UNCLASSIFIED

WHITE PAPER

Sustaining the Digital Thread:

Feedstock Supply Chain Challenges for Forward-Deployed Additive Manufacturing Capabilities

April 2026

Defense Logistics | Sustainment Policy | Advanced Manufacturing

UNCLASSIFIED

EXECUTIVE SUMMARY

Additive manufacturing (AM) has transitioned from an experimental capability to an operationally fielded technology across all U.S. military services. The Department of Defense committed approximately $797 million to AM in fiscal year 2024, reflecting a 166 percent year-over-year increase, and the FY2026 National Defense Authorization Act formally codified AM as critical defense infrastructure. Against this backdrop, the feedstock supply chain that sustains forward-deployed AM capabilities has emerged as a strategic vulnerability with direct implications for force readiness.

This white paper analyzes the principal challenges associated with procuring, transporting, storing, and managing AM feedstocks at and near the point of need. It draws on GAO reports, DoD and DLA policy documents, the 2021 DoD OIG cybersecurity audit (DODIG-2021-098), Army sustainment doctrine (FM 4-0, August 2024; ADP 4-0), DoDI 5000.93, open-source intelligence, and academic research to present an integrated analysis of the technical, logistical, regulatory, and security dimensions of this problem.

The analysis identifies seven primary challenge domains: (1) the physical and chemical degradation of feedstocks under deployed conditions; (2) weight, volume, and transport constraints; (3) the absence of standardized feedstock qualification and classification frameworks across services; (4) intellectual property and data rights restrictions that complicate material sourcing; (5) cybersecurity vulnerabilities in the digital thread connecting design repositories to forward printers; (6) foreign dependency risks in the feedstock industrial base, now explicitly addressed by NDAA FY2026 Section 849; and (7) workforce and training gaps that reduce organic capability at the tactical edge.

The paper concludes with a framework of recommendations organized across doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF-P) lines of effort, consistent with established joint capability development methodology.

TABLE OF CONTENTS

I. Background and Strategic Context 4
II. Feedstock Categories and Material Properties 6
III. Challenge Domain 1: Physical Degradation and Environmental Factors 7
IV. Challenge Domain 2: Transportation, Weight, and Footprint Constraints 8
V. Challenge Domain 3: Standardization and Qualification Gaps 9
VI. Challenge Domain 4: Intellectual Property and Data Rights 11
VII. Challenge Domain 5: Cybersecurity and the Digital Thread 12
VIII. Challenge Domain 6: Foreign Dependency and Industrial Base Risk 13
IX. Challenge Domain 7: Workforce and Training Deficits 14
X. DOTMLPF-P Recommendations 15
XI. Conclusion 17
References 18

I. BACKGROUND AND STRATEGIC CONTEXT

A. The Transition from Experimental to Operational

The U.S. military's adoption of additive manufacturing reflects a fundamental reconceptualization of forward logistics. Traditional supply chains were designed for scale and stability. They move physical goods across established routes from centralized depots to forward units, a model that performs adequately in permissive environments but becomes brittle in contested, degraded, or denied operational spaces. A single broken component on a ground vehicle or aircraft can ground a platform for weeks if the part must be sourced from a distant depot; in the Indo-Pacific theater or a high-end peer conflict, that delay translates directly into loss of combat power.

Additive manufacturing addresses this vulnerability by shifting the locus of production toward the point of need. Rather than shipping physical inventory forward, AM-enabled forces carry digital blueprints and raw material feedstocks, printing replacement components on demand. The Defense Logistics Agency has been developing shared technical standards and a unified data framework to allow AM-produced components to be certified, catalogued, and distributed across service branches. The Marine Corps has established Expeditionary Fabrication Facilities. The Army's R-FAB (Rapid Fabrication via Additive Manufacturing on the Battlefield) places 3D printing labs inside shipping containers for expeditionary deployment. The Navy's FLEETWERX initiative has demonstrated mobile nitrogen-powered metal printers and containerized AM pods capable of producing metal, ceramic, and composite parts in forward environments.

This shift is not merely technological. FM 4-0, Sustainment Operations (August 2024) explicitly acknowledges that investments in the production of repair parts at or near the point of need will help significantly reduce Army distribution requirements. The doctrine frames this as part of a broader imperative to reduce logistical footprints in multidomain contested environments where distribution nodes present high-value targets.

B. Scope and Definitions

For the purposes of this paper, 'feedstock' refers to the raw input materials processed by AM systems to produce end-use parts. These include polymer filaments (for fused deposition modeling and fused filament fabrication), metal powders (for laser powder bed fusion, directed energy deposition, and binder jetting), wire feedstock (for wire arc additive manufacturing), resins (for stereolithography and digital light processing), and specialty composites. 'Forward-deployed AM capability' encompasses systems fielded at echelons below theater sustainment command, including brigade support areas, expeditionary bases, and afloat platforms. 'Digital thread' refers to the integrated data linkage between design files, printer parameters, quality records, and part performance data.

C. Policy and Regulatory Framework

The governing policy landscape for DoD AM has grown substantially in recent years. DoDI 5000.93, Use of Additive Manufacturing in the DoD, provides the foundational instruction framework, directing military services to identify AM opportunities in acquisition and sustainment, establish quality assurance protocols, and develop digital repositories of validated designs. The 2021 Department of Defense Additive Manufacturing Strategy articulated five priority lines of effort: integrating AM across

the defense enterprise, boosting materiel readiness, securing the digital workflow, developing talent, and coordinating with allied nations.

The FY2026 NDAA (P.L. 119-60, signed December 18, 2025) represents the most significant legislative action to date. Section 849 prohibits the DoD from procuring AM machines manufactured in, networked through, or integrated with software originating from China, Russia, Iran, or North Korea. The prohibition takes effect one year after enactment. Additionally, the NDAA directs the qualification and approval of up to one million additively manufactured parts, a shift toward performance-based qualification and shared validation data across military branches. While these provisions address equipment provenance and qualification scale, they do not directly resolve the feedstock supply chain vulnerabilities that this paper examines.

D. The Feedstock Problem as a First-Order Logistics Challenge

Despite the maturation of AM hardware and digital workflow infrastructure, feedstock remains the essential physical input without which the entire capability fails. Unlike digital blueprints, feedstock cannot be transmitted over a network. It must be physically manufactured, transported, stored, and managed within established temperature, humidity, contamination, and shelf-life parameters. As shipboard AM research published in U.S. Naval Institute Proceedings has noted, feedstock materials range in price from approximately $30 to $700 per kilogram, and the annual costs for maintenance, spare parts, and feedstock resupply represent a significant and insufficiently planned financial commitment.

These considerations are compounded at the forward edge. Environmental extremes, constrained storage volume, contested resupply routes, and limited organic technical expertise create conditions under which the feedstock supply chain is among the most fragile elements of an otherwise promising capability.

II. FEEDSTOCK CATEGORIES AND MATERIAL PROPERTIES

Understanding the challenge domains requires a working knowledge of feedstock material categories and their inherent physical characteristics. The following table summarizes the primary feedstock types, their AM process associations, cost ranges, and key handling sensitivities relevant to forward deployment.

Feedstock Type	AM Process	Cost Range ($/kg)	Key Handling Sensitivity
Polymer Filament (PLA, ABS, PETG, PEEK)	FDM / FFF	$20 – $150	Moisture absorption, UV degradation, temperature cycling
Metal Powder (Ti-6Al-4V, Inconel 625, Stainless Steel)	LPBF, DED, Binder Jetting	$150 – $700+	Moisture, contamination, inert gas storage, fire/explosion risk
Photopolymer Resin	SLA, DLP	$50 – $300	UV exposure, temperature sensitivity, hazardous material handling
Wire Feedstock (Ti, Ni alloys, structural steel)	WAAM	$30 – $400	Surface oxidation, spool management, inert shielding gas
Composite Pellets / Carbon Fiber Reinforced Polymers	Large Format FFF	$40 – $250	Moisture, abrasive printer wear, fiber alignment requirements
Concrete / Geopolymer (field construction)	ACES / Contour Crafting	$5 – $30	Water ratio precision, ambient temperature, cure time management

Table 1. Feedstock categories, cost ranges, and handling sensitivities in forward-deployed AM contexts. Cost estimates derived from open-source procurement data and Naval Institute Proceedings research.

Metal powder feedstocks warrant particular attention. Fine reactive metal powders such as titanium alloys and nickel superalloys present combustion and inhalation hazards that require specialized handling, storage containers, inert gas environments (typically argon or nitrogen), and rigorously maintained cleanliness standards. These requirements are difficult to sustain in expeditionary conditions and largely absent from current forward logistics planning documents.

III. CHALLENGE DOMAIN 1: PHYSICAL DEGRADATION AND ENVIRONMENTAL FACTORS

A. Moisture and Contamination

The most pervasive feedstock challenge in forward environments is moisture absorption. Hygroscopic polymers, including nylons, PETG, PLA, and high-performance thermoplastics such as PEEK, absorb atmospheric moisture that causes voids, surface defects, and mechanical property degradation in printed parts. Under conditions common to tropical, maritime, and high-humidity theaters of operation, unopened feedstock spools can become compromised within days without active desiccant management. Metal powder feedstocks are similarly sensitive: moisture contamination promotes oxidation, alters powder flowability, and introduces inclusions that reduce the mechanical properties of printed metal parts.

ASTM International standards, specifically ASTM F2924 and ASTM F3049, provide guidance on metal powder characterization and storage, but these standards were written for controlled industrial environments and do not map cleanly onto forward-deployed operational realities. No equivalent forward logistics standard currently exists within Army or joint sustainment doctrine.

B. Temperature Extremes

Temperature cycling imposes severe stress on feedstock materials. Polymer filaments exposed to repeated heat and cold cycles develop brittleness and embrittlement that increases break rate during printing and degrades part mechanical properties. Photopolymer resins can separate, gel, or partially cure if exposed to temperature excursions above their storage thresholds. Metal powder containers that experience condensation cycles from temperature cycling can introduce moisture contamination even in sealed packaging.

Field exercises conducted by the Australian Army using SPEE3D's Expeditionary Manufacturing Units demonstrated that AM systems can operate in extreme heat and sub-zero temperatures. However, these demonstrations focused on printer operability, not feedstock integrity under the same conditions. Indian Army trials at high altitude (Project Prabal, approximately 11,000 feet in a high-altitude, low-oxygen environment) highlighted that both machines and feedstocks face compounded degradation from low oxygen partial pressure, UV exposure, and low humidity in ways that standard material data sheets do not address.

C. Shelf Life and Inventory Management

Feedstocks carry finite shelf lives that are reduced by the environmental factors described above. Polymer filaments carry manufacturer-specified shelf lives typically ranging from one to three years under controlled storage; in field conditions, that window compresses substantially. Metal powders recycled through multiple print cycles accumulate oxygen and nitrogen contamination that degrades part properties. Resin photopolymers begin photoinitiator degradation upon any UV exposure, including incidental exposure during field handling.

Neither the Army's Property Book nor the DLA supply system currently tracks feedstock lots with the shelf-life granularity necessary to ensure that deployed units are not attempting to print mission-critical

parts from compromised material. DLA's 2022 AM Implementation Plan acknowledges the need for systemic demand signal exchange between Military Services Commands (MILSVCs) and DLA, but the infrastructure for real-time feedstock condition monitoring and lot tracking at the forward echelon has not been established.

IV. CHALLENGE DOMAIN 2: TRANSPORTATION, WEIGHT, AND FOOTPRINT CONSTRAINTS

The promise of AM is that it replaces heavy physical parts inventories with lightweight digital files. In practice, this substitution is incomplete. Feedstock must still be transported forward, and the logistics calculus of feedstock supply is more complex than simple weight comparisons suggest.

A. Density and Packaging Inefficiencies

Metal powders are dense. Titanium alloy powder at a bulk density of approximately 2.5 grams per cubic centimeter and Inconel powder at approximately 4.5 grams per cubic centimeter occupy significant payload weight in airlift and ground transport. A forward-deployed laser powder bed fusion system capable of producing a meaningful range of structural components requires a minimum feedstock inventory measured in hundreds of kilograms, representing a nontrivial logistics burden. This reality led Naval Institute Proceedings researchers to conclude that fielding AM support ships analogous to Military Sealift Command's T-AOEs, with dedicated feedstock storage configured to minimize roll and pitch effects on powder dispersion, may be the only viable approach to sustained high-capability naval AM operations.

For polymer systems, the economics are more favorable. Polymer filament is lower-density, less sensitive to handling, and available in compact spool packaging. However, the parts spectrum addressable by polymer printing is substantially narrower, excluding structural metal components, high-temperature applications, and most load-bearing hardware.

B. Inert Gas and Support Infrastructure

Metal powder AM processes require inert gas environments (argon or nitrogen) for both printer operation and powder storage. Delivering bottled inert gas forward, maintaining cryogenic liquid nitrogen systems, or fielding nitrogen generation equipment adds logistics complexity, weight, and cost that is rarely incorporated into forward AM capability planning. The absence of an organic nitrogen supply solution has been cited by practitioners as a recurring barrier to fielding expeditionary metal AM at the company and battalion level.

C. The Logistics Tail Displacement Problem

A recurring finding in both GAO reviews and operational field trials is that AM does not eliminate the logistics tail; it displaces and transforms it. The 2015 GAO report (GAO-16-56) noted that the DoD lacked a systematic framework to track AM efforts department-wide, a finding that reflects a broader institutional tendency to focus on the capability of the printer while underestimating the sustainment requirements of the printer's inputs. When commanders invest in forward AM capability without a corresponding investment in feedstock resupply chains, the result is a printer that sits idle within weeks of deployment. FM 4-0 (2024) underscores this principle in its discussion of operational reach: advancements in production of repair parts at or near the point of need will only reduce distribution requirements if the production inputs are themselves reliably available.

V. CHALLENGE DOMAIN 3: STANDARDIZATION AND QUALIFICATION GAPS

A. Absence of Cross-Service Feedstock Standards

The DoD currently operates without a unified feedstock qualification standard applicable across services and echelons. The Army, Navy, Air Force, and Marine Corps have each developed organic AM programs with distinct material qualification procedures, testing protocols, and approved vendor lists. The result is a fragmented qualification landscape in which a material qualified for use by the Air Force on a C-17 legacy part may not carry reciprocal authorization for Army ground vehicle applications, even if the feedstock is nominally identical.

This fragmentation has direct operational consequences. When a forward unit requires a specific feedstock that is not in its approved vendor list, it cannot draw from another service's stockpile even if that stockpile is physically co-located. The DoD OIG's 2019 audit of AM implementation (DODIG-2020-003) identified areas for improvement in AM adoption and standardization across the DoD and cited the lack of a standardized DoD approach incorporating best business practices as a central deficiency. The Joint Additive Manufacturing Working Group, formalized in July 2017, was established specifically to reduce these barriers, but cross-service feedstock qualification harmonization remains incomplete.

B. Part Classification and Print Authorization

A related challenge is the classification of parts as printable or non-printable for forward operations. The AM community distinguishes broadly between non-critical or non-structural parts (cosmetic covers, handles, mounts, tools) and mission-critical structural or safety-of-flight components. The former can generally be printed forward with minimal qualification overhead; the latter require rigorous process control, material certification, and often depot-level approval chains that are incompatible with the timelines of forward operations.

DoDI 5000.93 directs the development of digital repositories for validated designs and qualified feedstock-process combinations. The Marine Corps uses the JTDI and Marine Maker websites for this purpose; the Army has its own repositories under development. However, these systems are service-specific, access is inconsistently available in degraded communications environments, and the authorization workflows have not been streamlined for tactical timelines. The AMUG Conference 2025 forward deployment panel heard from multiple practitioners that even at Technology Readiness Level 9, getting a solution into the hands of an operator can take years.

C. ASTM and Industry Standards Alignment

ASTM International's AM standards committee (Committee F42) has produced an extensive suite of material, process, and qualification standards. These include ASTM F3001 (titanium and titanium alloy powder), ASTM F2924 (Ti-6Al-4V by LPBF), ASTM F3049 (characterization of metal powders), and the broader ASTM/ISO 52900 additive manufacturing general principles framework. These standards provide a technical baseline but were developed primarily for industrial and aerospace manufacturing contexts.

Translating these standards to forward-deployed environments requires adaptation. Powder characterization equipment such as laser diffraction particle analyzers, rheometers, and scanning electron microscopes are not forward-deployable. The DoD has not yet published a companion standard that identifies minimum acceptable field-quality-assurance procedures for feedstock receipt inspection and in-use monitoring in austere environments. This gap leaves forward AM operators without authoritative guidance on whether their feedstock remains within specification.

VI. CHALLENGE DOMAIN 4: INTELLECTUAL PROPERTY AND DATA RIGHTS

The intellectual property (IP) and data rights structure governing defense weapon system parts constitutes one of the most legally complex barriers to forward AM feedstock utilization. Many of the parts most needed in forward environments, replacement components for legacy platforms, low-volume specialty hardware, and obsolete parts no longer in production, are precisely those for which original equipment manufacturers (OEMs) retain proprietary design data and process specifications that are not available to the government.

A. OEM Feedstock Restrictions

AM equipment manufacturers frequently restrict which feedstock materials may be used in their machines without voiding warranties or violating license agreements. This is particularly prevalent in metal powder bed fusion systems, where machine producers control approved material lists, calibration parameters, and process settings for qualified powders. Third-party feedstocks may be available at lower cost, but testing and parameter adjustment introduce qualification burden that cannot practically be sustained forward.

At the AUSA 2025 Annual Meeting, Lt. Gen. Christopher Mohan, acting commander of U.S. Army Materiel Command, raised the recurring issue of intellectual property held by lower-tier subcontractors, noting that the IP for many critical weapon system parts is buried within supplier tiers below the prime and is not available to the government at any price. This problem is not new, but it is increasingly acute as the digital thread required for AM depends on precise technical data packages that OEMs regard as core proprietary assets.

B. The Wartime Exception

Practitioners at the AMUG 2025 forward deployment panel acknowledged that in a conflict scenario, the DoD will manufacture what it must and address IP consequences afterward. 28 U.S.C. Section 1498 provides a statutory framework under which the government can authorize patent use with compensation to be determined after the fact. However, relying on this authority as an operational feedstock procurement strategy is legally and administratively cumbersome, and it does not resolve the fundamental problem that the technical data package (TDP), the digital blueprint specifying geometry, material, process parameters, and quality requirements, may simply not exist in government-accessible form.

C. Federal Acquisition Implications

DLA's AM Implementation Plan (June 2022) identifies TDP availability as a prerequisite for DLA to procure AM options for managed parts. The plan requires that MILSVCs provide DLA with signed, approved processes and/or approved vendors before DLA can engage the AM supply chain for a given part. This framework is logically sound but creates a chicken-and-egg dynamic: forward units need parts not in the approved list, but adding parts to the approved list requires TDP work that takes months or years. Addressing this dynamic requires both pre-conflict TDP acquisition campaigns and streamlined Other Transaction Authority mechanisms that allow rapid qualification of commercially available feedstock-process combinations.

VII. CHALLENGE DOMAIN 5: CYBERSECURITY AND THE DIGITAL THREAD

The AM digital thread, the secure link between design repositories and forward printers, is simultaneously the capability's greatest enabler and its most significant vulnerability. A printer without a validated design file is useless; a printer loaded with a manipulated design file may produce parts that fail catastrophically under operational loads.

A. DODIG-2021-098: Key Findings

The DoD OIG's July 2021 audit (DODIG-2021-098), Audit of the Cybersecurity of Department of Defense Additive Manufacturing Systems, examined whether DoD components secured AM systems to prevent unauthorized changes and ensure the integrity of design data. The audit found that DoD components did not consistently secure or manage their AM systems or design data. Officials at the five sites reviewed had not consistently addressed cybersecurity requirements because AM users considered the systems to be production tools rather than information technology systems requiring security controls. Components had incorrectly categorized AM systems as stand-alone systems and erroneously concluded they did not require an Authority to Operate (ATO) under the DoD Risk Management Framework.

The OIG noted that compromise of AM design data could allow an adversary to re-create and use DoD technology to the adversary's advantage on the battlefield. Equally important, if malicious actors alter the design data, the changes could affect the end strength and utility of printed products in ways that may not be detectable through visual inspection. The OIG issued eight recommendations, four of which remained open as of the most recent tracking update, indicating incomplete remediation.

B. Feedstock Implications of Cyber Vulnerabilities

The cyber challenge intersects the feedstock problem in two ways. First, compromised design files may specify incorrect process parameters, including incorrect material selections, that cause operators to use inappropriate feedstocks for a given application. A design file manipulated to specify standard stainless steel instead of a required high-temperature alloy would produce a part that appears correct but fails under service conditions. Second, cyber vulnerabilities in digital inventory systems could allow adversaries to corrupt feedstock consumption data, generating false demand signals that either deplete feedstock reserves through artificial over-ordering or create critical shortages by suppressing legitimate resupply requisitions.

Expeditionary AM systems that rely on removable media (USB drives and SD cards) for design file transfer, as is common in communications-degraded forward environments, present particularly acute vulnerabilities. The DODIG-2021-098 report specifically cited the failure of DoD components to label, secure, and scan removable media devices connected to AM systems in accordance with DoD guidance.

C. NIST Cybersecurity Framework Application

The NIST Cybersecurity Framework Manufacturing Profile (NIST IR 8183r1, 2020) provides a baseline for applying the Framework's Identify-Protect-Detect-Respond-Recover functions to manufacturing environments. AM systems deployed forward require implementation of all five

functions, adapted for bandwidth-constrained and intermittently connected environments. The DoD has not yet published forward-specific AM cybersecurity implementation guidance that addresses the unique threat environment and connectivity limitations of tactical-edge deployments.

VIII. CHALLENGE DOMAIN 6: FOREIGN DEPENDENCY AND INDUSTRIAL BASE RISK

The feedstock industrial base for AM is globally distributed in ways that create strategic risk at the intersection of national security and supply chain resilience. GAO-25-107283 (Defense Industrial Base: Actions Needed to Address Risks Posed by Dependence on Foreign Suppliers, July 2025) documents that DoD relies on a global network of over 200,000 suppliers, with limited visibility into the country of origin for a significant proportion of materials and components. The primary federal procurement database provides little visibility into where goods are manufactured or whether materials and parts suppliers are domestic or foreign.

A. Metal Powder Supply Chain Geography

The production of high-quality metal powders for AM, particularly titanium, nickel superalloy, and reactive metal powders, is concentrated in a small number of producers globally, several of which are located in or source precursor materials from geopolitically sensitive jurisdictions. While the GAO-25-107283 report focuses primarily on microelectronics, its framework applies with equal force to AM feedstocks: DoD's efforts to improve supply chain visibility are uncoordinated and limited in scope, with little insight into the vast majority of suppliers including those providing raw materials. The titanium supply chain is particularly exposed, given that Russia has historically been a major producer of titanium sponge, the precursor to titanium powder. The disruption of Russian titanium supply following 2022 sanctions prompted consolidation among remaining suppliers and price volatility that directly affects AM feedstock procurement.

B. NDAA FY2026 Implications for Feedstock

NDAA Section 849's prohibition on AM machines from covered nations (China, Russia, Iran, North Korea) addresses equipment provenance but does not directly restrict feedstock sourcing from the same nations. This creates an anomalous policy gap: a DoD facility could theoretically use a U.S.-made AM system while printing with metal powders whose precursor materials originated in sanctioned or adversary-controlled supply chains. The NDAA's broader direction on domestic sourcing and foreign dependency, reflected in its battery, photovoltaic, and biotechnology restrictions in Sections 842, 847, and related provisions, suggests a legislative intent to extend supply chain restrictions across multiple material categories. An AM feedstock corollary has not yet been enacted, representing a policy gap that warrants attention.

C. Polymer Feedstock Dependencies

Polymer feedstock supply chains present a different but related risk profile. Many high-performance polymers used in AM, including PEEK (polyether ether ketone), PEI (polyetherimide), and polycarbonate, are manufactured by a limited number of global producers. The raw petrochemical inputs for these polymers are subject to energy market volatility. Carbon fiber reinforcements, increasingly used in composite AM feedstocks, involve supply chains with significant Chinese production capacity, a factor that has drawn increasing scrutiny from defense acquisition policy offices. The NDAA FY2026 prohibition on Chinese AM machines does not extend to Chinese-origin carbon fiber or polymer precursors, a gap that could become operationally significant as composite AM printing expands forward.

IX. CHALLENGE DOMAIN 7: WORKFORCE AND TRAINING DEFICITS

The most capable AM system with the best-managed feedstock supply chain will fail to deliver operational value without trained personnel who understand both the capabilities and the limitations of the technology. Workforce and training deficits represent a consistently identified challenge across DoD AM assessments.

A. The Machine-Operator-Material Triangle

Effective forward AM requires integrated understanding across three domains: the machine (printer parameters, maintenance, calibration), the material (feedstock selection, condition assessment, process suitability), and the design (file management, print orientation, support structures, post-processing requirements). Most current training programs for forward AM operators focus on machine operation, treating feedstock management as a secondary concern and providing little instruction in material science fundamentals that would allow operators to identify degraded feedstock, select appropriate materials for a given application, or recognize process-induced defects.

Practitioners at the AMUG 2025 conference noted that expeditionary AM solutions are too often designed by engineers for engineers, with insufficient attention to user interface simplicity and training requirements for frontline operators. The Marine Corps and Army have invested in basic AM courses at installations including Camp Lejeune and Fort Bragg, but these programs have not yet been standardized or fully integrated into the institutional training base in a way that ensures consistent feedstock management competency across the force.

B. Warfighter-Engineer Integration

A broader cultural and organizational challenge involves the integration of manufacturing knowledge into warfighter culture. Forward AM requires what defense analysts have termed warfighter-engineers: personnel who think in both code and combat, who can translate a maintenance problem into a printable solution, manage feedstock inventories as they would manage ammunition, and sustain digital systems under field conditions. This combination of skills does not map cleanly onto existing MOS structures or officer career paths. The DOTMLPF-P implications of this gap are addressed in the recommendations section.

C. Post-Processing and Quality Assurance

Many AM parts require post-processing, including heat treatment, surface finishing, support removal, and dimensional inspection, that demands skills and equipment not currently organic to most forward units. Quality assurance for printed parts, in the absence of the industrial-grade inspection equipment available at depot echelons, relies heavily on operator judgment. Without training in visual inspection criteria, material defect recognition, and the limitations of field QA methods, forward units may inadvertently employ printed parts outside their qualified use envelope, with potentially severe consequences for personnel safety and equipment readiness.

X. DOTMLPF-P RECOMMENDATIONS

The challenge domains analyzed in preceding sections are not independent. They reflect systemic gaps across doctrine, organization, training, materiel, leadership, personnel, and facilities that, taken together, prevent the DoD from fully realizing the operational potential of forward AM. The following recommendations are organized within the DOTMLPF-P framework.

DOTMLPF-P Line	Key Recommendation(s)
Doctrine	Revise FM 4-0 and ATP 4-33 (Maintenance Operations) to include explicit feedstock supply chain planning guidance. Establish doctrinal definitions for feedstock class of supply, shelf-life management protocols for AM materials, and forward AM resupply planning factors analogous to Class III (petroleum) planning factors.
Organization	Establish a joint feedstock program management office under DLA to coordinate cross-service feedstock qualification, approved vendor lists, and demand aggregation. Assign feedstock management responsibility to designated MOS billets within forward support companies.
Training	Develop and mandate a modular AM feedstock management course within the CASCOM institutional training base. Integrate feedstock condition assessment, storage requirements, and material selection into all AM operator certifications. Fund forward-specific training ranges that replicate austere storage and operational conditions.
Materiel	Develop ruggedized, field-qualified feedstock storage containers with passive temperature and humidity management. Field compact powder moisture content analyzers compatible with forward environments. Evaluate nitrogen generation systems for integration into containerized AM facilities.
Leadership & Education	Integrate AM supply chain risk into senior leader PME (ILE, SAMS, AWC). Brief commanders at brigade level and above on feedstock logistics during AM capability integration briefings. Address the IP and TDP acquisition campaign as a Title 10 leadership responsibility.
Personnel	Create or designate an MOS or additional skill identifier (ASI) for AM feedstock technicians. Develop civilian/contractor hybrid support models for forward-deployed AM systems at OCONUS bases. Establish incentive programs to retain personnel with combined manufacturing and operational experience.
Facilities	Establish pre-positioned feedstock caches at strategic intermediate staging bases aligned with combatant command contingency plans. Design future Forward Operating Base (FOB) construction plans to include dedicated AM feedstock storage facilities meeting ASTM storage standards. Fund feedstock-compatible infrastructure in austere/expeditionary base design standards.
Policy	Direct DoD to conduct a feedstock foreign dependency assessment analogous to the equipment review under NDAA Section 849. Pursue harmonized feedstock qualification standards across services under the Joint Additive Manufacturing Working Group. Develop a forward AM cybersecurity implementation guide addressing removable media, disconnected operations, and design file integrity verification.

Table 2. DOTMLPF-P recommendations for addressing forward AM feedstock supply chain challenges.

XI. CONCLUSION

Additive manufacturing represents a genuine and growing contribution to forward logistics resilience. The DoD's $797 million FY2024 investment, the NDAA FY2026 legislative framework, and the operational demonstrations from Marine Expeditionary Fabrication Facilities to Army R-FAB deployments collectively confirm that AM has moved from laboratory to field. The question confronting logistics planners and policy developers is no longer whether to invest in forward AM, but how to manage the second-order challenges that deployment at scale introduces.

Feedstock is where the promise of AM most frequently meets the constraints of operational reality. A printer without reliable, specification-compliant feedstock is a liability rather than an asset, requiring cargo space, power, and skilled operators while producing nothing. The seven challenge domains analyzed here, environmental degradation, transportation constraints, standardization gaps, IP restrictions, cybersecurity vulnerabilities, industrial base dependencies, and workforce deficits, are not individually insurmountable. Each has a body of existing research, emerging doctrine, or developing policy that provides a foundation for solutions. What is missing is a coordinated, cross-service effort to address these challenges as an integrated system rather than as isolated problems within individual program offices.

The AM community has rightly focused on demonstrating that the printers work. The next phase of maturation requires equal investment in demonstrating that the supply chain for the printers' inputs is reliable, secure, domestically anchored, and resilient to the full range of operational environments in which U.S. forces will be required to fight and sustain themselves. That work is the essential foundation for the broader transformation that forward AM promises to deliver.

REFERENCES

Government Documents and Official Reports

- Government Accountability Office. (2015, October). Defense Additive Manufacturing: DOD Needs to Systematically Track Department-Wide 3D Printing Efforts. GAO-16-56. Washington, DC: GAO.
- Government Accountability Office. (2025, July). Defense Industrial Base: Actions Needed to Address Risks Posed by Dependence on Foreign Suppliers. GAO-25-107283. Washington, DC: GAO.
- Department of Defense Inspector General. (2019, October). Audit of the DoD's Use of Additive Manufacturing for Sustainment. DODIG-2020-003. Washington, DC: DoD OIG.
- Department of Defense Inspector General. (2021, July). Audit of the Cybersecurity of Department of Defense Additive Manufacturing Systems. DODIG-2021-098. Washington, DC: DoD OIG.
- Department of Defense. (2021, January). DoD Additive Manufacturing Strategy. Washington, DC: Office of the Under Secretary of Defense for Research and Engineering.
- Defense Logistics Agency. (2022, June). DLA Additive Manufacturing Implementation Plan for DoDI 5000.93. Fort Belvoir, VA: DLA.
- Department of Defense Instruction 5000.93. Use of Additive Manufacturing in the DoD.
- United States Army. (2024, August). FM 4-0, Sustainment Operations. Washington, DC: Headquarters, Department of the Army.
- United States Army. (2019, July). ADP 4-0, Sustainment. Washington, DC: Headquarters, Department of the Army.
- National Defense Authorization Act for Fiscal Year 2026, P.L. 119-60 (December 18, 2025). Section 849, Prohibition on Certain Additive Manufacturing Machines.

Academic and Research Sources

- Verboeket, V., & Krikke, H. (2020). Additive manufacturing in military and humanitarian missions: Advantages and challenges in the spare parts supply chain. Journal of Cleaner Production, 257.
- Dacanay, J., et al. (2022). Navigating Department of Defense Additive Manufacturing: A GAO Framework Assessment. Acquisition Research Program. Naval Postgraduate School. NPS-AM-22-017.
- NIST Information Technology Laboratory. (2020). Cybersecurity Framework Version 1.1 Manufacturing Profile. NIST IR 8183 Revision 1.
- Sames, W. J., et al. (2016). The metallurgy and processing science of metal additive manufacturing. International Materials Reviews, 61(5), 315-360.

Open-Source and Professional Publications

- Fuller, H. (2025, October). Reshaping Military Logistics Through Additive Manufacturing. Military.com.

- Pecota, M., & Guinn, M. (2025, April). [Panel Discussion: Additive Manufacturing for Military Forward Deployment and Rapid Sustainment]. AMUG Conference 2025, reported by 3D Printing Industry.
- Proceedings. (2024, July). The Promise and Challenges of Shipboard Additive Manufacturing. U.S. Naval Institute Proceedings, 150(7).
- War on the Rocks. (2025, December). The Additive Manufacturing Mirage in Defense.
- Defense.info. (2025, December). Additive Manufacturing and the Land Forces Supply Chain: A Revolution Within a Revolution.
- TCT Magazine. (2026, January). NDAA: DoD Prohibited from Using or Procuring Additive Manufacturing Systems Made in or Networked Through China, Russia, Iran, and North Korea.
- King & Spalding LLP. (2026, January). FY 2026 NDAA: Domestic Sourcing, Artificial Intelligence, Cybersecurity, and Acquisition Reforms.