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OUTLOOK PAPER 02 • AUGUST 2026 • REISSUED SEPTEMBER 2026

The Capability Answer

Europe cannot build its way out of the ammunition shortage on tonnage alone. Keep building, buy every hour of spare qualified capacity that exists now - and take the routes that break the feedstock bottleneck seriously, because they are the only ones that change the ceiling rather than the rate. Reissued with corrections of fact and a cross-reference to Outlook 03; the analysis is as issued.

CORE JUDGEMENT

Outlook 01 showed that Europe's ammunition problem is not the shell body. It is the charge that throws it down range, the explosive that goes in it, and the plants that fill and assemble the two. Announced capacity does not fill even a conservative thirty-million-round floor before 2030. Nothing this year has changed that, and the companies best able to fix it are holding their spending flat while their order books grow.

Three things follow, and they run together rather than in sequence. Keep building - the tonnage programme is necessary and none of it should stop. Buy spare qualified capacity now, wherever it already exists, because a running line is worth more than a funded one and the surplus price will not be this low again. And take the insensitive and composite routes seriously, not as a performance upgrade but as the way out of a nitrocellulose chain whose feedstock a strategic competitor controls.

One finding sits above the rest, and it is arithmetic rather than opinion. Europe has forty-two sites that can fill a 155mm shell and is adding more. It does not have the propellant to load them or, on the current chemistry, a secure way to get it. The charge, not the shell and not the filling line, is the narrowest stage in the chain.

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STANDING BASELINE OUTLOOK 01 (V4.1); COMPANION ANNEXES VOLUME A-G UNCHANGED

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Note on this edition

This is the paper issued on 1 September 2026, with eleven corrections of fact applied in place and dated, and with a cross-reference to the position Outlook 03 takes on the two judgements it revises. The range ladder, the composite-charge assessment, the stage-by-stage capacity table and the six key judgements stand as issued; the one judgement corrected (KJ-E) is corrected in its wording, not its direction. Cover and running furniture have been brought into line with the series. A separate errata audit (September 2026) re-checked every dated, priced and quantified claim in the paper against its cited source.

CORRECTIONS OF FACT

Each correction is marked in the text with a red superscript (E1, E2 ...) at the point it applies. The wording as issued is recorded here so that a reader holding the earlier version can see exactly what moved.

REF	WHERE	AS ISSUED	CORRECTED	BASIS
E1	Key judgement E; Section 4 box	"A composite charge is the only published way out of Europe's cotton dependency"	It is the only published route that removes nitrocellulose from the charge altogether. Two projects published before this paper change where the cellulose comes from instead: Verkan's pulp-based nitrocellulose plant at Kristinehamn (permit filed 23 June 2026) and the Eurenco-Biosorbe recycled-textile pilot (Vinnova, November 2024 to November 2026)	Verkan AB consultation document, Feb 2026, and permit notice, Jun 2026; Vinnova project page. Carried into Outlook 03, Section 4.1
E2	Section 3.2	The list of European propellant investments omits Synthesia and counts the Eurenco-MESKO venture twice	Synthesia's expansion from 6,000 to over 7,000 tonnes a year of nitrocellulose (Colt CZ, August 2025) added; "the Eurenco joint ventures in Poland and Slovakia, the Mesko modular charge venture" reads as one Polish venture (with MESKO) and one Slovak (with ZVS)	Colt CZ analyst presentation, 29 Aug 2025; ASD News, 15 Jun 2026; GlobeNewswire, 4 Mar 2026
E3	Sections 3.1 and 4 box	BAE's route announced "inside an £8.5m five-year envelope"	The £8.5m was research spent over the preceding five years, not a forward budget; industrial-scale capacity remains targeted for end-2026 with no interim milestone published	UK Defence Journal, April 2025, reporting BAE's release
E4	Section 3.1	Josef Meissner "commissioned" a 48-tonne-a-day nitrocellulose plant in Brazil, undated	The plant was commissioned in 1999 for Nitro Química; it is a reference plant, not a recent one	Josef Meissner news item, Sep 2000

REF	WHERE	AS ISSUED	CORRECTED	BASIS
E5	Executive summary; Section 5.3 table; Section 6	"The American stockpile" has taken average shelf life from 7.9 to 22.6 years	The figure is the US Army's missile-system surveillance programme (2015); it is evidence by analogy for artillery, not an artillery result	US Army, 19 Oct 2015 (the paper's source 173)
E6	Section 4.6 box	US Army sources-sought for 10,000 base-bleed grains a month presented as a current signal	The notice (W15QKN-23-X-0W2K) was posted 14 April 2023 and closed 8 May 2023	SAM.gov via HigherGov
E7	Section 4.4	A Korean group "is building" a US modular-charge plant on "roughly \$1bn"	At issue the plan stood at about \$1.3bn and was at site selection; nothing was under construction. On 21 September 2026 Hanwha announced a \$2.2bn campus at Pine Bluff Arsenal for charges and base-bleed units, operations about 2031	Arkansas Advocate, 21 Sep 2026; Manufacturing Dive, 22 Sep 2026
E8	Section 4.1 table; Section 5 table	TNT "about 10,000 t today, 25,000–30,000 t by 2028–29 across five projects" cited to source 198	Source 198 (The War Zone, May 2025) carries none of those figures. The tonnage is derived from Nitro-Chem's ~10,000 t and the announced projects listed in Outlook 01, and is now labelled as such	The War Zone, 12 May 2025; Outlook 01 Annex A
E9	Executive summary; Section 2.1	DM121 "in series production since late 2016"	The 2016 source records a contract for series filling from late 2016 (30,000 charges over three years); continuous production since is not evidenced	Army Recognition, 21 Jun 2016 (source 86)
E10	Section 3.3 table	Binder market "growing at 3–9%"	3–9.5% (the cited study gives 9.5% for 2026–36)	Fact.MR, 2026 (source 110)
E11	Companion volume, Annex D	Aschau "over 1.7 million modules at full rate"	300,000 modules today plus more than one million additional: over 1.3 million in total. The companion volume is not reissued; the correction is recorded here	Rheinmetall, 23 Jul 2026

JUDGEMENTS OVERTAKEN SINCE ISSUE

Outlook 03 (September 2026) takes the propellant question further and, in doing so, moves two of this paper's positions: the wood-pulp and recycled-cotton routes are treated there as the second published way round the cotton dependency, and artillery rockets are treated as a real draw on the same nitrocellulose rather than a trivial one (a Czech 122mm rocket carries about 20 kg of double-base propellant; Denmark plans 10,000 a year). Facts that have moved since issue without changing a judgement: the September 2026 USDA estimates put world cotton ending stocks at 69.86 million bales, still the lowest in fifteen years; European butadiene was about \$1.41 a kilogramme in September 2026; ZVS Snina was producing about 100,000 bodies a year after a fire on 16 September; the UK feasibility

studies were due back at the end of September, with design awards to follow. None of these is applied to the text.

WHAT HAS NOT CHANGED

The six key judgements stand as issued at their stated confidence, including KJ-E as reworded. The capacity table at Section 4.1, the second-demand-curve analysis at 4.2 and the process-technology assessment at 4.5 are unchanged. The companion Annexes volume (v5) travels with this edition unchanged; its one correction is listed above.

Basis

Everything here comes from public sources: government and NATO policy documents, permits and regulatory decisions, company disclosures, technical and academic literature, and reputable trade reporting. There is no classified material in it, no access to national stockpile figures, and no undisclosed plant tonnage. It contains no explosive or propellant recipes, no ingredient ratios and no manufacturing parameters.

Annexes A to G and the full source register travel as a separate companion volume, referenced inline from this paper, so that this one stays a working length. Every superscript resolves to a numbered entry in that volume. The annexes carry the supporting detail - the insensitive-munitions instruments clause by clause, the range ladder data, the chemistry and cost arithmetic, the charge-module and process-technology installed base, the standing judgements of Outlook 01, and the assumption register.

Capacity figures are as the operator or the authority published them. They are indicative rather than audited. Every number is marked **sourced** where a document states it, **derived** where we have calculated it from figures that are stated, and **estimated** where we have had to reason to it. Where a figure is estimated, the reasoning is shown so it can be argued with.

ESTIMATIVE LANGUAGE

Probability describes how likely something is. Confidence describes how good the evidence is. They are independent - a judgement can be highly likely and still rest on thin evidence.

PROBABILITY TERM	APPROX.	PROBABILITY TERM	APPROX.
Remote chance	≤ 5%	Likely / probably	55-75%
Highly unlikely	10-20%	Highly likely	80-90%
Unlikely	25-35%	Almost certain	≥ 95%
Realistic possibility	40-50%		

CONFIDENCE	MEANING
High	Several credible sources agree, or the issuing authority states it directly
Moderate	Credible sourcing with gaps; another reading is possible
Low	Thin or single-source evidence; treat as a planning input

Key judgements

THE QUESTIONS THIS PAPER ANSWERS

RESEARCH QUESTION		WHERE IT IS ANSWERED
RQ1	How far is it sensible to throw a shell, and what should be bought instead?	Section 1
RQ2	Legacy versus IM: who has adopted, and when does IM take market share?	Section 2
RQ3	Does an RDX-polymer route break Europe's feedstock dependency, or move it?	Section 3
RQ4	Which stage of the chain binds, and where does process innovation beat tonnage?	Section 4
RQ5	What would a war-footing qualification programme consist of, and what would it unlock?	Section 5

Six judgements, each with its confidence. The seven standing judgements of Outlook 01 are carried forward and summarised at Annex F.

KJ-A The tonnage answer will not arrive in time, and the companies best able to deliver it have decided not to try. HIGH CONFIDENCE

Rheinmetall spent €184m on its weapons and ammunition division in the first half of 2026, against €188m a year earlier - while that division's order book grew by €3.681bn to €25.274bn and its operating margin rose to 23.7%. Northrop Grumman said it would not buy binder or oxidiser ahead of a multi-year award. This is not an industry that cannot build. It is an industry that will not build ahead of a signed order, which is a different problem needing a different answer.

KJ-B Artillery range has run past the point where the targeting chain can use it - but the ceiling is higher than the common figure suggests, and it is set by what can be tracked rather than by what can be reached. MODERATE CONFIDENCE

The change is at battalion level. Brigade and divisional reconnaissance has always reached deep; what has moved is the organic asset a battalion owns and tasks itself, from about ten kilometres in 2022 to twenty to forty now^{101, 164}. The American army published a battalion requirement of more than forty kilometres in May 2026, and it is a requirement rather than a fielded capability¹⁶³; Britain has fielded ten thousand small drones in six months but concentrated on the twenty-kilometre band while Ukrainian units work towards seventy to a hundred¹⁶⁶. Above the battalion the picture is unchanged: brigade fixed-wing reconnaissance runs to between fifty and eighty-five kilometres^{165, 167}. The limit is no longer distance. It is that a moving target beyond about seventy kilometres cannot be held long enough to shoot at - in twenty-four days of August 2025, only twenty-three Russian tanks were observed operating within seventy kilometres of the front line¹⁶². Deep fire work against things that sit still.

KJ-C Insensitive fills are already in European service. The charge is where the chain is narrowest and where the chemistry has not moved - and that is the opening. HIGH CONFIDENCE

France has fielded an insensitive 155mm high-explosive shell since the mid-2000s⁸². Rheinmetall's DM121 was contracted for series filling from late 2016 on a cast-cured filling made in France^{E986}. Leonardo's Vulcano carries a polymer-bonded fill rated at the second-best reaction level in insensitive-munitions testing⁸⁸. The transition on fills is real and running. The charge is a different case in two respects. Its chemistry has not changed: no army anywhere has qualified a gun propellant on an energetic azide binder in any calibre, and every euro of announced European charge investment is going into the same nitrocellulose chemistry that has been used for a century^{3, 94, 98}. It is the stage with the least capacity behind it - announced European gun-propellant output of roughly twelve to twenty thousand tonnes a year supports between a quarter and two-fifths of the rounds the floor requires¹⁹⁷. It is also the one stage the European missile and interceptor surge does not bid for, because rocket motors do not use gun propellant and combustible cases are an artillery product - the second demand curve is set out at 4.2.

KJ-D Insensitive munitions take market share as new production lines are qualified, not by replacing what is already in the depot. On present behaviour that puts the changeover in the early 2030s - but the timetable is administrative, not physical, and a government that wanted it sooner could have it. MODERATE CONFIDENCE

Four countries hold a standalone national policy on insensitive munitions - France, Italy, the United Kingdom and the United States - and seven more work to draft or embed rules^{12, 13}. None of the nine reviewed sets a deadline, and only Canada and the United Kingdom reach stock already in service, both softly^{14, 16}. Even in the United States, sixteen years after the insensitive fill was approved, the Army called TNT the primary fill for 155mm shells in November 2024 and spent \$435m restarting domestic TNT production¹²⁵. The three-to-five-year figure usually quoted for a fill change describes queuing and duplicated national assessment rather than any test that takes that long: NATO's own chemical-stability standard certifies ten years of storage from about five weeks of measurement, the accelerated ageing matrix is bounded at six to eight months, and the American record took the current insensitive fill from formulation selection to a signed data package in under two years with the ageing run inside that window^{168, 169, 175}.

KJ-E A composite charge is the only published route that removes nitrocellulose from the charge altogether; two projects published before this paper, Verkan's pulp-based nitrocellulose plant at Kristinehamn (permit filed June 2026) and the Eurenco-Biosorbe recycled-textile pilot (Vinnova, to November 2026), instead change where the cellulose comes from. The composite route does not remove the exposure^{E1} - it swaps it for one Europe can do something about. MODERATE CONFIDENCE

European military propellant runs on nitrocellulose, and nitrocellulose runs on cotton linters, of which China supplies the large majority⁶⁰. A nitramine-in-polymer charge would remove that link entirely. The replacement exposure is a polymer binder, and it is a mild one: the binder is a real commercial product costing roughly \$5-10 a kilogramme in bulk, made from butadiene at under \$1.20 a kilogramme in Europe^{110, 111}. The risk is not price. It is that Western supply of the qualified grade rests on one plant in Texas and one in Germany^{108, 109}. That is a concentration a European government can act on. Cotton is not.

KJ-F The announcements are funding the visible stages. The charge and the chemicals behind it - the stages every round must pass through - are being funded last and by the fewest people. HIGH CONFIDENCE

Across July and August 2026, named European new-build clustered in shell bodies, explosives synthesis and rocket propulsion; every venture-funded new entrant identified was in motors^{67, 68, 69}, and no award in the \$191m US industrial-base tranche went to gun propellant⁶⁶. The European Union's own allocation says the same from the other direction: three-quarters of the €500m ammunition package went to powder and explosives rather than to plants. The United Kingdom's twenty-two energetics feasibility studies name six factories, nine materials and no filling or charge line at all^{9, 10}. And Britain has exactly one 155mm filling site out of the forty-two in Europe¹⁹⁷. Charge, feedstock and - for Britain specifically - conversion capacity is where the leverage sits.

REVISED IN OUTLOOK 03 (SEPTEMBER 2026)

JUDGEMENT AS ISSUED	POSITION IN OUTLOOK 03 (SEPTEMBER 2026)
KJ-E: a composite charge is the only published way out of the cotton dependency	Reworded here. Outlook 03, Section 4.1: wood-pulp nitrocellulose (Verkan) and recycled-textile cotton (Eurenco-Biosorbe) are a second route, and the one European capital is taking; it lands in 2028-29 at the earliest and inside the groups that finance it
Section 4.2: rocket-motor draw on nitrocellulose is trivial beside gun propellant	Outlook 03, Section 5.3: rockets share the chain. A 122mm rocket carries about 20 kg of double-base propellant; European rocket-artillery buying (Chunmoo, PULS, HIMARS) and a Danish 10,000-a-year line make it a demand line in its own right, though still small against gun propellant
Section 4.1: announced European gun-propellant capacity of 12,000-20,000 t supports 1.3-2.2 million rounds	Outlook 03 holds ~16,000 t of large-calibre output today, ~12,000 t of it for 155mm, and counts rounds at 13 kg (full charge) rather than ~9 kg: about 0.9 million full charges against ~2 million shells made. The delivery record discounts announced additions by stage

Executive summary

Outlook 01 was a paper about arithmetic. It set a deliberately cautious floor – thirty million rounds, worked up from consumption data, the number of European guns and what the other side can produce – and showed that the announced plants cannot fill it before the end of the decade. That still holds. If the number moves it moves up: Russian reconstitution, Chinese output and North Korean supply have taken European governments past the point where a ceasefire would change the requirement.

What has changed is not the arithmetic but the behaviour of the people who could answer it. Rheinmetall has now held its ammunition capital spending flat for a full year while its order book grew by €3.681bn and its margin widened². Northrop declined to secure binder and oxidiser ahead of a contract⁸. Public money has not filled the space: \$191m of American industrial-base funding against one company's own multi-billion plant programme names the gaps rather than closing them⁶⁶, and the US Army now writes its requirements to demand a line that is already built and qualified rather than paying for a new one⁶⁵. Capacity is not being withheld because it is impossible. It is being withheld because nobody wants to own it before the order arrives.

On the shell, range has run ahead of the ability to find a target. A conventional shell reaches about 18 kilometres from the old design and 22.5 from the modern one on a short barrel, about 30 on a long barrel, and about 40 with a base-bleed unit fitted. Above that sit guided rounds at 70, a hypervelocity round in development at 80 to 90, and ramjet-powered rounds projected at 150^{21, 22, 23, 25, 130}. Meanwhile the eyes have caught up, and the movement is at battalion level rather than above it. Brigade and divisional reconnaissance always reached deep; what is new is that a battalion now owns and tasks assets out to twenty or forty kilometres where in 2022 it owned about ten^{101, 164}. Beyond about 70, the problem is not seeing the ground but holding a target long enough while the higher organisation goes through a planning cycle it is not used to outside of its targeting cell – and the deep zone has been emptied by dispersal, with only twenty-three Russian tanks observed inside 70 kilometres of the front in twenty-four days¹⁰².

Europe has not been standing still on insensitive fills. France has fielded one since the mid-2000s⁸²; Eurenco has run an industrial cast-cured filling line at Sorgues since 2006, rated for up to 50,000 155mm shells a year^{84, 85}; Rheinmetall's DM121 has been in series production on that line since 2016⁸⁶; Leonardo's Vulcano carries a polymer-bonded fill⁸⁸. What has not moved is the charge. No army anywhere has qualified a gun propellant using an energetic azide binder, and the research base – Indian, German, Chinese, Polish and British – has been publishing on it for twenty years without a single programme taking it past demonstration firings^{95, 96, 97, 98}. That is the opening.

On factories, counting sites rather than announcements changes the answer. Europe and the United Kingdom hold forty-two plants that can fill a 155mm or 152mm shell, and the ten that publish a figure already total about 2.24 million rounds a year by 2028¹⁹⁷. Filling is not the empty stage. The empty stage is the charge. Announced European gun-propellant capacity of roughly twelve to twenty thousand tonnes a year supports 1.3 to 2.2 million rounds; announced explosive fill supports about 1.4 million now and 2.8 to 4.5 million by 2029 if every plant lands¹⁹⁸. Filling capacity that has nothing to put in the shell is a warehouse. That is the finding, and it is set out stage by stage at 4.1.

EXHIBIT 1

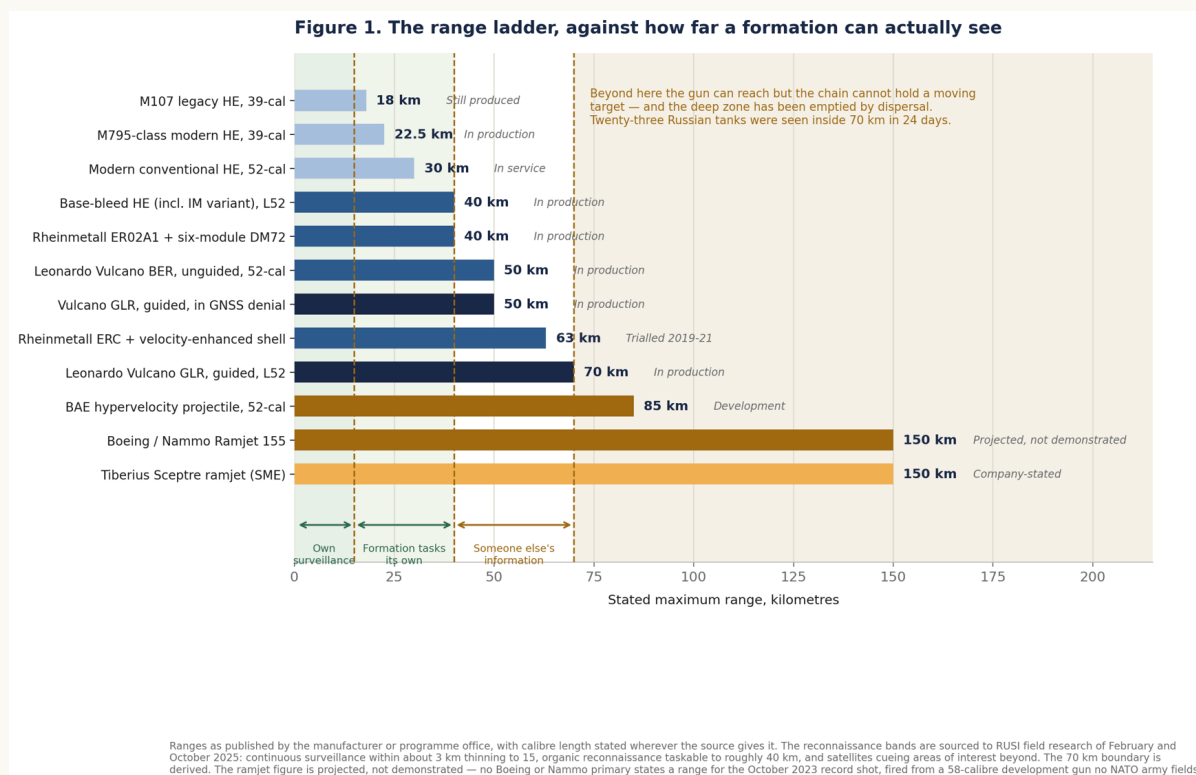


Figure 1. The range ladder set against how far a formation can see.

1.2 What the eyes can do, and at which echelon

The change is at battalion level, and conflating it with brigade and divisional reconnaissance is the commonest error in this argument. Brigade, divisional and army reconnaissance has always reached deep – that is what it is for, and the Russian Orlan and Zala families have flown at that layer throughout the war. What has moved is the asset a battalion owns outright, launches itself and tasks without asking anyone: from about ten kilometres in 2022 – the Raven class of hand-launched aircraft the American army has since declared unsurvivable – to twenty or forty kilometres now^{101, 163}.

ECHELON	ORGANIC REACH, UKRAINE 2026	WHAT IT MEANS FOR FIRES
Battalion, organic	Quadcopters at single-digit kilometres for the close fight; fibre-optic strike drones fielded at about 20 km with 30 and 40 km spools in development; heavy multirotors at about 19 km ¹⁶⁴ . The grey zone the battalion must see across widened from 0.5–2 km in spring 2024 to 5–7 km by April 2025	This is the band in which a firing unit finds and services its own targets. It has roughly quadrupled in four years, and it now overlaps the whole conventional range ladder
Brigade	Fixed-wing reconnaissance at 30–35 km (Spectator), about 50 km (Furia, Leleka), 60–80 km (Shark) and 85 km (PD-2) ¹⁶⁵ . A brigade reconnaissance wing states it flies to fifty kilometres and beyond, cueing strikes at about forty ¹⁶⁷	The band where a shell can be fired accurately on somebody else's information. Guided natures earn their cost here
Division and above	Long-endurance types to about 220 km (Raybird), deep-strike drones past 100, and the operational interdiction belt reported at about 150 km ^{164, 165} . Satellites point at areas of interest rather than tracking targets ¹⁰¹	Reachable, but by missiles and drones rather than by guns, and against fixed targets rather than moving ones

The rest of NATO is roughly one range band and two to three years behind at that battalion layer, and it knows it. The American army published a battalion reconnaissance requirement of more than forty kilometres and five hours' endurance only in May 2026 - a requirement, not a fielded system¹⁶³. Britain fielded ten thousand small drones, concentrated in the twenty-kilometre band, while Ukrainian units work towards seventy to a hundred¹⁶⁶. The planning consequence is that a European army sizing its ammunition against its own current organic reach will size it short, because the reach it will have in five years is the reach Ukraine has now.

The structure has changed with it. A Ukrainian battalion is now expected to keep four to six drones airborne at once - four supporting the fight, two looking deeper. Most brigades hold a drone company or battalion covering a frontage of forty to seventy kilometres¹⁰¹. And 155mm itself has moved up rather than down - Ukraine's 2025 reforms created new artillery brigades at corps level, sitting behind better reconnaissance than a line brigade holds¹⁰³. Counter-battery radars fill in above that, reporting a firing battery in under two minutes¹⁰⁴.

RQ1 - WHERE THE SENSIBLE LINE SITS

Up to about forty kilometres, artillery is self-sufficient. The firing formation owns the sensor, generates its own targets and can afford to expend rounds. This is where the great majority of fire missions happen and where the ammunition budget is spent.

Between forty and seventy, it works but needs help. The formation is shooting on someone else's information. The round must be accurate enough to justify the coordination, which means guidance, which means an answer to jamming.

Beyond seventy, it is a targeting problem with a gun attached. The range exists and can be bought. The tracking to use it against anything mobile does not, and the target set thins out sharply. Where a genuine deep-strike effect is wanted, a missile or a long-range drone is usually the better buy - Ukraine's deep-strike drones already reach well past a hundred kilometres at a fraction of a guided shell's cost per target^{105, 107}.

Held at **moderate confidence** and marked **derived**. What would change it: a formation-level sensor that tracks moving targets past seventy kilometres, or a guided round whose cost falls close to a conventional one. The second is what the ramjet entrants are betting on.

1.3 Jamming has become the design driver

Satellite navigation can no longer be assumed, and the numbers are stark. Leonardo publishes the honest version for its own product: a guided Vulcano reaches about 70 kilometres with satellite navigation and falls back to roughly 50 when denied - a penalty of about a third, applied exactly in the conditions the round is bought for²². The American Excalibur has been reported losing up to ninety per cent of its accuracy under Russian jamming¹⁰⁶. Navigation jamming is described as present across the whole combat area¹⁰¹.

The market is responding by moving the sensor onto the round. Semi-active laser guidance, where an observer illuminates the target and the shell homes on the reflection, is unaffected by satellite jamming - which is why Russia's Krasnopol has been resupplied and expanded, and why KNDS's KATANA pairs satellite and inertial navigation with a laser seeker and claims sub-metre accuracy beyond 45 kilometres¹²². Precision guidance fuzes, which screw into the nose of an ordinary shell in place of a conventional fuze, remain the cheap route to accuracy: over 100,000 have been delivered, taking a conventional shell from hundreds of metres of error to tens¹²³.

1.4 The top of the ladder, priced

The ramjet entrants are attacking cost as well as range, and their figures must be read carefully. Tiberius publishes \$52,000 a round at a thousand-round batch falling to \$40,000-42,000 in volume - explicitly excluding payload, fuel and fuze - alongside a separate cost-per-target-destroyed figure of \$175,000-\$206,000 that is a mission metric, not a price^{117, 118}. No primary source gives a demonstrated range for the Boeing and Nammo ramjet, and its record shot came from a 58-calibre development gun no army fields²⁵. The defensible statement is that the category targets a quarter to a tenth of guided-

round cost at three times the range, that none of it is in production, and that a customer should hold it to a price including the payload. Full figures at Annex B.

1.5 Where the shell itself is being innovated

Range is not the only thing happening to the projectile, and some of the rest is nearer to market. The table below is deliberately not confined to what has been announced: several of the entries are read from patents, contract notices and safety-community agendas rather than from press releases, and each is marked for what it is.

DEVELOPMENT	WHAT IT IS AND WHERE IT STANDS	WHY IT MATTERS
Area-effects carrier shells	The United States is rebuilding cannon-delivered area effects after two decades away. Its new shell carries nine submunitions, each throwing about 1,200 preformed tungsten fragments, with multiple fail-safes to cut the dud rates that made the previous generation unacceptable. In November 2025 the Army sought manufacturing capacity of 30,000 rounds a year ¹¹⁹ . Germany's sensor-fuzed shell went back into production in 2024 after twenty years ¹²⁰	A product category everyone had written off is reopening at scale, and it is filling-intensive: a carrier shell is an assembly job, not a pour
Gun-launched drones	China reported five successful live launches in June 2025 of a drone fired from a 155mm shell, deployed by a fully mechanical sequence with no electronics to survive the shock of firing ¹³¹	The first genuinely new carrier payload since sensor-fuzed munitions. If it works, the gun becomes a delivery system for reconnaissance as well as effect
Artillery as air defence	BAE is developing a system using guided hypervelocity rounds fired from 155mm guns against drones and cruise missiles, with a prototype battery targeted for the end of the 2027 financial year ¹²¹	An entirely new demand curve for the calibre, and one that consumes guided rounds rather than conventional ones
Body manufacture	Two routes are opening the bottleneck. Austempered ductile iron is being offered as an alternative to forging, with more than 180,000 bodies a year claimed and qualification firings through 2026 ³¹ . Machining-only feeder plants - a converted car-components site near Berlin is the model - add capacity fast because they hold no explosive and so escape the permitting regime	If the iron route qualifies, ordinary commercial foundries become recruitable and body forging stops being a gate
Additive manufacture	Past the demonstration stage on naval calibres and moving from components towards bodies. Five-inch naval gun projectile bodies are being produced in steel by robotic wire-arc deposition in place of forging, with the copper driving band laid in during the build and the process described as production-ready ¹³² . The US Army's research laboratory runs a dedicated programme whose stated aim is to print next-generation munitions, bodies and propellant both ¹³³ . In Britain, the Ministry of Defence's additive programme has printed and fitted gun-system components - a Light Gun part has been recommended for adoption into the inventory - and has moved from non-critical parts into safety-critical metal work ¹³⁴ . The Defence Science and Technology Laboratory prints high explosive by material extrusion, using the same acoustic mixing described at 4.4 ¹³⁵ , and the US Navy has taken a printed propellant grain through design verification and service-release testing ¹³⁶	The barrier is qualification rather than capability: standards exist for printed metal in general ¹³⁷ , but none is specific to gun launch, where the part is pressure-bearing and sees tens of thousands of times gravity. For a 155mm body it is a demonstration-stage technology. For fixtures, tooling, base and fuze components, and for charge geometries, it is available now
Base closures and the base end	The base of a shell is either integral or closed with a threaded plug, and the interface is established, patented practice - including a threaded converter that replaces a standard base to fit a base-bleed unit to an existing body ¹⁴⁰ . The base end is also where the transatlantic industrial traffic is: General Dynamics has partnered with an American propellant house to expand base-bleed production ¹³⁹	A threaded base decides which filling processes a plant can run: it allows loading and inspection from the rear, lets a base-bleed unit be fitted to a common body, and lets a pressed fill be seated and retained rather than poured and trusted.

DEVELOPMENT	WHAT IT IS AND WHERE IT STANDS	WHY IT MATTERS
Driving band and obturation	Quiet, patented and continuous. Rheinmetall filed in 2019 and was granted in 2021 an obturator integral to the metallic driving band, designed to shear cleanly at the muzzle ¹⁸⁹ ; the wire-deposition route at the row above lays the copper band in during the build rather than swaging it on afterwards ¹⁸⁴ . Neither is announced as a product	Inferred. Bands appear on nobody's bottleneck list, which is itself the signal: band capacity currently exceeds body capacity. But two independent lines of work are aimed at deleting the copper band as a separate part - one on wear at long-range charge pressures, one on process steps.
Inspection and non-destructive test	Industrial computed tomography with automated defect classification has crossed from aerospace into munitions inspection, and a prime that has just had a plant fail to produce a single qualifying part has signed a teaming agreement to put manufacturing software across its facilities	Inferred. After a public failure attributed to process capability rather than to design, per-unit imaging with recorded classification is the obvious next contractual requirement.
Condition-based surveillance as hidden capacity	NATO's munitions safety centre argues that assumed storage environments are harsher than real ones, and that the resulting conservatism has destroyed stock that could have been used safely for longer; instrumented munitions and data loggers are its answer ¹⁷⁴ . The US Army's missile stockpile reliability programme has taken average missile shelf life from 7.9 to 22.6 years on surveillance evidence ¹⁷³	Derived. A ten per cent life extension across a ten-million-round stockpile is a million rounds that do not be made - roughly three years of Europe's largest new plant, for the price of instrumentation and an analytics contract. Nobody has productised it at artillery scale
Charge module manufacture	Eurengo states that it qualified a new 155mm modular charge in under eighteen months, produced at Bergerac and Karlskoga, using additive manufacture of energetic material and robotised lines - the company's first ¹⁸⁵	Sourced, and underplayed in its own announcement. Additive manufacture inside a qualified modular charge means geometry control of the burning surface that conventional manufacture cannot reach. It also shows an eighteen-month qualification is achievable, which is the point Section 5 turns on

1.6 The corollary a government customer should not miss

The ladder above assumes suppressive mass has stopped mattering, and the evidence says otherwise. By June 2022 the Russian force held a ten-to-one advantage in volume of fire, and Ukrainian formations blunted the advance on Kyiv with massed fires from two artillery brigades²⁶. Precision is more efficient per effect and shortens the supply chain; it does not deliver sustained suppression, and no army has fought a war in which it did not need any. Consumption is structural in the same way: fire missions rarely exceed ten rounds, eight to ten are needed to destroy a soft target¹⁰², every new gun raises rounds per engagement, and live firing consumes conventional natures whatever the strategic weather.

The position for a ministry is therefore straightforward. Conventional short-range natures are a permanent requirement, the industrial base for them is mature, the qualification is done and the price is at the bottom of the ladder. A ministry spending its marginal pound at the top of that ladder, while its conventional war stock and training allocation are thin, has bought reach it cannot exploit and given up the mass it will certainly use. Assessed as **highly likely** to hold across the horizon, on the consumption and force-structure evidence above.

02 Explosives and charges: two transitions, one moving and one stalled

A shell contains two energetic products and they are constantly confused. The fill is the high explosive inside the body, which does the damage. The charge is the propellant outside it, in the gun chamber, which pushes the shell up the barrel. They are made by different processes, in different buildings, to different approvals.

2.1 The fill: Europe is twenty years into this transition

An insensitive munition is one designed to react less violently when something goes wrong - tested against fire, fragment and bullet impact, shock and detonation of a neighbouring round, with burning or venting rather than detonation as the desired result. The standard is a NATO one and applies to the whole round, not to the chemistry alone¹². It is a storage and survivability property before it is a lethality one, so it matters most where rounds sit densely and for a long time: ships' magazines, armoured vehicles, forward depots, and the large national reserves Europe has committed to build. That is precisely the demand Outlook 01 described, which is why the two arguments meet.

France has had an insensitive 155mm high-explosive shell in service since the mid-2000s. Its shell was classified under the French insensitive-munitions scheme in 1999 and went into mass production at La Chapelle Saint-Ursin; the fill is a melt-cast composition built on a different base explosive from TNT, and the successor nature uses the same one with a larger charge weight^{82, 83, 87}.

And European cast-cured filling is twenty years old as an industrial capability. Eurenco's semi-continuous cast filling process at Sorgues was authorised by the French defence procurement authority in 2005, with an automated facility commissioned in 2006 rated for up to 50,000 155mm shells or 100,000 120mm rounds a year, producing shells at the second-highest French insensitive rating^{84, 85}. The line's largest artillery customer is German: Rheinmetall's DM121 was contracted for series filling on it from late 2016⁸⁶. Italy's Vulcano carries a polymer-bonded fill tested to the second-best reaction category across the standard test set⁸⁸. The United Kingdom demonstrated cast-cured fills in 105mm, 4.5-inch and 155mm shells as early as 2006, surviving firing loads of 60,000 times gravity across more than a hundred rounds⁹⁰.

2.2 The charge: nothing has been qualified anywhere, and the research is twenty years deep

Conventional gun propellant is built on nitrocellulose - cotton or wood cellulose treated with acid - sometimes with nitroglycerine and other additives, extruded into grains. A composite charge instead holds nitramine crystals inside a polymer binder, in the same way a rocket motor is built, and is produced as granules or pellets rather than extruded grains. That distinction matters commercially: an extruded grain needs a nitration line and a solvent recovery plant behind it, and a granular composite does not.

The word binder covers two very different products. An inert binder – a cellulose ester, a thermoplastic, or the polybutadiene class used in rocket motors – holds the mixture together and contributes nothing energetic. It is an ordinary industrial polymer, made in Europe, and it dilutes the energy of the nitramine it carries. An energetic binder contributes energy of its own. The one that appears in every theoretical case for composite charges is glycidyl azide polymer, universally abbreviated to GAP: a rubbery polymer whose repeating units carry azide groups, giving it a positive heat of formation. It releases energy on decomposition rather than absorbing it, and the gas it produces is nitrogen-rich – which matters for barrel wear in a way set out at 2.4.

In a granular composite, replacing inert binder with an energetic one recovers the energy the binder was wasting, so the charge delivers more impetus for the same mass – more muzzle energy at the same pressure ceiling, or the same energy at lower pressure and temperature. That is the currency in which range beyond forty kilometres from a 52-calibre gun is bought. Against it: the cured polymer's mechanical properties are difficult, its low-temperature behaviour is the known weak point against the –46 °C qualification floor every artillery charge must meet, and it is a speciality chemical with very few producers and none advertising production scale in Europe¹⁸⁰. That combination – real performance, hard engineering, no European source – is why the inert-binder route is the first commercial step and GAP is the second.

The research base is substantial and long-established. Indian government laboratories have published on nitramine-in-polymer gun propellants since the 1990s and fired them in 120mm tank ammunition, reaching 1,661 metres per second at pressures within the gun's limits⁹⁶. The German Fraunhofer institute develops gun propellants using energetic thermoplastic binders and reports flame temperatures around 600 kelvin below conventional powders at comparable performance⁹³. Published work on azide-binder gun propellants calculates force constants – the energy available to push the shell – up to about 1,487 joules per gramme at combustion temperatures conventional chemistry cannot reach at that energy⁹⁷. Chinese, Korean and Polish groups are all active⁹⁸. And it has moved out of the laboratory: Eurenco's Swedish plant reported in 2024 a low-vulnerability nitramine family with part of the inert binder replaced by more energetic components, about twenty per cent more specific energy than the grade it already produces, demonstrated from bench to industrial scale – for tank ammunition first rather than artillery¹⁷⁹.

TWO THINGS CALLED THE SAME THING

The fill and the charge both use nitramine in a polymer, and both have been associated with acoustic mixing. They are different products, made in different buildings, to different approvals, and the public record conflates them constantly.

The fill is a polymer-bonded explosive that ends up as a solid mass inside the projectile body. Acoustic mixing is a genuine and increasingly industrial answer for it: the American army has a production machine at McAlester, the US Navy has replaced conventional mixing on a warhead line, and BAE's publicised claims at Glascoed – the twenty per cent figure – are about explosive fill, not about propellant^{34, 36, 38}. NATO's munitions safety centre has now held a dedicated technical meeting on what acoustic mixing does to a safety case, which is what happens when somebody is trying to field it rather than study it¹⁸⁷.

The charge is a granular or pelletised propellant that ends up loose inside a combustible case, sized and shaped to burn at a controlled rate. Producing it is a granulation problem, not a filling one, and the mixing step is only one part of it. The open record on acoustic mixing applied to a composite gun propellant is thinner and earlier: a laboratory-scale demonstration by BAE at Glascoed under Ministry of Defence funding, with scale-up stated as the intent¹⁷⁸, and a 2019 Cranfield doctorate on the same class of material^{91, 92}. A plant that has qualified acoustic mixing for fills has not thereby qualified anything for charges, and an investor told otherwise is being sold the wrong asset.

Read together, those two British data points are the lab-to-line path in one place: a national centre of excellence with a licence, a mixer and a demonstrated composite propellant, and a prime that has run the same class of material on the same class of equipment under government funding and said it intends to scale it. Neither is production. Both are further than any continental European equivalent on the charge side.

The United States is not moving either, which answers a question often asked the other way round. Its modular charge system remains the programme of record and is conventional nitrocellulose chemistry¹²⁹; the extended-range charge work is an incremental development of it rather than a change of chemistry³⁰; and every dollar of new American propellant money is deepening that base rather than replacing it¹²⁷. There is no American programme to move artillery charges to composite chemistry.

But no army has qualified it. Fielded low-vulnerability gun propellant exists and has for decades – the American 105mm tank round type-classified in 1989 uses one, Eurenco's Swedish plant has one in production for a 57mm naval gun, and Israel took one through full life assessment for 120mm^{94, 100}. Every one of them uses an inert binder. No gun propellant using an energetic azide binder has been qualified or fielded in any calibre by any country. In 155mm artillery there is no composite charge programme, trial or tender anywhere. Base-bleed units are composite, but on the conventional rocket chemistry, not an azide one.

WHY IT STALLED, AND WHY BRITAIN IS MOVING ON IT NOW

Four technical obstacles recur across the literature. Ignition: nitramine composites are harder to light reliably across the zone range, and a dedicated body of work exists on solving it. Vulnerability at high energy: American work found that pushing nitramine loading up to match conventional high-energy propellant produced a near-detonative response to attack, and recommended against manufacture⁹⁹. Erosion: contested, and dealt with at 2.3 – where the recent literature runs in the composite charge's favour rather than against it. Ageing: interactions must be re-proven for each new material, which adds to the qualification bill but, as Section 5 shows, adds months rather than years.

And one commercial obstacle that has mattered more than all four. The incumbent conventional charge already meets the insensitive standard at the second-highest reaction category and already delivers beyond forty kilometres. On performance alone there was no customer pull, so no producer took one through qualification, so no army had a qualified one to buy. That loop held for twenty years.

What broke it was not performance. It was supply. Britain stopped making its own gun propellant when Bishopton closed in 2002 and has imported the chemistry since. China supplies the large majority of the cotton linters behind European nitrocellulose and has already restricted exports. In April 2025 BAE announced a propellant that removes nitrocellulose and nitroglycerine altogether – after roughly £8.5m of research over five years, stated as demonstrated from small arms to large calibre, with first industrial capacity targeted for the end of 2026⁴². In June 2025 the Strategic Defence Review committed about £6bn to munitions and at least six new energetics factories; by August 2026 twenty-two firms held feasibility contracts against thirteen candidate sites, with design contracts of up to £5m to follow^{9, 10, 11}. And in May 2026 Britain ordered seventy-two 52-calibre guns, whose range growth past the current base-bleed envelope must come from charge energy inside fixed pressure limits¹⁸¹.

the sequence is legible even though no minister has stated it. A country with no sovereign propellant chemistry, a 52-calibre fleet on order, an energetics programme that names nitrocellulose alongside eight other materials it wants made at home, and a prime that says it can make propellant without nitrocellulose at all. **Inferred**, and worth stating as inference: the British push is driven by supply sovereignty first and ballistics second, and the composite architecture is the only published route that delivers both; pulp-based nitrocellulose addresses supply sovereignty alone.

Which splits the confidence. That the strategic driver is real and that Britain is acting on it: **high confidence**, on government and company documents. That a nitrocellulose-free propellant has been demonstrated at sub-scale across calibres: **moderate**, resting on one company's announcement cycle plus a conference paper trail^{42, 178}. That a qualified 155mm *modular charge* built on composite chemistry is in service or close to it: **low** – no firing of one, no qualification activity, no order appears anywhere in the open record. Those are three different claims and the paper does not lean on the third.

2.3 Barrel wear

The claim that a cooler-burning composite charge is kinder to a barrel is not supported by the literature as a general statement. The most complete open review concludes that chemical attack by the propellant gas, not heat alone, is the main driver of barrel erosion, and says directly that the common assumption that low flame temperature reduces erosion is not necessarily true. In one cited series across five nitramine propellants of equal energy, lowering the flame temperature increased the erosion²⁷.

What drives it is the composition of the gas. The carbon-bearing gases attack the bore chemically, carburising the surface and lowering its melting point; hydrogen embrittles it. Nitrogen is either harmless or actively protective, because it re-nitrides the bore surface as the gun fires. The commonest low-vulnerability formulations burn cooler but produce a hydrogen-rich gas and are generally more erosive than the conventional propellants they replace. That is a property of the binder, not of the nitramine - and the single most useful datum in the open literature makes the point exactly: a nitramine low-vulnerability propellant built on a nitrogen-rich binder measured about 40 per cent less erosive than triple-base while running 176 kelvin hotter, and about three times less erosive than a conventional inert-binder composite at similar energy^{27, 200}.

Which is why the erosion argument runs in the composite charge's favour once it is stated properly, and why the azide binder is the interesting case rather than the alarming one. An energetic binder carrying azide groups produces a nitrogen-rich exhaust by construction. On the published mechanism that is the favourable end of the gas-chemistry scale, not the unfavourable one. **Derived:** nobody has published 155mm barrel-life data for such a charge, and the reviewed erosion literature is overwhelmingly tank-gun work at high velocity.

The economics are worth carrying alongside the chemistry, because they are large. On the same review, a 155mm cannon firing triple-base charges showed a wear life around 2,700 effective full charges against roughly 30,000 for a single-base equivalent - an order of magnitude, set by charge chemistry rather than by the barrel²⁰⁰. Replacement tubes have been bought at around \$690,000 each, and Ukrainian demand exceeded thirty a month at one point, beyond the American army's own capacity to supply. And the top of the range ladder is where this bites hardest: the American extended-range cannon programme was cancelled in 2024 with rapid tube wear from its supercharge among the reasons. Barrel life is not a footnote to a charge decision. At the ranges Section 1 describes, it is the charge decision.

HOW TO STATE IT

Correct: the erosion behaviour of a composite charge is a design variable set by the binder chemistry, not a fixed property of the nitramine and not predicted by flame temperature. A well-designed composite charge can be markedly kinder to a barrel than a conventional triple-base charge. A poorly designed one is worse than what it replaces.

Incorrect, and a technical reviewer will know it: that composite charges reduce barrel wear. Two further points belong in any technical discussion - the low-vulnerability erosion literature is overwhelmingly tank-gun work at high velocity and does not transfer to a howitzer charge without saying so, and the standing review dates from 2005.

The one directly relevant production datum: Rheinmetall states that its high-performance extended-range charge delivers its velocity gain at the same barrel cost as a mid-zone charge rather than a top charge⁵. That is a manufacturer's claim measured against a sub-maximum comparator, not an independent trial.

2.4 RQ2 - legacy versus insensitive: who has adopted, and when share moves

Adoption is narrower than the language around it suggests. Four countries hold a standalone national policy: France, Italy, the United Kingdom and the United States. Seven more work to draft policy or to rules embedded in wider munitions-safety documents - Australia, Canada, Denmark, Finland, the Netherlands, Norway and Sweden - and Germany applies its requirements inside general safety policy rather than as a separate instrument^{12, 13}.

NATION	INSTRUMENT	DATE	SCOPE
United States	Statutory direction plus acquisition policy and hazard-test standards	2001–2022	New procurement, with tailoring and named exemptions
United Kingdom	Defence code of practice on munition vulnerability, version 2.0	Feb 2026	New acquisition, plus a duty to keep reviewing in-service stock for improvement opportunities
France	Ministry instructions, graded across three levels	2011	New procurement; small-quantity exemptions
Italy	National guidelines, three graded levels	2000	New procurement; heavy fragment impact mandatory
Canada	Departmental order	2004, amended 2017	All ammunition used by the department and armed forces; the pre-2004 exemption lapsed in 2020
Norway	National insensitive munitions policy	2017	All procurement must demonstrate compliance with the NATO standard
Australia	Explosive ordnance policy chapter	2021	New acquisitions only; assessment mandatory in the safety case
Germany	Requirements inside wider munitions-safety policy	-	Small-arms exemptions

Two things follow. No country sets a compliance deadline. Only Canada and the United Kingdom reach stock already in service, and both do it softly - Canada through an exemption that has since lapsed, Britain through a duty to keep looking for improvement opportunities under a reasonableness test rather than an absolute standard^{14, 16}. The United Kingdom reissued its code in February 2026 and added neither a deadline nor a mandate on fielded stock.

The American case shows how slowly this moves even where the policy is oldest. The insensitive fill was approved for artillery in July 2010 and has been bought at scale ever since¹²⁴. Yet in November 2024 the US Army described TNT as the primary explosive fill for 155mm shells and awarded \$435m to restart domestic TNT production, and the surge buys of 2023 covered both the old and the new chemistry^{125, 126}. The Marine Corps kept the TNT-filled version. Sixteen years in, the transition is substantial and incomplete.

THE EXPLANATION THE QUALIFICATION STORY LEAVES OUT

Regulation is the reason that gets published. Incumbency is the reason that fits the pattern. Every European producer with a large paid-for melt-pour position - the Polish plant that is effectively Europe's TNT supply, the Czech and Slovak fillers, the acquired Spanish network - is expanding on the old chemistry rather than converting. Every producer that has moved decisively on the new chemistry did so where a single customer made a single decision, or where the producer had a reason to retool anyway.

The two explanations are complements, not rivals, and that is the useful part. Fragmented national qualification is precisely what makes writing off a working melt-pour line irrational for any one European firm: with twenty-seven safety authorities and no common procurement pull, the firm that moves first pays the whole conversion bill and captures a fraction of the market. The American case is the control: one service, one type classification in 2010, one government-owned plant, and the transition happened - though even there the Army is now rebuilding TNT capacity at \$435m, so the change was substantial rather than clean¹²⁵.

Which makes it a decision problem rather than a technology problem, and decisions can be taken. BAE retooled its energetics base twice while its competitors bought more of the old one - a new filling facility at Glascoed, a nitrocellulose-free propellant route, and continuous-flow synthesis in distributed nodes^{42, 54}. It is not a larger company than Rheinmetall or a better-funded one. It made a different call. The lesson a new entrant should take is not that the incumbents are wrong; it is that they are structurally unable to move first, which is what leaves the position open.

Stated as what it is: the incumbency reading is **inferred** from the pattern of who is expanding on which chemistry. No European prime has publicly cited sunk melt-pour capital as its reason, and none is likely to. The regulatory reading is **sourced**. Both are true and the second is what makes the first rational.

The reason usually given is the qualification path, and the usual version of it does not survive checking. Changing the fill in an existing shell family means re-firing the full test set in the munition's own configuration, building several hundred test rounds, re-shooting the firing tables, releasing a new technical data package and transitioning production. The step normally described as the immovable one is the temperature-cycled ageing study behind the service-life claim. Set against the documents, that description is wrong in its arithmetic and wrong in its structure.

On the arithmetic, NATO's own chemical-stability standard certifies ten years of storage at 25 °C from a measurement lasting about thirty-five days at 70 °C - under five weeks for a decade of proven life¹⁶⁸. The formal accelerated ageing programme that sits behind qualification is bounded, not open-ended: sampled to eight months at 60 °C or six at 70 °C, with the ambient-temperature leg running alongside the programme rather than gating it¹⁶⁹. The longest physics-bound element of a fill qualification is therefore six to eight months, and it is the only one.

On the structure, NATO's material-qualification doctrine explicitly allows partial ageing results to be submitted, with completion required before service approval rather than before type qualification - so the ageing programme runs in parallel with the firing campaign by design¹⁷⁰. Britain's own code sets no

timeline at all, says evidence should be gained as early as reasonably practicable, and contemplates a store being brought into use before its explosive is fully qualified¹⁷¹. And the American record shows what that looks like when a single customer drives it: twenty-three candidate formulations evaluated in 2009, material qualification in January 2010, safety confirmation in March, a signed technical data package in June and production transition the following year – with the ageing matrix run inside that window and testing parallelised across four laboratories^{17, 18, 19, 175}.

the three-to-five-year figure describes queuing, sequential contracting and duplicated national assessment, not physics. Section 5.3 sets out what a war-footing programme would do about it. The historical benchmark is worth keeping in view: the plant that made the West's nitramine explosive in the Second World War went from ground-breaking in 1942 to fully operational by mid-1943, and the material was in combat use that year¹⁷⁶.

EXHIBIT 6

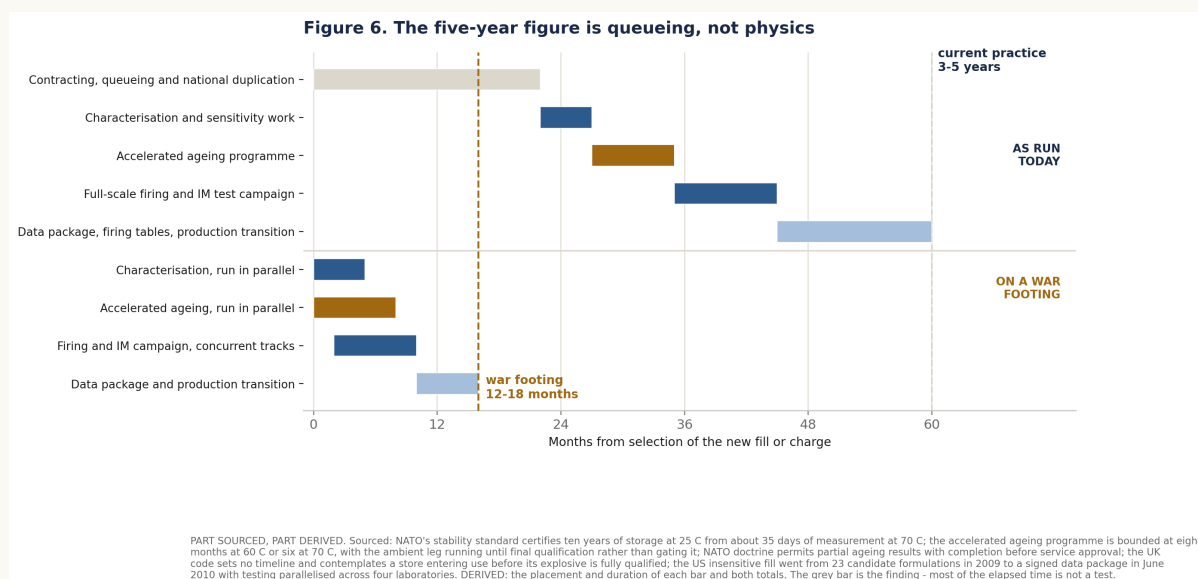
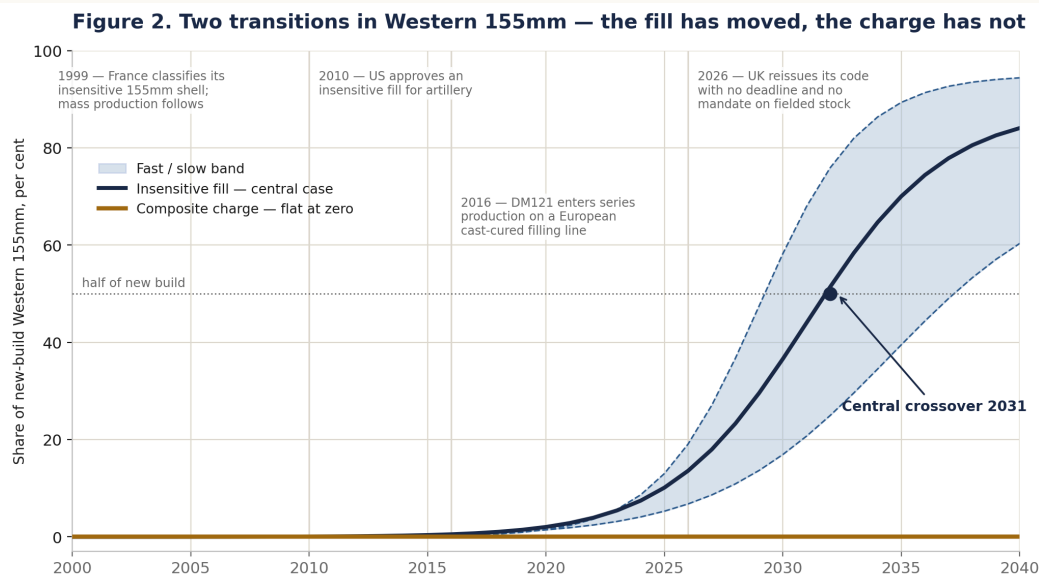


Figure 6. Changing the fill or the charge: where the time goes, and what a war footing removes.

Figure 2 puts insensitive fill as a share of new-build Western 155mm high explosive on a central crossover of 2031, with a fast case of 2029 and a slow case of 2036. It is a derived model: no government or producer publishes fill by chemistry, so any figure here is reasoned rather than read. What is sourced beneath it is the adoption table above, the absence of deadlines, the qualification path, and the four European and American natures now in production on insensitive fills. The single event that would break it is a country setting a dated compliance deadline reaching stock already in service. None has in twenty-six years.



The fill curve is a DERIVED MODEL: no government or producer publishes fill by chemistry. It is built from the four nations holding a standalone policy, the absence of a compliance deadline in any of the nine instruments reviewed, the three-to-five year path for changing a fill in a fielded family, and the European and American natures now in production on insensitive fills. The charge line is not a model. No army in any country has qualified a gun propellant using an energetic azide binder, in any calibre, and there is no 155mm composite charge programme, trial or tender anywhere on the public record.

The chart carries a second line, and it is the one that matters commercially. The share of Western 155mm charges using composite chemistry is zero and has been zero throughout. Two transitions, one running and one that has not started.

Figure 2. Two transitions in Western 155mm - the fill has the charge has not.

WHAT THIS MEANS FOR A PLANT FINANCED NOW

Specify it to run both routes from the first drawing. A filling and assembly facility financed in 2027 will spend most of its working life on the far side of the crossover, but will earn its first years on conventional demand. Designing the lines, safety cases and quality systems for both at the outset costs a fraction of retrofitting them, and turns the transition from a risk into a second wave of demand.

And design for the filling method, not just the chemistry. Test work on how fills behave under the shock of firing ranks pressed fills as the most resistant, melt-poured fills with cavities in the middle, and soft cast-cured fills with gaps at the base as the most sensitive; the American guided round moved to a pressed fill after a cast-cured candidate failed a setback test⁸⁹. A press-fill capability is therefore not the poor relation of cast-curing. For high-acceleration natures it is the safer engineering answer, and it is the one a smaller operator can run.

03 Raw chemicals: what a composite route costs Europe

The composite charge argument ends up here. Removing nitrocellulose from the propellant removes Europe's deepest single dependency – and creates a new one. This section puts numbers on both sides so the trade can be judged rather than asserted.

3.1 The dependency as it stands

European military propellant runs on nitrocellulose, and nitrocellulose runs on cotton linters – the short fibres left on the seed after ginning. Europe depends on China for more than seventy per cent of them, on the estimate of Rheinmetall's own chief executive, and China has already restricted nitrocellulose exports and tightened dual-use controls⁶⁰. The exposure worsened during 2026 on volume rather than price: the August world agricultural estimates cut world cotton ending stocks by 1.53 million bales to 69.69 million, the lowest since 2011/12, with mill use exceeding production for the first time in three years⁵⁹. Linters are a by-product with no published index of their own, so fewer bales ginned means fewer linters whatever the lint price does.

A second dependency sits above the material, and it is usually stated too loosely. The claim that almost nobody can design a nitrocellulose line does not survive a count. Somewhere between eight and a dozen credible engineering houses can do it – Josef Meissner in Cologne, whose reference plants include a fully automated 48-tonne-a-day nitrocellulose line in Brazil, commissioned in 1999^{E4195}; Bowas-Induplan in Austria; Repkon in Turkey, now building the first new American TNT plant in four decades; EKOCEM at Pardubice in Czechia; plus the vertically integrated primes that engineer for their own account, and Korean, Indian and Chinese contractors. There are no shortages of chemists or of process knowledge.

The chokepoint is narrower and more specific: Western, export-cleared houses with a recent reference plant are a handful, and they are being bought. On 3 June 2026 the Pardubice firm was acquired by an American holding company^{61, 196}. The American army hired a Turkish contractor to rebuild its own TNT capacity. Both facts point the same way. The practical question for a European build is not whether an engineer can be found; it is whose export-control regime the engineering, the equipment and the licensed process end up sitting under.

The one published alternative is now being discussed by government in real terms, which is the signal that matters. BAE's route removes nitrocellulose and nitroglycerine from the propellant entirely and makes the explosive by continuous flow in small distributed nodes rather than one large plant. It was announced in April 2025 after about £8.5m of research over the preceding five years, with industrial-scale capacity targeted for the end of 2026^{E3}, and the company has published no interim industrialisation milestone since⁴². But the state has not been silent about it. The Strategic Defence Review response committed about £6bn to munitions with at least six new energetics factories, the Defence Industrial Strategy names energetic material as a capability Britain must hold, and by August 2026 twenty-two firms held funded feasibility contracts against thirteen candidate sites^{9, 10}.

The shape of that programme matters more than its wording. It is chemistry-agnostic - it still lists nitrocellulose and nitroglycerine alongside seven other materials - and it is distributed across many small sites and many firms rather than concentrated on one prime. **Inferred:** a government that thought the incumbent chemistry was sufficient would not be funding twenty-two feasibility studies, and a government that thought one company's route was sufficient would not be hedging across nine materials. The programme is structured to let several answers compete and to pull firms other than the incumbent into the base. That is the same move visible across British defence procurement this year - a ring-fenced innovation budget, a small-business office, and direct small-firm spend targeted to rise from £1.24bn to £2bn by 2027/28^{190, 191}. Treat the nitrocellulose dependency as structural across the planning horizon, and the policy appetite for an alternative as real and rising.

3.2 Meanwhile Europe is spending its propellant capital on the chemistry that carries the risk

Every announced European charge and powder investment inside the window is nitrate-ester chemistry - Rheinmetall's €650m across its propellant sites, the Eurenco joint ventures in Poland (with MESKO) and Slovakia (with ZVS), Synthesia's expansion of its nitrocellulose output from 6,000 to over 7,000 tonnes a year, and the Czechoslovak Group's assembly of nitrocellulose capacity in Germany and nitroglycerine capacity in Saxony^{E23, 53, 74, 75}. Poland's own research institutes state openly that the country cannot yet produce modern low-vulnerability gun powders and treat the absence as a serious problem⁹⁸. Stated plainly: the cotton dependency is not a legacy exposure being engineered out. It is the exposure the new European capacity is being built on - once-in-a-generation propellant capital spent reproducing the chemistry whose feedstock a strategic competitor controls, now that competitor has shown it will restrict it. That is the finding of this section and it needs no commercial interest to reach.

3.3 Where the dependency moves, and what it costs

A polymer-bound route does not remove Europe's import exposure. It relocates it, from agriculture to petrochemicals - and that is a better place for it to sit.

INPUT	PRICE AND MARKET POSITION	ASSESSMENT
Polymer binder, hydroxyl-terminated polybutadiene class	A real commercial product with a real market: roughly \$150–270m and 30,000–40,000 tonnes a year worldwide, growing at 3–9.5% depending on which market study is used ^{E10110} . Working from market value against volume, bulk grade sells at about \$5–10 per kilogramme ; aerospace-qualified grade with certified lots and traceability at perhaps \$15–40 ; laboratory quantities above \$100 (derived , with the arithmetic in Annex C). Its feedstock, butadiene, traded at \$0.76 per kilogramme in North America, \$1.16 in Europe and \$1.58 in north-east Asia in August 2026 ¹¹¹	Cheap, and the price is not the risk. At roughly a tenth of the mass of the finished item, even the qualified grade adds a few pounds per kilogramme of product. The risk is structural: Western qualified supply is one plant in Texas – the sole approved American source for fifty years – and one at Marl in Germany, expanding on stream in the second quarter of 2027 with an Asian site behind it ^{58, 108, 109}
Energetic polymer binder, azide type	No price has ever been published. Its precursor, epichlorohydrin, is a commodity at about \$1.70–1.90 per kilogramme, though European capacity is shrinking – a major producer announced the permanent closure of its German epichlorohydrin and chlorine units in October 2025 on energy costs ¹¹² . Production is small-batch in licensed energetic plant at tonne scale rather than continuous at ten-thousand-tonne scale. On scale economics alone that puts it at roughly \$300–1,500 per kilogramme (estimated, reasoning in Annex C)	One and a half to two orders of magnitude above the inert binder. Cheap feedstock, expensive process. This is why the inert-binder route – the one Cranfield demonstrated – is the commercially realistic first step, and the energetic-binder route is the second
Nitramine explosive	Nothing material lands in Europe before 2028. Chemring Nobel's Norwegian first phase is complete with the second advancing and revenue from 2028; its greenfield site is 2030 at the earliest and contested at planning; Rheinmetall's Hungarian line is stated for 2027; the American centre of excellence is not fully running before 2031, leaving existing US output committed to US programmes ^{48, 49, 79}	The hardest input, and a composite route makes it harder rather than easier – both the fill and the charge draw on the same molecule. This is the honest cost of the argument and it should be priced into any plan
Concentrated nitric acid	Made captively beside the plant that consumes it, moved under bespoke contract, and too hazardous to freight into a spot market – so it has no merchant price and will not acquire one. The technical grade that is priced is not a substitute and the two are linked only through ammonia ⁶²	Route-independent. Whichever chemistry is chosen this is the cost base, and it must be priced as on-site or contracted supply rather than bought on a market
Hexamine, the other input to the nitramine	The acid is only half of it. Hexamine is the carbon-bearing input, it is an ordinary industrial commodity, and and it is the node most often left out of dependency maps. It is bought rather than made by every nitramine producer that does not sit inside a large chemical group	The gap in most published analysis. A nitramine plant with acid and no hexamine is not a plant. Any sovereign nitramine proposition must name its hexamine source, and a national programme that lists nine energetic materials without listing this one has drawn its boundary one level too low

INPUT	PRICE AND MARKET POSITION	ASSESSMENT
Formaldehyde and methanol, sitting behind hexamine	Hexamine is made from formaldehyde and ammonia; formaldehyde is made from methanol. Both are high-volume commodities with deep merchant markets and no defence connection at all - which is exactly why nobody tracks them in this context. European formaldehyde capacity is tied to the phenolic and amino resin industry, whose construction and wood-panel end markets have been contracting	Derived. The exposure is not scarcity - these are among the largest-volume organic chemicals made. It is that the European capacity sits inside a shrinking industry, so the relevant question for a planner is not global supply but whether the nearest plant is still open in 2030. That is a question a national programme can answer and has not asked
Ammonia, sitting behind both the acid and the hexamine	UK ammonia was the most expensive in the second-quarter 2026 survey at \$871 a tonne against \$342 in China ⁶³ - the reason is gas price rather than scarcity, and the arithmetic is at Annex C. Note that ammonia enters this chain twice, through nitric acid and through hexamine, which roughly doubles its leverage over the finished item	A siting cost, not a scarcity. It should be priced explicitly into any British proposition, and it is the single most defensible upstream integration in the chain because it serves two branches at once
Toluene, behind TNT	TNT is made from toluene, which comes out of refinery reformat and cracker by-product streams. European refinery closures have thinned the domestic aromatics base at the same time as European TNT capacity is being rebuilt - Poland's single plant at about 10,000 tonnes a year is the continent's dominant source today, with a path to roughly 25,000-30,000 tonnes by 2028-29 across five projects, all of it pre-sold (derived from Nitro-Chem's stated base and the projects listed in Outlook 01; source 198 for the shortage itself) ^{198E8}	The binding number in this paper, and it is arithmetic rather than opinion. At six to eleven kilogrammes of fill a shell, today's NATO-accessible TNT supports 0.9 to 1.5 million rounds a year and the 2029 position supports 2.8 to 4.5 million , against a floor of five million (derived). Every European filling line built above that number is idle capacity unless the fill chemistry changes
Nitroguanidine, behind the triple-base charge	A named single point of failure in the Western charge chain, sole-sourced from one German producer for practical purposes ¹⁹⁹ . It has no substitute inside conventional triple-base chemistry	The quietest concentration in the whole chain. It sits behind the charge rather than the fill, so it does not appear in shell-counting analysis at all, and a composite route removes it entirely rather than relocating it

Two things fall out of that table. The first is that ammonia enters the chain twice - through the acid and through the hexamine - which makes it the highest-leverage upstream position available, and Europe holds 17.7 million tonnes a year of capacity against a defence requirement of under half a per cent of it (Annex C). The second is that the two hardest numbers in European rearmament are both one level above where the analysis usually stops: toluene into TNT, and cotton into nitrocellulose. Both are agricultural or refinery by-products whose supply is set by industries that have no interest in defence, and neither is fixed by building another filling line.

EXHIBIT 3

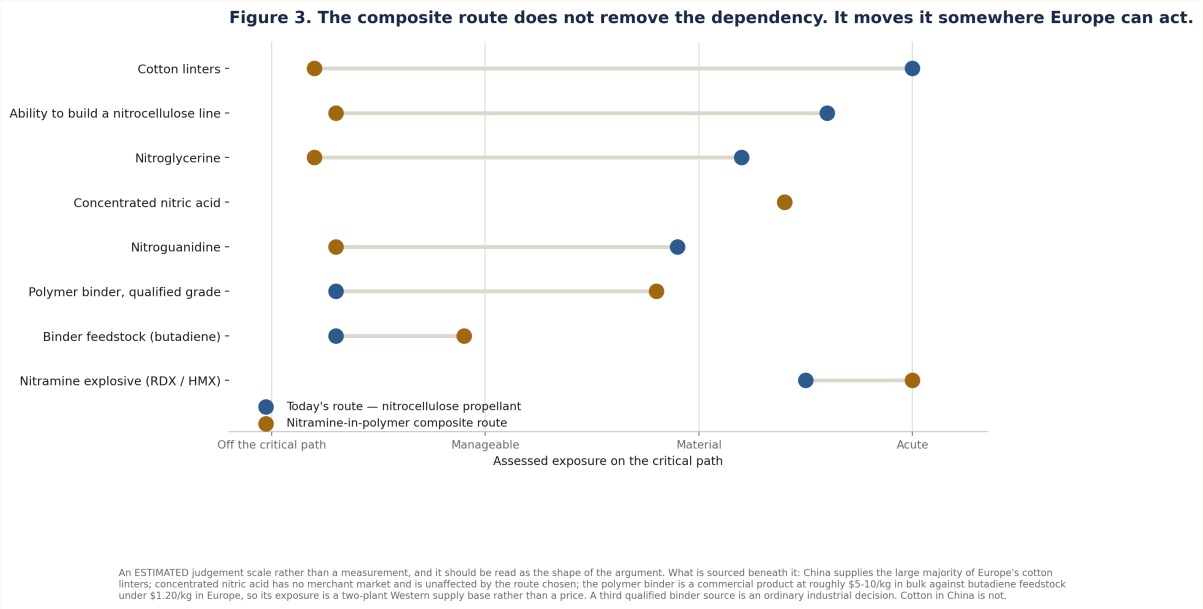


Figure 3. What each route depends on, and how exposed each dependency is.

MAKE OR BUY THE BINDER

The inert binder: buy. The chemistry is made in Europe - France and Germany both hold producers¹⁴⁸ - and the material is a commodity-priced specialty at a few pounds a kilogramme. The qualification-grade product lines are narrower than the chemistry, and historically run through American and Japanese production, so a European programme can buy the class locally while still finding its qualified grade routed through a foreign plant. That is a second-source problem with an ordinary answer: qualify a European line. It is not a reason to build.

The energetic azide binder: there is nothing to buy in Europe, and that is an opportunity rather than a verdict. No European producer advertises production-scale capacity and none has been announced. The clearest advertised merchant supply anywhere is Korean¹⁴⁷, with small-lot American speciality supply behind it and pilot-scale European research capability at Fraunhofer^{144, 180}.

The question is not whether Britain can make it. It is whether Britain should, and what the risk is. The honest answer is that this is a speciality polymer produced at tonne rather than kilotonne scale, in licensed plant, from a commodity precursor - which makes it a small plant, not a large one, and puts it in the same capital bracket as a small ammonia plant rather than the €350m bracket of a powder factory. Britain already holds the two things that are genuinely hard to acquire: a national centre of excellence in energetic materials with a manufacturing licence, accredited hazard testing and an explosives range^{37, 91}, and a government programme actively funding twenty-two firms to design energetics plant^{9, 10}. What it does not hold is a customer requirement, which is the same thing missing everywhere else in this section.

The risk worth taking, stated plainly. Building a pilot-to-production energetic binder line is a tens-of-millions decision with no order behind it and a real chance the qualification takes longer than the business plan. Against that: it is the one node in this entire chain where being first in Europe means being the only one in Europe, the precursor is a traded commodity rather than a controlled material, and the alternative is to swap a Chinese dependency for a Korean one. A country that says it wants to lead on innovative energetics must be willing to own a node nobody else owns. This is the cheapest one on the list.

Which sets the sequencing rather than the destination. The inert-binder composite route is the commercially available first step - the binder is purchasable, the demonstration exists in Britain, and it already removes the cotton dependency. The energetic-binder line is the second step and the sovereign one, and the case for starting it early is that a pilot plant takes about as long to qualify as a charge does.

RQ3 - DOES THE COMPOSITE ROUTE BREAK THE DEPENDENCY, OR MOVE IT?

It moves it, and the move is worth making. The composite route removes the cotton exposure, which is concentrated, weaponisable and outside European control. It replaces it with a polymer binder that is cheap, commercially traded, made from an ordinary petrochemical, and currently supplied to defence standard from two Western plants. It leaves the nitramine and nitric acid exposures where they are, and increases the nitramine draw.

Sold as sovereignty that argument fails technical scrutiny. Sold as swapping a dependency Europe cannot influence for one it can, it is correct, and it is the strongest strategic case in this paper. Building a third qualified Western binder source is an ordinary industrial policy decision costing tens of millions. Growing cotton in China is not a decision Europe gets to make.

04 Factories: working out where the chain breaks

Nothing in the two preceding sections becomes a usable round until somebody fills it, assembles it, inspects it, proves it, packs it and stores it under licence. This section takes each stage of the chain in turn, measures what is being added against what is needed, and lets the gap identify itself.

4.1 Counting sites, not announcements

Announcement-counting gives the wrong answer here. The standard approach – take the largest single announced European addition per stage and set it against the requirement – makes filling look like the empty stage, because filling is where announcements are smallest relative to need. It is also where the existing installed base is largest, and an announcement count cannot see an installed base. Europe and the United Kingdom hold forty-two plants with a 155mm or 152mm filling capability, from a global census of 136¹⁹⁷. Ten of them publish a capacity figure. Those ten alone total about 2.24 million rounds a year by 2028.

The floor and its derived rates are carried unchanged from Outlook 01: about five million rounds a year through filling and assembly, and behind them roughly 30,000 tonnes a year of nitramine explosive, 20,000 tonnes of TNT and 42,500 to 52,500 tonnes of propellant. The table below sets each stage against that requirement using site counts and published capacities rather than headline projects.

STAGE	WHAT EXISTS AND IS BEING BUILT IN EUROPE AND THE UK	ROUNDS A YEAR IT SUPPORTS	SHARE OF THE FIVE-MILLION FLOOR
Shell bodies	Forging and machining across Slovakia (Snina 360,000), Czechia (300,000 from 2026), Poland (Kraśnik 150,000 by 2027), Belgium, Romania, France, Lithuania, Germany and Britain, plus a converted car-components plant near Berlin ¹⁹⁷	~0.9m quantified; 1.5–2m with the sites that publish no figure	30–40%
Filling and assembly	Forty-two sites. Ten publish figures totalling ~2.24m: Rheinmetall at Unterlüß (350,000), Spain (450,000), Lithuania (100,000) and Bulgaria (100,000); KNDS at Bourges (250,000); ZVS Dubnica (280,000); Nowa Dęba (180,000); STV Poličká (150,000); ARCA in Estonia (300,000); BAE Glascoed (80,000). Nammo's Norwegian expansion and its new Danish line, the Greek site at Lavrio and the Czech and Slovak screw-fill lines publish no figure ^{77, 78, 197}	2.2m quantified; 3–3.8m plausible across all forty-two	45–75%
Explosive fill material	NATO-accessible TNT of about 10,000 tonnes a year today, dominated by one Polish plant, with a path to roughly 25,000–30,000 tonnes by 2028–29 across five projects – SWEBAL's fully financed Swedish plant at about 4,500 tonnes a year the clearest of them – all of it pre-sold ^{57, 198} . Nitramine capacity moves on the same clock and is less well disclosed: the clearest European addition is a joint-venture plant at Várpalota in Hungary, ready in 2027, with Rheinmetall as the primary purchaser of its output and no published tonnage ^{56, 211} . Insensitive fills add to this rather than replacing it in the near term	0.9–1.5m now; 2.8–4.5m by 2029 if every project lands	18–30% now; 56–90% in 2029
Gun propellant	Roughly 12,000–20,000 tonnes a year announced across Nitrochemie Aschau, Eurenco Bergerac and Bofors, Explosia, and the Rheinmetall sites in Romania and Bulgaria ^{3, 116, 197} . At about nine kilogrammes a round averaged across firing zones	1.3–2.2m	26–44%
Charge module assembly	Announced European module output of roughly three million modules a year across Aschau, Bergerac, Pionki, Strážske and Victoria ^{3, 197} . A full-charge shot takes five to six modules	0.5–0.6m round-sets	10–12%
Fuze and fuze train	No European producer publishes a 155mm fuze volume. One framework holds much of the available Czech pyrotechnic capacity ⁷¹	Not stated by anyone	Unknown – and that is itself a finding

EXHIBIT 4

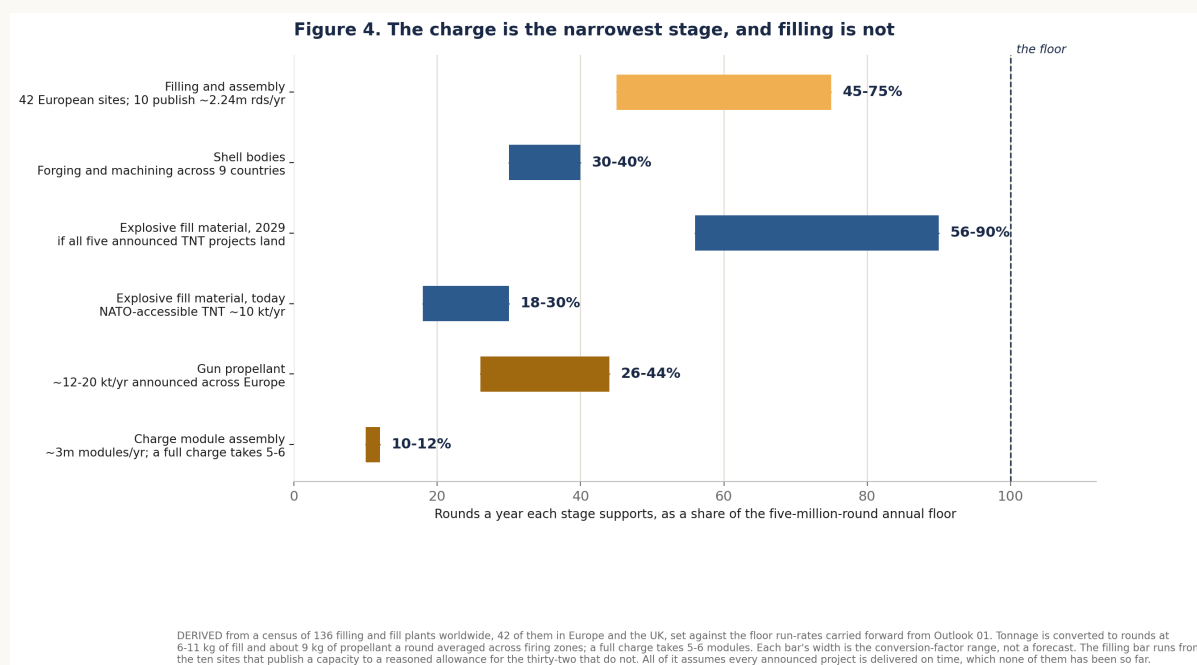


Figure 4. What each stage of the European chain supports, against the five-million-round floor.

WHAT THE ARITHMETIC SAYS

The narrowest stage is the charge, and it is narrow twice over. Announced European gun propellant supports about a quarter to two-fifths of the floor. Assembled charge modules support a tenth. Those two numbers are the tightest in the chain by a wide margin, and tighter than the fill, the body or the filling line.

Filling is not the empty stage. It is the exposed one. Forty-two sites and 2.24 million rounds of published capacity mean Europe is building conversion capacity faster than it is building the material to put through it. The risk on this stage is not that it will not exist; it is that it will exist and sit idle.

The third number is the specifically British one. Britain holds one of Europe's forty-two filling sites, rated at about 80,000 rounds a year and about six months late^{54, 197}, and its energetics programme names nine materials and six factories without naming a filling line or a charge line^{9, 10}. That is a national gap rather than a European one, and the only stage where a single decision would change Britain's position materially.

4.2 The other claim on the same molecules

Artillery is not the only European programme drawing on energetic materials, and a paper that counted only 155mm would be answering half a question. Since 2024 the guided missile and air-defence interceptor programmes have grown faster than artillery has. NATO's support agency awarded a contract worth up to \$5.6bn for up to a thousand Patriot GEM-T interceptors, the first under the

European Sky Shield Initiative, with the motors built at Aschau and the warheads at Schrobenhausen^{202, 203, 204}. Diehl is moving from eight hundred to a thousand IRIS-T missiles a year towards a stated ceiling of two thousand, on about €1bn of expansion²⁰⁵. MBDA carries a €44.4bn backlog against €5bn of investment over five years and has halved its Aster lead time^{206, 207}. Poland's Narew programme commits more than a thousand interceptors to 2039 on a programme value near €23bn²⁰⁸. And ATACMS will be built at Unterlüß from 2027, alongside a rocket-motor plant there, a solid-propellant plant in Denmark and an Estonian entrant planning two European sites at more than a hundred small interceptors a day each^{209, 210, 216, 217}.

The obvious inference is that this crowds out artillery, and on tonnage it does not. Five million shells a year at about eleven kilogrammes of fill is roughly 54,000 tonnes of high explosive. A thousand GEM-T at about eighty-four kilogrammes of warhead is 84 tonnes; two thousand IRIS-T at about eleven is 23; a thousand Aster at about fifteen is 15. Even a generous accounting of every European interceptor programme lands in the low hundreds of tonnes, under one per cent of the artillery fill requirement (**derived**, on standard-reference warhead masses that are **estimated** rather than sourced). The counter-drone interceptors that dominate the unit counts are mostly battery-powered rounds carrying sub-kilogramme warheads, and they barely register at all. Anyone arguing that missiles are what starves 155mm has the arithmetic against them.

The competition is real in three narrower places, and they are the ones worth watching. The first is the premium end of the nitramine chain. Europe's one merchant producer of the harder nitramine is doubling its Norwegian site for about £180m, of which £90m is government money, with live production from early 2027 and a second plant more than six times that size proposed for around 2030^{212, 214}. Its new capacity is largely sold before it opens, and the tenors tell the story: the artillery-linked framework with a German customer is the largest by disclosed value at about €231m initial order, but its firm commitment runs five years, while the missile-side agreements run ten and fifteen^{212, 213}. The premium grade is committed into the 2030s to warhead programmes. Any future artillery product needing it queues behind them.

The second is licensed ground and the people who work on it. No European filling line has been converted from shells to warheads, and none is likely to be. But Nammo makes 155mm ammunition and solid rocket motors from one Norwegian industrial park and one energetics workforce; Eurenco is doubling loading at Sorgues for both artillery fills and warhead compositions, and its partnership with Thales runs both ways - powders out for guided and unguided propulsion, TNT and nitramine in²¹⁵; the Schrobenhausen cluster is expanding missile and warhead work on a single site. What these programmes compete for is hazard-zone land, safety-case approval, permitting attention and qualified staff - the inputs that take years rather than months and that no amount of order book creates. The third is grant capital. The Norwegian ammunition and missile roadmap, the European Union's €500m ammunition package and the national instruments behind them funded the nitramine line, the charge lines and the shell plants out of one envelope. Money given to interceptor energetics was, at the margin, not given to gun propellant.

INPUT	SHARED WITH MISSILES AND INTERCEPTORS?	WHAT FOLLOWS
Nitramine - the harder grade	Yes, and contested. Warhead compositions and premium boosters draw on the same molecule from the same European merchant producer ^{212, 213}	The one place where artillery is demonstrably queuing behind missiles, and it is on ten- and fifteen-year tenors
Nitramine - the bulk grade, and the insensitive fill family	Partly. Artillery insensitive fills are built on the softer nitramine with NTO and DNAN rather than on the harder grade, so the premium contest above does not reach them ²¹²	The artillery fill chain is more separable than it first appears. Its constraint is TNT and plant, not competition from missiles
Ammonium perchlorate and polymer binder	Yes, at the margin. Base-bleed and rocket-assisted projectiles use the same composite architecture as a solid rocket motor ²¹⁸	A long-range-heavy 155mm mix competes for composite mixing capacity. Small in tonnage, but it is the reason extended-range natures behave as a separately scarce category
Licensed filling, hazard-zone land, permits, staff	Yes, and this is the binding overlap. Dual-site operators expand both from the same land and workforce	Years rather than months to create, and not solved by an order book. It is also why the entrants at 4.4 are buying qualified running capacity rather than building it
Nitrocellulose gun propellant and cotton linters	No, in any material quantity. Some European rocket motors use double-base propellant containing nitrocellulose ²¹⁹ , but the tonnages beside gun propellant are trivial	The cotton dependency is an artillery problem and stays one. Nobody else is bidding for the feedstock, and nobody else will solve it
Charge modules and combustible cases	No. Combustible cases are themselves nitrocellulose products and sit on the artillery chain	The narrowest stage in the artillery chain is also the least contested. That is the finding

WHAT THE SECOND DEMAND CURVE DOES TO THE ARGUMENT

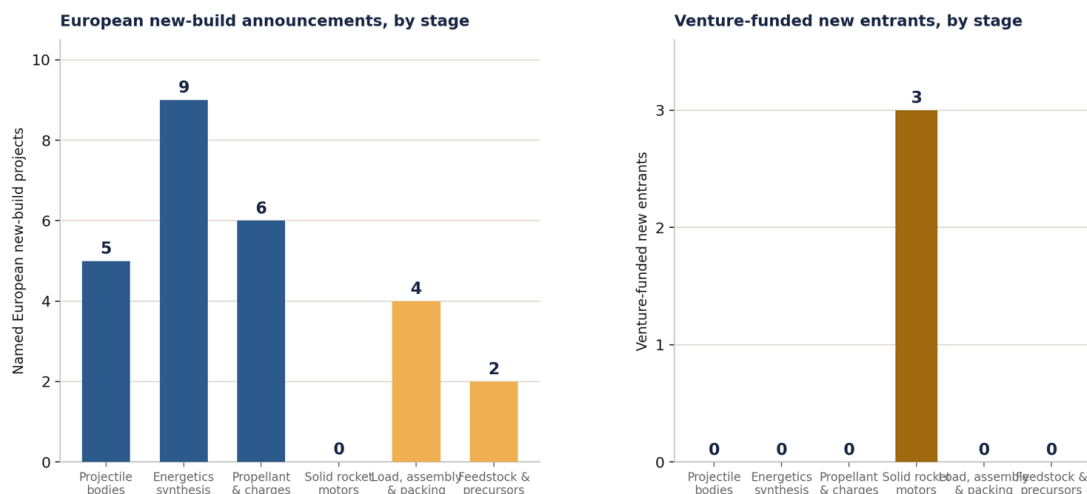
It strengthens it rather than weakening it. The missile surge tightens the premium nitramine grade, the licensed ground and the grant capital. It does not touch gun propellant, charge modules or the cotton chain, because rocket motors do not use gun propellant and combustible cases are an artillery product.

he stage this paper identifies as narrowest is also the stage with no competing bidder. Every other position in the chain now has a better-funded, longer-tenor customer standing next to it. The charge does not.

For a government customer the read is different and less comfortable. A ministry that treats energetics as one budget line will find that interceptor money and artillery money come from the same envelope and the same permitting queue, and that the interceptor case is easier to make in public. The charge loses that argument every time it is held.

4.3 Confirming it from the other direction: where the money is going

Figure 5. Everyone is entering the same three lanes



DERIVED, counted from the named projects in the standing scan record for the period 1 July to 29 August 2026; a count of announcements, not of tonnes or of capital, and one large project outweighs three small ones. The right-hand panel is the sharper finding: every venture-funded new entrant identified in the window — Ursa Major, Mach Industries, X-Bow — is in propulsion. No fund-level private capital entered munitions or energetics at all in the window, no award in the \$191m DPA Title III tranche targets gun propellant, and the UK's twenty-two energetics feasibility studies name no loading, assembly and packing facility anywhere in the programme.

The capital flow tells the same story independently. Across July and August 2026, named European new-build clustered in explosives synthesis, shell bodies and rocket propulsion – every venture-funded new entrant identified was in motors, three companies, all in the same lane^{67, 68, 69}. No investment fund entered munitions or energetics at all in the period, and no award in the \$191m American industrial-base tranche went to gun propellant⁶⁶. The European Union's own allocation is the clearest statement of where the constraint was judged to be: of the €500m ammunition package, roughly three-quarters went to powder and explosives rather than to plants. And the United Kingdom's own programme – twenty-two feasibility studies at up to £300,000 each, engineering design contracts of up to £5m, at least six factories with construction targeted from the end of 2026 – names nine materials and no charge or filling line^{9, 10}.

Figure 5. Where the new money is going.

4.4 Who the opportunity belongs to

Conversion capacity is being built hardest in North America. Kansas Army Ammunition Plant opened a new 155mm line in April 2026 rated at 12,000 projectiles a month⁵¹; Canada committed up to C\$642m to a projectile filling facility and a further C\$57.9m to the first charge filling plant ever built in the country⁵⁰; the Iowa complex is under construction on a \$632m contract for 36,000 rounds a month from 2029⁵²; and a Korean group had committed roughly \$1.3bn to a modular charge plant in the United States, then at site selection (announced in September 2026 as a \$2.2bn campus at Pine Bluff Arsenal)^{E7186}. That last one is the significant entry: the United States accepting a foreign builder for its charge supply is an admission of which stage it thinks is short.

Europe's position is different in kind, and Britain's is different again. Continental Europe has the sites and is adding to them. Britain has one, and no charge line at all¹⁹⁷. The gap is not global and it is not

really European. It is British, and it is at the charge end more than the filling end - which is a narrower and better-defended position than the one this paper set out with, and an investment case claiming a Europe-wide filling vacuum will be corrected by the first person who counts the sites.

And building a plant is not the same as having one - but the cautionary tale is about metal parts, not filling, and the distinction matters. The \$469m contractor-operated plant in Texas has been widely cited as a filling failure⁶⁴. It was not. It produced projectile *bodies*, and the American inspector general's finding is that projectile metal part production is the limiting factor on the whole ramp, with output at about 36,000 a month in March 2026 against a 100,000 goal¹⁸². The root cause was process capability in flow-forming: the equipment had never produced the current shell in its specified steel, the process was adapted from older practice, the flow-forming cracked the steel, and the Army had not required the full process to be demonstrated end to end before award¹⁸³. Two of three lines have been halted since August 2025. The lesson is not that filling is dangerous. It is that transferring an unvalidated process onto a new steel specification at rate is dangerous, and the same vendor's lines are proceeding elsewhere on specifications they were qualified against. The US Army now writes its requirements to demand a line already active, qualified and operating rather than paying to create one⁶⁵ - which is the same conclusion from the customer's side.

4.5 Process technology is the only lever that works inside the window

A new licensed explosives site takes years - permits, safety distances, blast-protected structures, magazines, laboratories, a trained workforce. Throughput per licensed square metre does not. That is why process technology, normally an engineering footnote, is the decisive item here: it is the only way to add capacity on a timescale shorter than the threat window.

PROCESS	WHAT IT IS, AND WHERE IT IS RUNNING	WHAT IT CHANGES
Resonant acoustic mixing	Mixing by vibrating the whole vessel at resonance instead of stirring it, so nothing mechanical touches the explosive. In production at McAlester in Oklahoma on a 55-gallon-class machine serving a new loading facility, installed 2024 ^{34, 35} ; in production at a US Navy site on a smaller unit that replaced conventional mixing, with about \$1m of annual saving on one line and a two-and-a-half-year payback ³⁸ ; at pilot scale in the UK at Glascoed, where BAE claims roughly a twenty per cent increase in explosive power and states production scale-up as the intent ³⁶ ; and at Cranfield, where it was used to demonstrate the composite gun propellant described in Section 2 ^{37, 91}	A documented ladder from bench scale through about 36 kilogrammes to about 400 kilogrammes a batch, adopted across three US services. The vendor's claims of six to ten times the capacity are marketing ³⁴ ; the installed base is not, and the British rungs of the ladder are domestic
Screw extrusion filling	Forcing solid explosive into the shell under pressure rather than pouring it molten. A mature, vendor-supplied European product line: one Czech producer has run a single-spindle line since August 2023 on 76mm to 155mm, rated 56,000 to 150,000 pieces a year depending on calibre ³² , and the same Slovak vendor supplies two further sites ³³	It avoids the voids and cavities that dog casting, and is faster and less energy-hungry. It is also the countable unit for anyone modelling central European filling capacity - one machine is one unit of capacity, and a second machine at a site is a visible signal
Press filling	Compacting explosive into the shell rather than pouring or curing it. The route the American guided round adopted after a cast-cured candidate failed a firing-shock test, and the one that ranks most resistant to setback in published test work ⁸⁹	For high-acceleration natures this is the safer engineering answer, not the budget one. It also suits a smaller plant, because it buys in qualified explosive rather than synthesising it
Continuous flow synthesis	Making explosive in a continuous stream rather than in batches, in equipment small enough to distribute. Demonstrated at pilot scale in the UK in 2025, with no industrialisation milestone since ⁴²	Would allow many small production nodes instead of one large plant - which is also the right answer to the siting and targeting problem at 4.7

WHO CAN DO THIS WORK

The capability is narrower than the number of companies in the sector suggests, and the steps are held by different people. Anyone building a proposition needs to know which step a counterparty holds, because the names blur in company literature.

STEP	WHO HOLDS IT IN THE WEST	NOTE
Nitramine synthesis	Three at scale: BAE Systems at Holston in Tennessee, the largest anywhere ¹⁴³ ; Eurenco at Sorgues in France; Chemring Nobel at Sætre in Norway, Europe's largest producer of the harder nitramine and expanding on government co-funding ¹⁴¹ . Beyond them, Turkey's state producer at about 200 tonnes a year ¹⁴⁶ , plus Korea, Australia and India	The Norwegian government's own position is that continental Europe has two major producers. Holston is government-owned with output allocated by the US Army, so it is not a merchant source
Formulation and fill	Formulation: Eurenco, Chemring Nobel, Nitro-Chem, BAE at Holston, Northrop Grumman, Hanwha, and Fraunhofer ICT at pilot scale ¹⁴⁴ . Fill: forty-two European sites, from Rheinmetall at Unterlüß and in Spain through Nammo, KNDS, BAE at Glascoed, Nitro-Chem, STV, Mesko, ZVS and Hellenic Defence Systems ¹⁹⁷	Formulation is the step a specialist can hold without holding synthesis. Fill is the longest list in the chain and - on the arithmetic at 4.1 - not the constrained one
Charge and propellant	Nitrochemie at Aschau and Wimmis, Eurenco at Bergerac and Karlskoga, BAE at Radford, Nammo in Finland and Norway, Roxel, and the American solid-motor houses	All of it conventional nitrocellulose chemistry, and the shortest list against requirement. This is the row the paper turns on
Merchant supply of qualified explosive	Chemring Nobel is the clearest - it sells to third parties on long-term agreements including a fifteen-year supply agreement with an American prime carrying guaranteed quantities and lead times ¹⁴² . Eurenco sells from a published catalogue; Nitro-Chem sells nitramine-based compositions; Indian and Korean producers sell for export	The commercially decisive row. Almost everyone else in the chain is a net buyer of nitramine, not a seller
Research capability with real facilities	Cranfield's Centre for Defence Chemistry holds a manufacturing and storage licence, accredited hazard testing, an explosives range and the acoustic mixing equipment used to demonstrate the composite propellant at 2.2 ^{37, 91, 92} . Fraunhofer ICT runs synthesis and processing to pilot scale ^{144, 180} ; the US Navy's energetics centre spans research to limited production, and Purdue runs a funded programme on continuous-flow manufacture and acoustic mixing ¹⁴⁵	A university with a licence and a mixer is a qualification partner, not a supplier - but it is the cheapest route to a demonstrated process, and Britain's is on the charge side

A point follows from the merchant row. A filling operation does not need to synthesise anything. It needs qualified explosive delivered, a licensed site, a process and an approval. The step that is genuinely scarce - synthesis - is also the step a small operator has least business attempting, and the step that is available to buy. That is what makes the filling position reachable.

The technology-selection evidence cuts both ways. The Czechoslovak Group runs solid screw extrusion on its European lines and chose conventional melt loading for its largest new North American complex^{32, 52}. That is a company with direct experience of both picking the conventional route for its biggest investment. The reading is not that the newer process is wrong. It is that at very large scale, with a qualified product and a committed customer, proven throughput beats process novelty. The innovative route suits an operator whose advantage must come from something other than scale - which is the position of every small entrant in this market.

4.6 The charge module casing: innovation arriving from a stage nobody watches

The clearest current illustration of where innovation comes from is not an explosive or a projectile. It is a wrapper. A modular charge is propellant inside a combustible case that burns away with it and leaves the barrel clear. It is a nitrocellulose-based consumable that almost no capacity model tracks, and it sits on the critical path of the six-module high-zone charge that the extended ranges in Section 1 depend on.

In July 2026 VEGA, a Polish manufacturer with close to thirty years in nitrocellulose products and no published large-calibre record, announced next-generation combustible cases for NATO modular charges, developed with the Polish military armament institute^{40, 41}. The published specification is an operating band of -50 °C to +70 °C, more than ten years of storage without loss of properties, smokeless combustion leaving minimal residue in the barrel, high resistance to mechanical damage, and a positive energy contribution to the charge. Commercial entry is stated for 2027. All of it is company-stated ahead of first public showing, and is marked **medium confidence**.

Two things make it worth more than a line. The claimed temperature band is wider than the -46 °C to +63 °C band to which the incumbent modular charge system is qualified^{4, 5}, which is either a component-level claim set against a system-level qualification or a genuine advantage; on the evidence available the first is more likely, and it should be established before the claim is relied on commercially. And the scale of the adjacent requirement is large: Rheinmetall's Aschau expansion alone will produce more than five million combustible components and over a million charge modules a year at full rate in 2028³. A consumable made in millions, qualified to a defined environmental band, on the critical path of the highest-value charge configuration, supplied today by very few firms.

THE GENERAL POINT

Innovation in this chain does not appear where the capital does. It appears at whichever component is simple enough for a small firm to own end to end, and consequential enough that the system does not work without it. A nitrocellulose converter in Poland is not where anyone modelling European artillery capacity was looking for the next constraint on realised range.

The same logic points at where else to look. Base-bleed units, which bolt on as interchangeable modules and therefore behave as a separately scarce category - one US supplier is contracted to move from about 336 tonnes a year to 1,400, with nothing produced before summer 2027^{80, 81}, against a US Army sources-sought of April 2023 asking industry^{E6} for 10,000 base-bleed grains and 2,500 rocket-motor grains a month qualified inside twenty-four months¹⁸⁸. Publishing a requirement at that volume is an admission the incumbent base cannot meet the extended-range mix. Fuze-train pyrotechnic components, where a single agreement above €100m has locked much of the available Czech capacity⁷¹. And the primers and igniters that no capacity model tracks at all - a filled shell with no qualified fuze train is not a round.

4.7 Siting, permitting and the back end

A single large flagship site now inherits a targeting narrative that did not exist two years ago, with six incidents at European defence-industrial sites on the 2026 record across five countries, arrests in three and no government attribution. Sustained strikes on Russian chemical rather than ordnance plants have measurably cut that country's precursor output. Dispersal and hardening belong in the engineering case from the start, and insurance and physical-security loading should be expected in every European energetics quotation - which is a further argument for the distributed-node model at 4.4 rather than one large plant.

Permitting is moving the other way and partly offsets it. The European Union's defence readiness simplification package sets a 102-working-day permitting ceiling with tacit approval for defence-readiness projects, against national explosives permitting that has historically run to years, and carries exemptions in chemicals legislation for defence-readiness purposes⁷⁰. British sites sit outside the instrument, though the European benchmark will be cited in British policy argument. And the back end is emptier than the front: disposal capacity gates stockpile turnover and the return of energetic material into supply, a German prime bought a disposal business in July 2026, and an American plant broke ground on a \$74m remotely operated demolition facility^{72, 73}. A prime buying disposal capacity is a signal that the whole lifecycle is being industrialised.

05 Approval, standards and the political case

Everything above assumes a small firm can get an approved product in front of a customer. That assumption is the weakest link in the chain, and it is not a technical problem. Having to prove the same round separately in every country is the main non-tariff barrier keeping small suppliers out of multi-country business, and it costs more than the innovation it gates. What is new is that policy has started to dismantle it.

5.1 What the threat assessments are driving

Between February 2025 and February 2026 every northern European intelligence service converged on the same shape of threat, and it is not an imminent invasion. It is a reconstitution race whose warning time collapses the moment the fighting in Ukraine subsides. Denmark put numbers on it first – a local war against a neighbour possible within about six months of a reduction in intensity, a threat to a Baltic member within about two years, a large-scale European war within about five – and by December 2025 had compressed its own reconstitution estimate from a decade to one to two years^{149, 150}. Germany plans against 2029; Estonia records Russian artillery ammunition output up more than seventeenfold since 2021¹⁵¹.

The operative variable in all of them is whether NATO rearms faster than Russia reconstitutes, and ammunition is where that race is most legible. Britain's defence committee recorded the Army running out of munitions eight days into a ten-day wargame¹⁵²; NATO has quantified \$145bn of shared munitions and air-defence requirements¹⁵³; the European Parliament's research service puts European production at half the necessary capacity with much of the base already committed¹⁵⁴. That is converting into buying in three modes: aggregated frameworks that turn sovereign demand into a bankable order book – €1.1bn of multinational 155mm contracts through NATO's support agency, an €8.5bn German framework with Dutch, Estonian and Danish access, an ammunition budget line guaranteed to 2037^{155, 156}; sovereign capacity building¹⁶⁰; and buying from outside the incumbent base to fill the gap now, which is the mode that matters to a new supplier.

THE THIRD MODE IS THE OPENING

Sweden bought propelling charges for its own gun from a Korean supplier, in a three-year framework, explicitly because European production capacity had been consumed¹⁵⁷. That is a NATO state qualifying a non-traditional supplier on an in-service weapon because the incumbents were full - and paying the qualification cost to do it.

The Nordic four went further and attacked the qualification barrier directly. In March 2025 they signed a technical arrangement harmonising ammunition certification with mutual recognition, so that a round certified once can be procured by all of them¹⁵⁸. That is the same reform the European Defence Agency is attempting at twenty-seven, delivered at four by states with the shortest warning times. Governments under compressed timelines treat qualification as a bottleneck to be engineered away rather than a gate to be defended.

And the legal scaffolding for mobilisation has arrived. The European defence industry programme, in force since 30 December 2025, creates Europe's first mechanism resembling American priority ratings - compulsory prioritisation for crisis-relevant components and materials, request-based for finished defence articles - alongside funding for manufacturing capacity held in reserve and a dedicated fund to pull smaller firms into defence supply chains¹⁵⁹. Reserve capacity is capacity somebody must own and operate.

The states signalling hardest are the ones with the least warning time, and they are lowering the barriers. Estonia is openly recruiting foreign producers into its defence industrial park and advertising low entry barriers¹⁶¹; the Nordic four have signed a partnership covering ammunition supply in peacetime, crisis and conflict¹⁶². A supplier offering complete NATO-standard rounds or critical components at short lead time, willing to sell through an aggregator and to localise final assembly where sovereignty rules require it, is selling into an openly stated shortage.

5.2 The barrier is being lowered, and the timing is the only open question

The European Defence Agency's joint ammunition qualification programme is confirmed on primary source: €50m from the European defence industry programme, coordinated by the agency, all twenty-seven member states taking part, 155mm artillery ammunition first, with the stated objective that ammunition tested in one member state need not be retested in the others⁴³. If it lands as written, an approved round sells across the bloc on one test campaign, and the addressable market in any bid model goes from one country to twenty-seven on the same fixed cost.

Its timeline and legal mechanism have not been published, and that is the open question rather than the money. Mutual recognition requires national safety authorities to accept another authority's evidence into their own safety case, which is a harder negotiation than a budget line - though Britain's own code already permits it and the Nordic four have already done it^{158, 171}. Assessed as a **realistic possibility** that a published mechanism exists within twelve months, at **low confidence**; the confirming event is public and unmistakable, being the first round accepted across a border on a single national qualification. Meanwhile the cost of proof is being demonstrated at the top of the market: Northrop Grumman took nine-figure adverse programme adjustments in a single quarter attributed to

development and qualification, moving a divisional margin by about five percentage points at a company carrying a \$104.7bn order book⁷. If qualification can move the margin of a company that size, an entrant without an order book cannot carry it alone.

5.3 A war-footing qualification programme, and what it would consist of

The evidence at 2.4 says the delay is administrative, which makes it a policy choice, and policy choices can be made differently. What follows is not a proposal to lower a standard. Every measure below is either already written into NATO or British doctrine and simply not used, or already funded and not yet delivered. A government that adopted the set would take a fill or charge change from three to five years to somewhere between twelve and eighteen months, which is roughly what the American programme achieved in peacetime with one customer and no urgency.

MEASURE	WHAT IT MEANS IN PRACTICE	WHY IT WORKS, AND WHO HAS DONE IT
Run the tracks in parallel and say so in the contract	Sensitivity, thermal, mechanical and performance characterisation, the accelerated ageing programme and the full-scale firing campaign let as concurrent workstreams from day one rather than as sequential contract phases	This is already permitted: NATO doctrine allows partial ageing results with completion before service approval, and the American insensitive-fill programme ran its four test categories concurrently across four laboratories ^{170, 175} . Most of the delay is contracting practice, not science
Qualify the material separately from the munition, and start it earlier	Material qualification and munition type qualification treated as two overlapping programmes rather than one serial one, with the material entered into the process before the platform decision is taken	The two-phase architecture already exists in AOP-7 and in the British code. Overlapping them removes a full contract cycle. Britain's own code sets no timeline and expressly contemplates a store entering use before its explosive is fully qualified ^{170, 171}
Prove by read-across, modelling and component test before spending full-scale rounds	Use the evidence hierarchy that already exists rather than defaulting to full-scale trials for everything	NATO's insensitive-munitions standard lists read-across from similar designs, modelling and analysis, and component-level testing as acceptable evidence, with full-scale test as the fallback rather than the default ¹⁷² . For a fill change inside a known chemistry family the reference dataset already exists
Accept another nation's qualification instead of repeating it	Formal reliance on a NATO partner's material qualification, and mutual recognition of test results between allies	Already lawful in Britain: the code permits reconsidering the extent of testing where a material has been qualified by another national authority to the NATO standard, and endorses joint qualification to prevent duplication ¹⁷¹ . The Nordic four signed a mutual-recognition arrangement in March 2025 ¹⁵⁸ ; the European Defence Agency is funding the same thing at twenty-seven, starting with 155mm ²⁰¹
Provisional release under restricted conditions	A conditional in-service release with constrained storage, transport or climatic limits while the remaining evidence is completed, rather than waiting for the full package	The British urgent-requirement route has done this at scale under operational pressure - two-thirds of 312 requirements delivered on time and 96 per cent of deployed items rated effective or better ¹⁷⁷ . The American system retains a case-by-case release of unqualified explosives after safety board review
Manage life by surveillance instead of proving it in advance	Field on the bounded stability and accelerated ageing evidence, then extend and manage service life on stockpile surveillance and instrumented data	This is how the US missile stockpile is already run: average missile shelf life extended from 7.9 to 22.6 years on surveillance evidence ¹⁷³ . NATO's own safety centre argues the assumed environments are harsher than reality and that the conservatism destroys usable stock ¹⁷⁴

MEASURE	WHAT IT MEANS IN PRACTICE	WHY IT WORKS, AND WHO HAS DONE IT
Treat test capacity as a national asset and schedule it	Accredited test-house slots, instrumented range time and safety-authority review capacity published as a schedule an applicant can plan against, with reserved allocation for qualification of national priority materials	Range time is the hardest input for a small firm to buy and a fixed national asset idle much of the year. The European Union has already identified testing and certification capacity as one of five ammunition chokepoints worth funding. Allocating it costs almost nothing
Attach an order to a successful qualification	A minimum committed quantity contingent on passing, stated up front, rather than a grant with nothing behind it	The gating risks for a new entrant are approval and offtake, not demand. A grant addresses neither. A small guaranteed order addresses both, because a bank will lend against it

The limits of this argument are worth stating so that a safety authority can engage with it. Insensitive properties can themselves degrade with age, so surveillance-led release moves the ageing burden into service rather than removing it - which is exactly why the instrumentation in the sixth row is the enabling condition and not an optional extra. Read-across works best for a material close to a known chemistry family; a genuinely novel molecule still needs the full campaign. And acceptance standards can be dropped too far: the surplus market that supplied Ukraine at speed also generated documented quality complaints. None of those is an argument for a five-year default. They are the reasons the programme must be designed rather than merely accelerated.

The United Kingdom's own programme states the funding position explicitly, and it is worth quoting because it is government writing the case for private risk capital into its own guidance: ministry investment will "typically form part, but not all, of the funding required", with internal investment and external venture capital expected to make up the majority⁹. That is an unusually clear statement of intent, and an acknowledgement that the programme depends on capital it is not providing. The four measures above are the practical way the state can make that capital viable.

5.4 **The move from primes to small firms is real, measurable, and smaller than the rhetoric**

The fast-contracting argument is usually made in theory. Ukraine has been running it for three years and publishes the numbers. Brave1 has issued close to a thousand grants totalling UAH 5.8bn, scaled by technology maturity, with breakthrough competitions above UAH 100m per project through the end of 2026 - and six Ukrainian companies received UAH 944m specifically to expand domestic explosives production, of which the government co-financed UAH 620m⁴⁵. A government putting grant money directly into nitramine capacity at small-company scale has no European equivalent. It is no longer only Ukrainian: BRAVETECH EU carries over €100m of joint European and Ukrainian funding across three routes, with field testing in Ukraine built into the award^{46, 47}.

Britain has now built the equivalent machinery, and the tense matters. A fair critic in late 2025 could say it existed on paper only: UK Defence Innovation launched in July 2025 with a ring-fenced £400m and, five months on, had issued no challenge calls. Through 2026 that changed - a Defence Office for Small Business Growth with thirty pathfinder firms in January; a small-business action plan in July setting direct departmental spend with small firms from £1.24bn in 2024/25 to £2bn in 2027/28 with

rapid contracting up to £50m; ten thousand drones fielded in six months on annual rather than multi-year cycles; and an artificial-intelligence defence partnership with Ukraine in August giving Britain access to battlefield data with three British small firms in pilot roles^{166, 190, 191, 192}.

The proportion is the part that gets overstated. £1.24bn of direct small-firm spend sits against a procurement budget above £28bn, and about three-quarters of the department's total small-firm spend still reaches those firms through prime supply chains rather than directly¹⁹⁰. Decentralisation is a real, now target-bound direction of travel. It is not an accomplished fact, and an entrant planning on the assumption that the primes have stepped back will be wrong for several more years. What has changed is that the state now publishes numbers it can be held to.

5.5 Why funding small-firm risk pays, and what government will do

The return argument is a comparison rather than an assertion. Against a prime's own plant programme the sums that would transform a small operator's position are rounding errors: the entire \$191m American industrial-base tranche is small against one company's multi-billion plant spending⁶⁶, and the €165m first European energetic components call drew eighty-three proposals from twenty-four countries, implying a rejection rate above eighty per cent⁴⁴. That leaves roughly seventy unsuccessful applicants, each with a developed plan and an identified site and no grant - the best-defined partnering pool in the European market, and it exists because demand for second-wave capacity is measurably greater than the public money available.

What government will prioritise is the harder question, and the answer is not what an entrant would prefer. The current climate rewards visible sovereign capability with a national flag on it - a named factory, a ribbon, a materials list, a jobs number. That is why the British programme names nine materials and six factories and names neither a charge line nor a filling line: making a molecule reads as sovereignty, converting it into a round reads as logistics. The United States has been slower still on structure - the office created by its 2024 defence act to run a national energetics strategy was only stood up in early 2026, and it publishes no named priority-materials list at all¹²⁸. It is also why the venture capital in this market has gone to rocket motors, where the story is a company rather than a process step.

RQ5 - WHAT WOULD MUST CHANGE

The mismatch is the opportunity. Government is funding the stages that photograph well and leaving the stages the chain converts through to private capital - while stating in its own guidance that it expects private capital to carry the majority⁹. An entrant positioned on the unglamorous stages is not competing with the state's money. It is completing the state's programme, which is a materially better position than competing for the same grant as seventy other applicants.

The war-footing measures at 5.3 are what would make that work, and none is a subsidy. Parallel test tracks, read-across, mutual recognition, provisional release, surveillance-led life management, scheduled national test capacity, and a small committed order behind a successful qualification. Each cuts the cost of proof rather than the standard of proof - the only form of support a safety authority can accept and the only form an investor can bank.

06 The case against

Three arguments against this paper's central claims, put as strongly as they deserve. For each: what would must be true, what would show first, and why we do not currently hold it.

AGAINST THE RANGE CEILING - IT IS A FAILURE OF IMAGINATION, NOT A REAL LIMIT

The case. The sensor argument is a snapshot. Reconnaissance reach has quadrupled in four years and there is no reason to think it has stopped; deep-strike drones already reach past a hundred kilometres and return targeting data to the fires chain. No army buying a 150-kilometre round intends to find the target with its own quadcopter. And a new entrant offering a ramjet round at a claimed quarter of a guided round's cost is attacking the economic objection directly¹¹⁷.

Why we do not hold it. The published evidence on the deep zone runs the other way - dispersal has emptied it of mobile targets, and the one hard figure on contested navigation is a range penalty of about a third applied exactly where the round would be used. But the cost trajectory is the half of this argument that could move, and it is cheap to watch.

AGAINST THE COMPOSITE CHARGE OPENING - TWENTY YEARS OF RESEARCH WITHOUT A PROGRAMME IS A VERDICT, NOT A GAP

The case. Indian, German, Chinese and Polish laboratories have published on nitramine-in-polymer gun propellant since the 1990s. Not one army has qualified an energetic-binder charge in any calibre. That is not an oversight; it is repeated expert judgement that the ignition behaviour, the ageing burden, the manufacturing route and the erosion risk are not worth the gain - particularly when the conventional charge already meets the insensitive standard and already reaches beyond forty kilometres.

Why we do not hold it. The Swedish producer reported six higher-energy low-vulnerability variants in 2024, at twenty per cent more pressure output than the one it already has in production, made by a route it presents as scalable⁹⁴. That is movement from a manufacturer rather than a laboratory. And Cranfield's demonstration of the same class of propellant made by acoustic mixing removes one of the four objections - the manufacturing route - for an operator that already holds the mixing capability⁹¹. This is the strongest counter-case in the paper and the one to keep testing.

AGAINST THE FILLING OPPORTUNITY - THE STAGE IS EMPTY BECAUSE IT IS A BAD BUSINESS

The case. Filling carries the full weight of explosives permitting, safety distances, licensed storage and liability, on thinner margins than synthesis and with the customer concentration of a prime's subcontractor. The primes are keeping conversion in-house - Rheinmetall is co-locating powder, combustible components and charge assembly on one site³. And on the count at 4.1, Europe already has forty-two filling sites: the stage is not empty, so an entrant is joining a crowd rather than filling a vacuum¹⁹⁷.

Why we do not hold it. The count is right and the conclusion drawn from it is wrong. Forty-two sites do not mean forty-two available lines: what is scarce is qualified, *running* conversion capacity against a specification, which is why three states placed reserve and next-generation orders outside their own national primes in this window⁷⁶, and why the US Army now requires a line already active and qualified rather than paying to create one⁶⁵. Britain, separately, holds one of the forty-two and no charge line at all. And the Texas plant is regularly produced as evidence against filling; it is not, because it made bodies and failed on flow-forming process capability against a steel specification^{182, 183}. This is the strongest of the three counter-cases, and it is the reason the position at 8.1 is stated as a British one rather than a European one.

07 What to watch

Sixteen public, observable indicators tied to this paper's judgements. They sit alongside the twenty-one standing indicators of the monthly programme rather than replacing them.

#	INDICATOR	WHAT IT TESTS
1	Any country setting a dated compliance deadline for insensitive munitions, or extending a mandate to stock already in service	KJ-D - the single event that breaks the crossover model
2	The first round accepted across an EU border on one national qualification, and publication of the joint qualification programme's legal mechanism	KJ-F, Section 5 - the addressable market in every bid model
3	A European tender specifying a composite or low-vulnerability charge, or a producer announcing a line that is not nitrate-ester	KJ-C, KJ-E - the composite charge opening
4	A published industrialisation milestone on the British continuous-flow propellant route, now sixteen months silent	KJ-E - the alternative escape from the cotton dependency
5	Any European announcement whose scope includes gun propellant or charge module assembly rather than fill or bodies	KJ-C, KJ-F - the stage that binds
6	Rheinmetall's weapons and ammunition capital expenditure line at the next two half-year reports	KJ-A - two more flat prints and the judgement is settled
7	The British engineering design awards: whether any names a filling facility, and whether the nine-material list changes	KJ-F - programme structure
8	A third qualified Western source of aerospace-grade polymer binder	KJ-E - the structural half of the binder exposure
9	The Polish combustible-case entrant's 2027 commercial entry, and whether its temperature claim is component-level or system-level	Section 4.6 - the components thesis
10	Any new acoustic mixing or screw extrusion installation at production scale in Europe	Section 4.5 - process technology as a capacity lever
11	A guided or ramjet round priced below about \$30,000 at volume with the payload included	KJ-B - the cost half of the range argument
12	Glascoed's new filling facility opening, and its throughput figure when it does	KJ-F - Britain's only 155mm filling site
13	Any national or NATO adoption of parallel-track, read-across or provisional-release qualification for a 155mm fill or charge, and the first cross-border acceptance under the European qualification programme	Section 5.3 - whether the war-footing argument is being acted on
14	A European instrumented-stockpile or condition-based surveillance contract at artillery scale	Section 1.5 - life extension as unclaimed capacity
15	Any new European nitramine supply agreement, its customer and above all its tenor	Section 4.2 - whether the premium grade keeps going to warhead programmes

#	INDICATOR	WHAT IT TESTS
16	A European energetics permitting or land decision that visibly favours an interceptor programme over an artillery one	Section 4.2 - the binding overlap is licensed ground, not tonnage

08 In summary

Six findings.

One. The tonnage programme is necessary and not sufficient. Announced European capacity does not fill a conservative thirty-million-round floor before 2030, and the companies best able to close it are holding capital spending flat while their order books grow^{2, 8}. Nothing here argues for building less; it argues that more of the same does not move the ceiling. High confidence.

Two. The stage that binds is the charge. Announced European gun propellant supports a quarter to two-fifths of the floor and assembled charge modules about a tenth, against forty-two European sites able to fill a shell and 2.24 million rounds a year of published filling capacity¹⁹⁷. A filling line with no propellant is a warehouse with a licence. High confidence on the ranking, moderate on the absolute figures, which rest on the conversion factors at Annex G.

Three. The charge is also where the sovereignty problem sits, which makes the capacity case and the strategic case one case. European propellant runs on nitrocellulose, nitrocellulose runs on cotton linters, China supplies the large majority and has already restricted exports⁶⁰, and every euro of announced European charge investment reproduces that chemistry. A nitramine-in-polymer route swaps it for a concentration a European government can act on. Moderate confidence, and the strongest strategic case in the paper.

Four. Britain is moving on this, though it has not said so. No sovereign propellant chemistry since 2002, seventy-two 52-calibre guns on order, an energetics programme funding twenty-two firms against thirteen sites, and a prime stating it can make propellant without nitrocellulose^{9, 10, 42, 181}. Read as inference: supply sovereignty first, ballistics second. High confidence that the driver is real; low confidence that a qualified 155mm composite modular charge is near service.

Five. The qualification timetable is administrative rather than physical, and shortening it is the cheapest capacity in Europe. The NATO stability standard certifies ten years of storage from about five weeks of measurement, the accelerated ageing programme is bounded at six to eight months and may run in parallel with type qualification, and Britain's own code sets no timeline at all^{168, 169, 170, 171}. The three-to-five-year figure describes queuing and duplicated national assessment. The measures at 5.3 bring a fill or charge change inside twelve to eighteen months without lowering a standard. Moderate-to-high confidence, on primary doctrine.

Six. Innovation is arriving from components nobody counts. A Polish nitrocellulose converter entering combustible cases; a French producer qualifying a modular charge in under eighteen months using additive manufacture of energetic material; wire-deposition of naval projectile bodies with the driving band laid in during the build; and condition-based surveillance, where the US Army's missile-system surveillance programme has taken average missile shelf life from 7.9 to 22.6 years on evidence alone, a result by analogy for artillery^{E5173, 184, 185}. A ten per cent life extension across a ten-million-round European stockpile is a million rounds nobody must build. Moderate confidence, mixed sourcing, itemised at 1.5.

THE ONE SENTENCE

The question that decides this market is not who can make an explosive. It is who owns the charge.

