

Every load-bearing assumption, what it rests on, and what happens to the argument if it fails.

ASSUMPTION	BASIS	IF IT FAILS
The thirty-million-round floor and its derived rates remain the right denominators	Sourced to Outlook 01 and carried forward unchanged	Every share in Figure 4 moves proportionally. The ranking between stages survives, because all five use the same denominator family — filling would still be the thinnest
Insensitive share tracks new build rather than retrofit	Sourced: no compliance deadline in any of nine instruments; only Canada and the UK reach fielded stock, both softly ^{12, 13, 14, 16}	The crossover arrives sooner and steeper, and the recommendation to specify a plant for both routes becomes more valuable rather than less. The argument does not invert

ASSUMPTION	BASIS	IF IT FAILS
Artillery is self-sufficient to about forty kilometres and needs help beyond it	Sourced on the reconnaissance reach and the target-density evidence ^{101, 102} ; the boundary itself is derived	The extended-range market is larger than assessed and Section 1's recommendation weakens. The corollary on conventional natures is unaffected — it does not depend on the boundary
No qualified composite or energetic-binder charge exists anywhere	Sourced as an absence across the national programme record, and consistent with twenty years of published research reaching demonstration but not qualification ^{94, 95, 96, 98}	If a national tender or a producer announcement appears, the opening is being taken by someone else and the window is shorter than assessed. Indicator 3 watches for it
Bulk polymer binder costs \$5–10 per kilogramme and the exposure is structural rather than financial	Derived by two independent methods that agree, from sourced market value, volume and feedstock price ^{110, 111}	If the qualified grade proves far more expensive or supply-constrained than assessed, the composite case weakens on cost as well as on qualification. Indicator 8 watches for a third qualified source
Europe can secure ammonia at defence scale cheaply	Derived from sourced capacity, gas-cost and capital-intensity figures, with the arithmetic shown at Annex C ^{113, 114, 115}	If European capacity closes faster than forecast, the offtake route narrows and the modular-plant route becomes the only one — which raises the capital requirement to \$35–110m and no further
The charge is the narrowest European stage, and filling is not	Derived from a site census of 136 plants worldwide and 42 in Europe, ten with published capacities, set against the floor's derived rates ^{197, 198} . The tonnage-to-rounds conversions use 6–11 kg of fill and about 9 kg of propellant a round	The conversion factors are the soft point: a heavier average fill or a lower average charge zone moves the shares by tens of per cent. The ranking survives either way, because propellant and modules are short by a factor of two to ten while filling is short by a factor well under two
The forty-two European filling sites without published figures average meaningful throughput	Estimated. Ten of forty-two publish capacity; the remainder are assumed to average enough to bring the stage to 3–3.8m rounds a year	If the unpublished thirty-two are mostly small or mostly committed to other calibres, filling returns to being a genuine constraint and the first position at 6.1 changes back. Direct enquiry closes this, and it is the single most valuable piece of primary research available on this question
The joint European qualification programme lands as written	Sourced on funding, participation and objective; timeline and legal mechanism unpublished ⁴³	The addressable market reverts to one country at a time and the cost-of-proof measures at 5.3 become the only route. Assessed as a realistic possibility at low confidence

Source register

Every source cited in the paper, numbered in citation order so a superscript in the text resolves directly to an entry here. Where a claim rests on a relay rather than on the issuing authority, or on a single secondary outlet, that is stated in the paper at the point the claim is made rather than buried in this list.

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