

# GLOBAL ANALYTICAL REPORT

## Titanium Demand Expansion Driven by Next-Generation Fighter Jets and Military Aerospace Programs

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## EXECUTIVE SUMMARY

Titanium has emerged as a strategically critical material in modern military aviation, driving measurable global demand expansion across defense and civilian aerospace sectors. This report synthesizes publicly available evidence to assess titanium's role in next-generation fighter jet production, the structural drivers of demand, and the geopolitical and supply-chain implications of concentrated production capacity.

### Key Findings

**Strategic Criticality:** Titanium constitutes approximately 25–42% of modern fighter jet airframes by weight in platforms including the F-22 Raptor (42%), F-35 Lightning II (~33%), and fifth-generation Chinese J-20 and Russian Su-57 variants. Its exceptional strength-to-weight ratio, corrosion resistance, and thermal properties are irreplaceable in hypersonic and high-performance flight environments.

**Global Fighter Production Surge:** Global fifth- and fourth-generation fighter production has accelerated significantly. Notable production rates include: - F-35 Lightning II: 191 aircraft delivered in 2025 (record pace), with production running 5× faster than any other allied fighter - Chinese J-20: Over 300 units produced by October 2025, with estimated annual output of 70–100 units - Eurofighter Typhoon: Production to increase from 12 to 20 aircraft annually, with potential to reach 30/year - Dassault Rafale: 220-aircraft backlog representing approximately 10 years of current production - Emerging fifth-generation programs: South Korea's KF-21 entering production (120 planned by 2032), India's AMCA, Japan's F-X (90 planned by 2035)

**Demand Drivers:** Military defense spending reached \$2.72 trillion globally in 2024 (9.4% YoY increase—the steepest since the Cold War), with projected continued growth to \$2.8+ trillion in 2025 and approaching \$3.0 trillion by 2028. This structural rearmament cycle is synchronized across Europe (+13% YoY), Asia-Pacific (+7–8% CAGR), and North America (+5.7%), reflecting deterrence-based procurement, NATO commitment acceleration, and defense industrial sovereignty initiatives.

**Supply Constraints:** Aerospace-approved titanium sponge production is concentrated in four manufacturers (Japan: 55,000 tonnes/year; Kazakhstan: 19,000 tonnes/year; Saudi Arabia: 15,000 tonnes/year; Russia: ~17,000 tonnes/year—down from 32,000 tonnes pre-2022). This 89,000-tonne annual capacity is insufficient to support projected fighter jet production increases without supply bottlenecks. China dominates total titanium production volume (220,000 tonnes/year) but 97% remains non-aerospace-grade certified.

**Geopolitical Leverage:** Russia's post-2022 reduction in titanium output (from 32,000 to ~17,000 tonnes annually) and continued exclusion from Western aerospace supply chains demonstrate the vulnerability of aerospace manufacturing to sanctions. Conversely, Western OEMs (Boeing, Airbus) have successfully reduced Russian titanium dependency from 60–80% to 20% or less, establishing supply chain resilience through diversification to Japan, Kazakhstan, and Saudi Arabia. However, this transition remains incomplete;

continued capacity constraints favor continued gradual transition rather than abrupt supply shifts.

**Market Trajectory:** The global titanium market is projected to grow from \$28.58 billion (2024) to \$53.65 billion by 2034 (6.9% CAGR), with aerospace and defense representing an accelerating share. Aerospace-specific titanium demand is forecast to grow from \$4.7 billion (2025) to \$9.15 billion (2035), reflecting both military and commercial aviation drivers (Boeing 787, Airbus A350 production ramps).

**Strategic Autonomy Initiatives:** The European Union has launched the RESourceEU Action Plan (€3 billion, December 2025) to coordinate critical minerals procurement and establish strategic stockpiling. The United States is pursuing domestic titanium sponge capacity expansion via IperionX and other producers. India and Japan are advancing indigenous aerospace-grade titanium processing. These initiatives aim to reduce single-supplier dependencies, particularly regarding China and Russia.

### **Policy Implications**

- **Industrial Sovereignty:** Next-generation fighter jet production is increasingly conditioned on access to certified titanium supplies, incentivizing governments to invest in domestic or trusted-partner processing capacity.
- **Sanctions Architecture:** Titanium's exclusion from post-2022 Russia sanctions remains contested, with growing pressure to extend restrictions given successful Western supply chain diversification.
- **Critical Material Classification:** Titanium is not formally designated as a "critical mineral" in EU or US frameworks but exhibits supply-chain vulnerabilities and strategic importance warranting future review.
- **Demand Predictability:** Estimated fighter jet procurement pipelines extend 10–15 years, providing reasonable visibility for supply chain planning, though demand variability remains dependent on geopolitical escalation scenarios.

## TECHNICAL ROLE OF TITANIUM IN MODERN FIGHTER JETS

### Why Titanium Displaces Steel and Aluminum

Modern fighter aircraft prioritize weight reduction and structural integrity under extreme thermal and mechanical stress. Titanium's unique combination of properties makes it operationally superior to alternative materials in these demanding environments.

**Density and Strength Comparison:** Titanium exhibits a density approximately 60% that of steel while maintaining comparable or superior yield strength. This enables substantial weight reductions in airframe and engine components, directly translating to improved fuel efficiency, extended range, increased payload capacity, and enhanced maneuverability. A reduction of 1,000 pounds in airframe weight can extend combat radius by several hundred nautical miles or reduce fuel consumption proportionally.

**Thermal Resistance:** Titanium alloys retain high structural strength at temperatures exceeding 600°C, a critical requirement for military jet engines and supersonic airframe leading edges. Steel loses ductility at such temperatures; aluminum melts near 660°C. This enables titanium to serve in compressor blades, turbine casings, and external heat-critical surfaces exposed to friction heating during hypersonic flight.

**Corrosion and Fatigue Resistance:** Titanium exhibits exceptional resistance to both atmospheric corrosion and galvanic corrosion. This property is particularly valuable in naval and maritime applications and when titanium is joined to carbon fiber-reinforced polymer (CFRP) composite structures—increasingly common in fifth-generation aircraft. Dissimilar-metal corrosion, which occurs when aluminum is fastened to carbon fiber, does not significantly affect titanium-CFRP interfaces, enabling seamless integration of metal and composite airframe sections.

**Thermal Expansion Compatibility:** Titanium's coefficient of thermal expansion closely matches that of carbon fiber composites, reducing internal stress from cyclic temperature variations during flight operations. Aluminum's higher thermal expansion coefficient creates differential stress, accelerating fatigue failure at composite-metal junctions. This compatibility enables longer composite-titanium hybrid structures with improved reliability.

## Titanium Content in Fifth- and 4.5-Generation Fighters

The strategic value of titanium in fighter design is quantified through its proportion of total airframe weight:

Aircraft	Titanium Content	Notes
<b>F-22 Raptor</b> (5th gen, US)	~42%	Single-engine, air superiority, full stealth
<b>F-35 Lightning II</b> (5th gen, US)	~33% (~one-third)	Multi-engine variant, multirole, distributed across airframe and engines
<b>Chinese J-20</b> (5th gen)	Estimated 30–35%	Comparable structural design to F-35 class
<b>Russian Su-57</b> (5th gen)	Estimated 25–30%	Heavier relative to wing area; less extensive titanium use than F-22
<b>Eurofighter Typhoon</b> (4.5 gen, EU)	~15–20%	Fourth-generation baseline, lower thermal environment
<b>Dassault Rafale</b> (4.5 gen, France)	~12–18%	Modular design; lower proportion than Typhoon
<b>Modern military jets (average)</b>	~25%	Industry benchmark for structural airframe
<b>SR-71 Blackbird</b> (historical)	93% of alloys contain titanium	Extreme case: sustained Mach 3.3 flight

These figures represent titanium’s mass fraction in structural alloys and engine components. Not all airframe weight is metallic; composites and ceramics comprise increasing proportions of modern aircraft structures. Titanium’s proportion of total system

weight has stabilized in the 25–42% range for current fifth-generation designs, reflecting mature optimization between titanium’s benefits and manufacturing complexity.

### Specific Applications in Fighter Airframes

**Airframe Structures:** - **Fuselage sections:** Primary longitudinal and circumferential stiffeners; wing carry-through boxes; fuselage frames where internal volume constraints limit composite substitution. - **Landing gear:** Main and nose gear structures; shock-absorber components; attachment fittings subject to repeated high-load cycles. - **Engine pylons and nacelle attachments:** Load-critical junctions bearing engine thrust loads and aerodynamic forces. - **Control surface attachments:** Root fittings for canards, stabilators, and control surfaces requiring fatigue resistance and thermal tolerance. - **Leading-edge thermal protection:** Slats and leading-edge structures exposed to kinetic heating above 150°C during supersonic flight.

**Engine Components** (proportionally, the largest titanium consumer): - **Fan blades and compressor rotors:** Titanium alloys (Ti-6Al-4V, high-temperature variants) in low-pressure compressor stages; nickel-based superalloys in high-pressure stages. - **Compressor casings:** Titanium used in low-pressure compressor shrouds and casings. - **Thermal management housings:** Ducting and fasteners in high-temperature engine sections.

### Material Specifications and Alloy Families

Fighter jet titanium applications employ three principal alloy classes:

1. **Commercially Pure Titanium** (Grades 1–4): Limited use; primarily in low-stress thermal or corrosion-critical areas.
2. **Alpha-Beta Alloys** (Ti-6Al-4V, Ti-5Al-5V-5Fe-3Cr):
  - Operating range: up to 300–350°C
  - Highest damage tolerance; excellent fatigue strength
  - Machining and forging challenges; cost-intensive
  - Primary aerospace-grade specification for airframe and low-pressure compressor
3. **Near-Alpha and Metastable-Beta Alloys** (Ti-834, IMI 834, near-alpha variants):
  - Operating range: 600°C and above
  - Developed for supersonic cruise and engine environments
  - Extremely limited production; only four aerospace-approved sponge producers globally
  - Certification timelines: 5–10 years per alloy variant

The progression from commercially certified alloys to performance-critical variants represents decades of development and qualification, creating high barriers to entry for new suppliers and making the four aerospace-approved titanium sponge producers (Japan, Kazakhstan, Saudi Arabia) quasi-monopolistic in the defense aerospace segment.

## GLOBAL FIGHTER JET PRODUCTION & UPGRADE PROGRAMS

### United States

#### F-35 Lightning II Production and Deployment

The F-35 Lightning II represents the largest active fighter jet production program globally. As of January 2026, the program has achieved unprecedented delivery velocity:

- **2025 Deliveries:** 191 aircraft delivered in 2025, surpassing the previous record of 142 jets
- **Production Tempo:** Annual production running at 5× the rate of any other allied fighter program
- **Global Fleet:** Approximately 1,300 aircraft in global service across US and 19+ allied nations
- **Future Orders:** Lots 18–19 finalized in September 2025, covering production and delivery of up to 296 F-35s for \$24 billion

**International Customer Expansion:** - Italy: Expanded program of record by 25 additional aircraft - Denmark: Expanded by 16 aircraft; domestic assembly capability being developed - Finland, Belgium, Norway, and other NATO members accelerating deliveries and integration

**Projected US F-35 Production Trajectory:** - Baseline: 156–170 F-35s annually through 2030 - High-case scenario: 190+ annually if supply chain constraints ease - Program total: Over 3,000 aircraft anticipated globally by program conclusion (2050s+)

**Other US Fighter Programs:** - **F-22 Raptor:** Production ended 2011 (187 aircraft total); sustainment-focused; no new production - **F/A-18 Super Hornet:** Continued production support; no major expansion - **F-15EX Eagle II:** Limited production increase; lower titanium content than F-35/F-22 - **NGAD F-47** (sixth-generation): Limited production commenced; details classified

### China

#### J-20 Mighty Dragon Expansion

China's J-20 stealth fighter production has accelerated to unprecedented levels, positioning Beijing as the largest fifth-generation aircraft producer globally:

- **October 2025 Milestone:** Over 300 J-20s manufactured, including prototypes, test articles, and operational variants
- **Production Rate:** Estimated 70–100 units annually (independent assessments); some sources suggest 120+ units in 2025–2026
- **Current Fleet:** Majority of 300+ integrated into active PLAAF service across multiple commands
- **Facility Optimization:** Chengdu Aerospace Corporation (CAC) optimized assembly using pulse-line production technology since 2022

- **Growth Projections:** If current tempo continues, J-20 inventory may exceed 500 by late 2026 and approach 1,000 by 2030

**Manufacturing Scale and Supply Chain Integration:** - CAC pulse-line production enables simultaneous assembly of 15–20 airframes in various stages - Digitalized factories and AI-assisted quality control ensure consistent output - Integration across Chinese state-owned aerospace network (AVIC, AECC, CETC) creates synchronized supply chain unprecedented in scale - Chinese analysts assert J-20 production demonstrates capacity to sustain prolonged fifth-generation manufacturing without foreign dependency

**J-35 Development:** - Approximately 57+ units produced to date - Estimated annual output target: 70–100 units - Designed for potential carrier operations and export

**Additional Chinese Fighter Programs:** - **J-31 (FC-31):** Shenyang-developed export variant; approximately 30–50 units in various development stages - **J-10C, J-11, J-16:** Fourth- and 4.5-generation variants totaling 100+ units annually (lower titanium requirements) - **Total Chinese fighter production:** Estimated 240+ aircraft annually (all types combined)

## Russia

### Su-57 Felon Limited Expansion

Russia's fifth-generation fighter program remains constrained by technical, industrial, and geopolitical factors:

- **Production to Date:** Approximately 22 aircraft delivered by late 2024; fewer than 15 operational in active service
- **Contractual Target:** Russian Defense Ministry contract with Sukhoi for 76 aircraft by 2028
- **Production Facility:** Komsomolsk-on-Amur Aviation Plant (KnAAZ); expansion announced August 2024
- **Facility Upgrades:** New testing facilities for fuel systems, avionics integration, and system trials commissioned; additional hangar reconstruction planned
- **Production Challenges:** Ukraine war impact on supply chains; component sourcing difficulties; limited domestic engine availability (second-stage AL-41F1 engine development ongoing)

**First Export Customer:** - Algeria announced as first export customer (November 2025) - Initial order: 6 Su-57E aircraft (export variant) for delivery by late 2025, operational 2026 - Follow-on order: 8 additional aircraft rumored but unconfirmed

**Production Trajectory Uncertainties:** - Sanctions on VSMPO-AVISMA (titanium supplier) and Russian Titanium Resources (RUSTITAN) imposed November 2023 - Ukraine war diversion of production resources and supply-chain disruptions - Achieving 76-unit target by 2028 requires sustained 15–20 aircraft annually; current capacity estimated at 8–12 annually

## EUROPEAN FIGHTER PROGRAMS

### Eurofighter Typhoon Modernization and Production Ramp

The Eurofighter Typhoon remains the primary European fourth-generation (with 4.5-generation enhancements) fighter and is experiencing deliberate production increases to address NATO rearmament imperatives:

**Current and Projected Production Rates:** - **Current baseline:** 12 aircraft per year - **Confirmed increase:** 20 aircraft per year by 2025–2026 - **Potential expansion:** 30 aircraft per year dependent on confirmed export orders and NATO member demand - **Production timeline:** Stable orders through 2032+ across consortium partners

**Recent Domestic Orders:** - Germany: 38 Tranche 4 aircraft (Quadriga program, €5.4 billion, November 2020); additional 20 units ordered June 2024 for delivery through 2032 - Spain: 45 additional aircraft (Halcón I and Halcón II phases, €6.5 billion total) for delivery 2026–2035 - Italy: Tranche 4+ configuration; integration of new EJ200 engines announced

**Production Capacity Management:** - Four final assembly lines operate across consortium nations: Warton (UK), Manching (Germany), Turin (Italy), Getafe (Spain) - Supply-chain coordination required for component manufacturing across Belgium, Netherlands, Norway, Sweden, and other European suppliers - Current bottleneck: Supply-side constraints limit ramp from 12 to 20 annually; achieving 30 aircraft annually would require synchronized capacity adjustments across entire supply chain

**Typhoon as Bridge Platform (2025–2035):** - Enhanced radar integration (ECRS Mk2) development funded at £204.6 million to maintain industrial continuity during transition to GCAP - Extended service-life upgrades through 2060 planned - Radar and avionics technology insertion supports eventual GCAP transition

### Dassault Rafale Demand and Production Constraints

The Rafale represents the highest-export success of any European fighter, with sustained demand outpacing production capacity:

**2025 Production Performance:** - 26 Rafale fighters delivered in 2025 (15 export, 11 French Air Force) - Production rate: 2.3 aircraft per month; constrained below 3 per month target - Supply-chain bottleneck: 400+ suppliers, with post-COVID recovery and raw material cost pressures limiting final assembly acceleration

**Order Backlog and Export Demand:** - **Backlog:** 220 aircraft (45 for France, 175 for export customers) - **Backlog duration:** 10 years at current 26-aircraft-per-year delivery rate - **Total orders since program inception:** 507 aircraft (273 export, 234 French)

**Recent Export Wins and Prospects (2025–2026):** - **Egypt:** Negotiations for 14 Rafale F4 fighters (10 single-seat, 4 two-seat) expected to conclude 2026 - **India:** Multi-Role Fighter Aircraft (MRFA) program pursuing up to 114 additional Rafale aircraft; advanced negotiations ongoing - **Ukraine:** Letter of intent (November 2025) for potential acquisition

of 100 Rafale F4 fighters over next decade - **Iraq, Qatar, UAE, Indonesia, Serbia, Greece, Croatia:** Prior export commitments sustaining order flow

**Industrial Constraints:** - Supply-chain resilience remains the critical bottleneck - Dassault-Tata partnership announced for Rafale fuselage manufacturing in Hyderabad, India (assembly, not production) - Increasing supplier consolidation and capacity challenges limit rate increases without multi-year investment cycles

### **Global Combat Air Programme (GCAP/Tempest) – Sixth-Generation Development**

The UK-Italy-Japan partnership on the Global Combat Air Programme represents the next generation of fighter development:

**Program Timeline:** - Formal development phase: 2025 onwards - Demonstrator aircraft flight: 2027 (target) - Production aircraft service entry: 2035 - Expected total orders by 2035: 350+ aircraft (minimum requirement across three core partners: 290 airframes)

**Industrial Partnership Structure:** - Prime contractors: Leonardo (Italy), BAE Systems (UK), Mitsubishi Heavy Industries (Japan) - Engine developers: Rolls-Royce, Avio Aero, IHI (signed evolved collaboration agreement, September 2025) - Estimated workforce: 9,000+ personnel globally; 1,000+ suppliers across three nations - Component suppliers: 600 UK-based, 400+ Italy-based, Japan-based ecosystem

**Titanium and Advanced Materials Strategy:** - Sixth-generation specifications will likely demand higher-performance titanium alloys and greater use of advanced composites - Smaller proportional titanium content expected (composite-primary designs) - Higher-grade metallic requirements in specific structural and thermal zones

## ASIAN FIGHTER PROGRAMS

### India

#### HAL Tejas Mk1A Production Expansion

India's indigenous fighter program represents a strategic pivot toward defense self-sufficiency:

**September 2025 Procurement:** - Contract value: ₹62,370 crore (approximately \$7.5 billion USD) - Aircraft count: 97 Tejas Mk1A (68 single-seat fighters, 29 twin-seat trainers) - Delivery timeline: 2027–2028 through 2033 (6-year manufacturing window) - Indigenous content: 64%+ with 105 Indian suppliers supporting ecosystem - Jobs creation: Estimated 11,750 direct and indirect jobs annually

**IAF Fleet Modernization Path:** - First order (2021): 83 Tejas Mk1A (₹46,000 crore) - Second order (2025): 97 Tejas Mk1A (₹62,370 crore) - Total IAF commitment: 180+ Tejas Mk1A aircraft - Additional contemplated orders: 120+ Tejas Mk2 (advanced variant, later production) - Historical baseline: 40 Tejas Mk1 delivered 2016 onwards

**Concurrent Multi-Role Fighter Aircraft (MRFA) Program:** - Pursuing acquisition of 114 additional Rafale fighters (government-to-government) - Dassault-Tata partnership for partial assembly in Hyderabad - Delivery timeline: Extending to 2035+

**Supply Chain and Titanium Implications:** - Tejas Mk1A titanium requirements: Estimated 8–12 tonnes per aircraft (based on 23.5-tonne total weight and structural design) - Total Tejas Mk1A program demand: ~776–1,164 tonnes of aerospace-grade titanium - Current Indian titanium sponge capacity: 300 tonnes annually (Titanium Sponge Plant of India at Kerala Minerals and Metals Ltd) - Import requirement: 90%+ of aerospace-grade sponge sourced from Japan, Kazakhstan, or Russia

### Japan

#### F-35 Acquisition and Domestic Assembly

Japan is integrating the F-35 as its primary fifth-generation fighter while pursuing independent sixth-generation development:

**F-35 Fleet Plan:** - Total acquisition: 147 aircraft (142 CTOL, 5 STOVL initially, subject to revision) - Deliveries to date: 40+ aircraft - Domestic assembly: Mitsubishi Heavy Industries (MHI) final assembly at Nagoya FACO facility - Component manufacturing: IHI (engines), Mitsubishi Electric (radar), MHI (structures) - Assembly completion: Remaining 100+ aircraft

#### F-X (F-3) Sixth-Generation Development

Japan is advancing an indigenous sixth-generation fighter to reduce dependency on US technology:

**Program Schedule:** - Development phase: 2024 onwards - Prototype construction: 2024–2027 - First flight: 2028 (target) - Full-scale production: 2031 onwards - Service entry: 2035 - Total fleet requirement: ~90 aircraft

**Program Structure:** - Lead contractor: Mitsubishi Heavy Industries - International partners: Lockheed Martin (confirmed), BAE Systems and Northrop Grumman (potential) - Program cost: Approximately \$48 billion - Supplier base: 1,000+ Japanese companies

**Titanium Requirements:** - F-X material specifications: Not publicly disclosed; likely employs advanced composite-primary design with reduced titanium proportion compared to fifth-generation - Current Japanese titanium sponge production: 55,000 tonnes annually (Toho Titanium, Osaka Titanium) - Supply strategy: Domestic production capacity anticipated to increase to support F-X and continued commercial aircraft demand

## South Korea

### KF-21 Boramae Transition to Production

South Korea's domestically developed 4.5-generation fighter is entering serial production:

**Production Timeline** (as of January 2026): - First production model: Final assembly phase entered May 2025 - Delivery to ROKAF: Scheduled 2026 - Initial production batch: 40 aircraft (Block 1, air-to-air configuration) - Second batch: 80 aircraft (Block 2, air-to-ground configuration) planned - Total procurement target: 120 aircraft by 2032

**KF-21 Configuration and Titanium Demand:** - Aircraft class: 4.5-generation multirole fighter - Estimated operating empty weight: 10,500 kg (23,100 lbs) - Estimated titanium content: 12–18% of airframe weight (~1.5 tonnes per aircraft) - Total program demand: ~180 tonnes of aerospace-grade titanium

**Operational Capability Acceleration:** - Air-to-ground strike capability accelerated from original 2029 timeline to 2027 - Integration of advanced avionics and weapons systems on track - Export prospects: KF-21 reportedly included in \$15 billion arms package to UAE

**Supply Chain:** - Korean domestic titanium capacity: Limited; primary reliance on Japanese and international suppliers - Component suppliers: 400+ companies across South Korea and allied nations

## TITANIUM DEMAND IMPACT ANALYSIS

### Military Aviation Titanium Consumption

#### Current Annual Military Fighter Titanium Demand (2025–2026 Estimate):

Program	Annual Aircraft	Titanium/Aircraft (kg)	Annual Demand (tonnes)
<b>F-35 Lightning II</b>	170	2,800	476
<b>Chinese J-20</b>	80	2,600	208
<b>Chinese J-31/FC-31</b>	50	2,400	120
<b>Eurofighter Typhoon</b>	20	1,800	36
<b>Dassault Rafale</b>	26	1,600	42
<b>Russian Su-57</b>	10	2,200	22
<b>HAL Tejas Mk1A</b>	15	2,200	33
<b>KF-21 Boramae</b>	20	1,600	32
<b>Other 4th-gen programs</b>	100+	800–1,200	80–120
<b>TOTAL ESTIMATED DEMAND</b>	~560–600	—	<b>1,050–1,270 tonnes/year</b>

**Notes:** - Estimates based on publicly disclosed aircraft weights, design documentation, and industry precedents - Titanium content varies by application: engines (higher density), airframe structures (moderate density), fasteners and miscellaneous (lower density) - F-35 estimate reflects tri-variant fleet (CTOL, STOVL, CV); F-22 estimate uses historical data - Chinese production estimates reflect independent assessments; official figures not disclosed - Fourth-generation programs (F-16, MiG-29, variants) included at lower per-aircraft rates (800–1,200 kg vs. 2,000–2,800 kg for fifth-gen)

**Validation Against Supply Capacity:** - Aerospace-approved titanium sponge capacity: 89,000 tonnes annually (Japan 55,000 + Kazakhstan 19,000 + Saudi Arabia 15,000) - Military demand: 1,050–1,270 tonnes annually (~1.1–1.4% of total aerospace-grade sponge) - Commercial aerospace demand: 30,000–45,000 tonnes annually (Boeing 787, Airbus A350, regional aircraft) - **Total aerospace demand:** 31,000–46,000 tonnes annually - **Capacity utilization:** 35–52% of available aerospace-grade sponge

**Structural Assessment:** Current aerospace-approved titanium sponge capacity is sufficient to meet near-term demand (2025–2030). However, this assessment carries significant qualifications:

1. **Demand growth trajectory:** If fighter production rates increase as planned (F-35: 190+/year; J-20: 100+/year; Typhoon: 30/year; others), demand could reach 1,500–1,800 tonnes annually by 2030, consuming 1.7–2% of total sponge capacity.
2. **Commercial aviation rebound:** Boeing 787 production targeting 10 aircraft per month (120 annually) by 2026 and Airbus A350 ramp would increase non-military demand to 40,000–55,000 tonnes annually, absorbing 45–62% of capacity.
3. **China’s non-aerospace-certified sponge:** Approximately 220,000 tonnes of Chinese titanium sponge production remains non-aerospace-certified, representing unused capacity. Certification pathways would require 3–5 years and substantial investment; unlikely to ease pressures before 2028–2030.
4. **Supply chain bottlenecks:** Forging, ingot melting, and mill product capacity (downstream of sponge) represent secondary constraints not fully captured in sponge production figures.

## Comparison: Military vs. Civilian Aerospace Demand

### Civil vs. Military Titanium Consumption (2025 baseline):

Segment	Annual Titanium Demand	Proportion	Key Drivers
<b>Civil Aerospace</b>	30,000–45,000 tonnes	87–94%	Boeing 787 (primary), Airbus A350, regional aircraft, general aviation
<b>Military Aviation</b>	1,050–1,270 tonnes	2.3–3.0%	Fighter jets, transport aircraft, helicopters, UAVs
<b>Marine/Naval</b>	1,500–2,000 tonnes	3–4%	Submarine hulls, naval vessels, subsystems
<b>Industrial/Medical</b>	3,000–5,000 tonnes	6–10%	Chemical processing, medical implants, other applications
<b>TOTAL</b>	~35,000–53,000 tonnes	100%	—

**Critical Observation:** Military aviation, despite its strategic importance and high titanium concentration per unit, represents a small percentage of total aerospace titanium consumption. Commercial civil aviation (Boeing 787, Airbus A350) drives majority demand. This structural imbalance creates policy asymmetry: supply disruptions affecting military production may be tolerated if civil aviation access is preserved, and vice versa.

### Long-Term Structural vs. Cyclical Demand

**Structural Demand Drivers (15–30 year horizon):**

- Fighter fleet modernization cycles:** NATO and allied nations replacing fourth-generation aircraft (F-16, Gripen, Typhoon) with fifth-generation platforms through 2040s
- Chinese fleet expansion:** Sustained J-20 and J-31 production to achieve fighter parity with US Air Force (currently 5,000+ aircraft)
- Emerging market fighter upgrades:** India (Tejas), Japan (F-X), South Korea (KF-21), Turkey (KAAN), UK-Italy-Japan (GCAP) introducing next-generation platforms
- Commercial aircraft growth:** Long-term air travel demand growth in emerging markets (Asia-Pacific +3.2% annual CAGR through 2043) sustaining Boeing 787 and Airbus A350 production

**Cyclical Demand Factors:** 1. **Geopolitical escalation:** Taiwan strait tensions, NATO-Russia escalation, or Middle East conflicts could accelerate procurement cycles, creating 2–3 year demand spikes 2. **Defense budget fluctuations:** Recession, domestic fiscal constraints, or political shifts in leading spenders (US, China, Europe) could defer procurement 3. **Technology substitution:** Additive manufacturing, advanced composites, or alternative structural materials could reduce per-aircraft titanium content by 15–25% over 10 years 4. **Supply chain disruption recovery:** Bottleneck relief in forging, ingot melting, or mill products could shift demand forward or backward

**Net Conclusion:** Structural demand is likely to sustain 35,000–50,000 tonnes of annual aerospace-grade titanium consumption through 2035, with cyclical variations of  $\pm 10\text{--}20\%$ . Military aviation, while strategically critical, remains a modest proportion of total demand (2–3%), but is concentrated in high-titanium-content platforms, creating focused supply pressure on certified sponge producers.

## GLOBAL TITANIUM SUPPLY CHAIN OVERVIEW

### Mining and Ore Production

Titanium is a relatively abundant element (4th most plentiful metal in Earth's crust) but occurs primarily in compound ores (ilmenite and rutile). The concentration and purification sequence determines supply-chain economics and geopolitical leverage.

### Global Titanium Mineral Production (2024):

Country	Ilmenite (tonnes TiO <sub>2</sub> content)	Rutile (tonnes)	Total Share (%)
<b>China</b>	3,300,000	–	35%
<b>Mozambique</b>	1,900,000	8,000	17.5%
<b>South Africa</b>	1,300,000	100,000	15%
<b>Australia</b>	400,000	200,000	6%
<b>Vietnam</b>	331,500	–	3.5%
<b>Senegal</b>	300,000	–	3%
<b>Canada</b>	350,000	–	3%
<b>Others</b>	1,119,000	142,000	12%
<b>WORLD TOTAL</b>	<b>8,910,000</b>	<b>450,000</b>	<b>100%</b>

**Reserve Distribution:** - **China:** 26% of identified global reserves (~270 million tonnes TiO<sub>2</sub> content) - **Australia:** 21% of reserves - **India:** 15% of reserves - **Others:** Mozambique, Ukraine, South Africa, Canada, Vietnam

**Key Observations:** 1. China dominates current production (35%) but reserves are not disproportionately large, suggesting intensive mining that will face future depletion unless discoveries offset extraction. 2. Mozambique and South Africa represent critical supply sources but are not politically stable or diversified (both countries dependent on ore export, with limited downstream processing). 3. Australia's rutile production (31% of global rutile) is strategically important for aerospace-grade titanium processing via sulfuric acid (chloride) routes.

## Titanium Sponge Production and Refining

Titanium sponge represents the first-stage reduction product from ore concentrates. Only four facilities globally produce aerospace-grade titanium sponge—a critical vulnerability.

### Aerospace-Approved Titanium Sponge Producers (2024):

Producer	Country	Facility	Capacity (tonnes/year)	2024 Output	Utilization
<b>Toho Titanium</b>	Japan	Taoka	40,000	35,000	87.5%
<b>Osaka Titanium</b>	Japan	Amagasaki	25,200	20,000	79.4%
<b>UKTMP</b>	Kazakhstan	Ust-Kamenogorsk	~21,000	19,000	90.5%
<b>AMIC Toho Titanium</b>	Saudi Arabia	Yanbu	15,600	15,000	96.2%
<b>VSMPO-AVISMA</b>	Russia	Verkhnyaya Salda	Formerly 32,000; now ~20,000	~17,000	85%
<b>TOTAL (excl. Russia)</b>	—	—	101,800	89,000	87.4%
<b>TOTAL (incl. Russia)</b>	—	—	121,800	106,000	87.0%

**Reduction Process Technology:** - **Hunter Process** (dominant, calcium-based reduction): Energy-intensive; requires high-purity feedstock; mature, stable process - **Kroll Process** (magnesium-based reduction): Higher yield; lower raw-material efficiency; less common in aerospace applications - **Calcium Hydride Process** (emerging): More energy-efficient; lower emissions; limited scale; under development by IperionX and others

### Critical Constraints:

1. **Aerospace Certification Barriers:** Only four facilities meet aerospace quality standards (AS9100, NADCAP accreditation, DOD/NASA/FAA approvals). New entrants face 3–5 year certification cycles and \$200–500 million capital investment. This certification moat creates quasi-monopolistic leverage for existing producers.
2. **Production Bottleneck (non-aerospace):** China produces 220,000 tonnes of titanium sponge annually but 97% is non-aerospace-certified. Upgrading Chinese production to aerospace standards would require:
  - Facility modifications (\$50–150 million per plant)
  - Process control and quality documentation systems
  - Third-party audits and accreditation (2–3 years minimum)

- Likelihood: Low in near term (2–3 years); moderate over 5–10 years
3. **Capacity Additions:**
- Japan: Toho Titanium announced 10,000 tonnes additional capacity (total to 50,000 tonnes), representing 25% increase
  - Kazakhstan: UKTMP operating near capacity; expansion plans unclear
  - Saudi Arabia: AMIC Toho operating at 96% capacity; limited expansion headroom
  - US domestic revival: IperionX (Virginia) targeting 125 tonnes annually (demonstrator), scaling to 10,000 tonnes within 5 years; timeline to full aerospace certification 2027–2030
4. **Russia Post-Sanctions Impact:**
- VSMPO-AVISMA output fell from 32,000 to ~17,000 tonnes (47% reduction)
  - Western aerospace OEMs (Boeing, Airbus) have successfully diversified away from Russian sponge
  - VSMPO's output now primarily serves Russian defense sector (Su-57, Mil helicopters) and domestic civilian aircraft (MS-21, MC-21 commercial aircraft)
  - Long-term: Russian production unlikely to recover export status while sanctions persist; domestic growth possible if MS-21 production accelerates

### Downstream Processing: Ingot Melting and Mill Products

After sponge production, titanium undergoes consolidation (vacuum arc remelting, VAR) to ingots, followed by forging, rolling, or extrusion into aerospace-qualified mill products. This downstream capacity represents secondary constraint.

#### Key Ingot-Melting and Mill-Product Suppliers:

Company	Country	Function	Capacity Status
<b>PCC</b> (Precision Castparts Corp.)	USA	Forgings, castings, mill products	High capacity, expanding
<b>Aubert &amp; Duval</b>	France	Forgings, ingots, mill products	Modernized 60,000-tonne press; capacity increased 2024
<b>Howmet Aerospace</b>	USA	Forgings, castings, superalloys	Reduced Russian sourcing; expanded alternative suppliers
<b>ATI</b> (Advanced Alloys)	USA	Alloys, engineered mill products	Strong capacity; aerospace-focused
<b>VSMPO-AVISMA</b>	Russia	Integrated (sponge through forgings)	Reduced output; domestic-focused
<b>Kobe Steel, Nippon Steel</b>	Japan	Forgings, mill products	Stable capacity; export-oriented
<b>Baoti (Baoji Titanium Industry)</b>	China	Sponge, forgings, mill products	Largest by volume; mostly non-aerospace-grade
<b>Otto Fuchs KG</b>	Germany	Forgings, rings, aerospace components	Stable capacity; EU-focused
<b>Forgital Group</b>	Italy	Forgings, machined components	Acquired by Stonepeak (Dec 2024); capacity integration ongoing
<b>IperionX</b>	USA	Titanium powder, recycled sponge	125 tonnes/year (demonstrator); targeting 10,000 tonnes/year within 5 years

**Capacity Assessment:** - Forgings and mill-product capacity globally is estimated at 200,000–350,000 tonnes per annum - Utilization rates: 60–75% (post-COVID recovery phase) - Bottleneck locations: Specific large-format forgings (>2 tonnes) requiring 3,000+

tonne presses; limited to 3–4 facilities globally (Aubert & Duval, PCC, VSMPO-AVISMA, Kobe Steel)

## **GEOPOLITICAL & STRATEGIC RISK ASSESSMENT**

### **US–China Rivalry and Aerospace Dominance**

The competition for fifth-generation fighter superiority reflects broader US-China technological and military rivalry, with titanium representing a critical enabler.

**US Strategic Interests:** - **F-35 Global Dominance:** 19+ allied nations operating or committed to F-35 fleets; global deployment of 1,300+ aircraft by 2026 - **Supply-Chain Localization:** DoD prioritizes domestic titanium production as strategic imperative; IperionX expansion and sanctions on Russian suppliers target supply-chain independence - **Allied Interdependence:** Secure titanium supply underpins NATO cohesion; supply disruptions would create transatlantic tensions

**Chinese Strategic Position:** - **Domestic Sufficiency:** J-20 production relies on internally controlled supply chains; Chinese dominance in titanium mining (35% global) provides raw-material security - **Export Control Leverage:** China's 220,000 tonnes annual sponge production (non-aerospace-certified) represents potential future leverage; certification of Chinese sponge would allow export competition - **Belt-and-Road Titanium Access:** Chinese companies have invested in titanium mining in Vietnam, Mozambique, and other BRI countries, securing long-term supply independent of Western suppliers

**Scenario Implications:** - **Intensification:** Escalated US-China tech competition could trigger titanium export restrictions (US sanctions on Chinese aircraft or titanium; Chinese retaliatory restrictions on rare earths or other materials) - **Decoupling:** Complete US-China supply-chain separation would require US domestic titanium capacity expansion (IperionX and others) and EU/allied production localization—feasible but capital-intensive over 5–10 years - **Stalemate:** Current trajectory suggests continued US-allied reliance on Japanese and Kazakh titanium, with Chinese independence for domestic use; neither power achieves unilateral leverage

### **Russia Sanctions and Supply-Chain Weaponization**

Post-2022 Ukraine war sanctions on Russian titanium represent the most consequential material-specific sanctions episode in recent history.

**Historical Context:** - **Pre-2022:** VSMPO-AVISMA supplied ~80% of Boeing's and ~60% of Airbus's titanium requirements - **November 2023:** US Treasury and State Department sanctioned VSMPO-AVISMA and Russian Titanium Resources (RUSTITAN), citing national security concerns - **Response:** Boeing and Airbus had already begun diversification; by 2025, Russian titanium share fell to <20% for Airbus and 0% for Boeing

**Supply-Chain Resilience Evidence:** - Japanese titanium (Toho, Osaka Titanium) successfully absorbed ~15,000–20,000 tonnes displaced from VSMPO-AVISMA -

Kazakhstani (UKTMP) and Saudi Arabian (AMIC Toho) capacity increased to accommodate demand - Aubert & Duval's modernized French facility added ~5,000–8,000 tonnes of forgings capacity - No reported material shortage or aircraft production delays directly attributable to titanium scarcity

**Ongoing Vulnerabilities:** 1. **VSMPO-AVISMA Domestic Production:** Russian output fell to ~17,000 tonnes annually (from 32,000 pre-war); this reduction impacts Russian military aircraft (Su-57, Mi-8/17 helicopter) production indirectly through reduced availability for civilian uses and export revenues 2. **Supply-Chain Traceability:** Estimates suggest 20–30% of Russian titanium exports are routed through third countries (China, Kazakhstan, Türkiye) to circumvent sanctions; Western compliance monitoring faces attribution challenges 3. **Strategic Stockpiling:** Some aerospace OEMs increased titanium inventory ahead of sanctions, creating artificial demand buffer; as inventories normalize (2026–2027), underlying demand may fall, reducing pricing pressure on suppliers

**Policy Crosscurrents:** - **Arguments for Extended Sanctions:** Western aerospace has demonstrated supply-chain resilience; continuing titanium exclusion prevents revenues flowing to Russia's war effort; formal sanctions would eliminate legal ambiguity - **Arguments Against Escalation:** Current de-facto diversion of VSMPO-AVISMA to Russian military use already maximizes impact; formal sanctions add legal compliance burden without material supply-chain benefit; risk of supply-chain volatility if China or Kazakhstan face pressure to enforce sanctions

### **NATO Strategic Sourcing and European Defense Autonomy**

European defense autonomy initiatives directly intersect with titanium supply-chain sovereignty.

**RESourceEU Initiative** (announced December 2025): - €3 billion allocation to support critical minerals sector development and stockpiling - Centralized procurement authority to coordinate across 27 EU member states - Strategic reserve targets: 3–6 months of consumption for priority critical materials - Titanium explicitly under review for designation as critical raw material (formal determination expected 2026–2027)

**European Titanium Strategy Implications:** 1. **Stockpiling:** Establishing 3–6 month strategic reserve would require ~2,500–5,000 tonnes of aerospace-grade titanium sponge or mill products; representing €75–150 million acquisition cost at current market prices 2. **Localized Production:** EU emphasis on domestic and allied titanium processing would support increased capacity in France (Aubert & Duval), Germany (Otto Fuchs), Italy (Forgital), and UK (BAE Systems) 3. **Allied Sourcing:** Long-term offtake agreements with Japanese (Toho), Kazakhstani (UKTMP), and Saudi Arabian (AMIC Toho) producers to secure supply outside China-Russia axis 4. **GCAP Integration:** Sixth-generation fighter program expected to source 100% of titanium requirements from NATO-allied suppliers by development phase (2025 onwards)

**Strategic Vulnerability:** - European titanium consumption (~8,000–12,000 tonnes annually for aerospace and defense) is modest relative to global supply but regionally concentrated; reliance on four suppliers creates geopolitical leverage if sanctions, war, or

supply disruptions occur - Certification of Chinese aerospace-grade titanium could disrupt European supply strategies if China chooses to export; current policy assumes Chinese supply exclusion, limiting European leverage

### **India's Defense Industrial Push and Regional Supply Chain**

India represents an emerging strategic player in titanium supply chain, driven by defense self-sufficiency ambitions.

**Current Position:** - Indian titanium mining: 222,000 tonnes mineral production (2.4% global share); mostly export-oriented - Titanium sponge production: ~300 tonnes annually (Titanium Sponge Plant of India, Kerala); severely insufficient for domestic demand - Import dependency: 90%+ of aerospace-grade titanium sourced from Japan, Kazakhstan, and Russia (historically)

**Strategic Initiatives:** 1. **Tejas Program Supply Localization:** HAL and suppliers targeting 64%+ indigenous content; however, titanium sponge and aerospace forgings remain primarily imported 2. **Domestic Sponge Capacity:** Plans to increase TSPI production to 2,000–5,000 tonnes annually (timeline: 2027–2032) 3. **Rafale-Tata Partnership:** Partial assembly of Rafale fighters in India; technology transfer includes fuselage manufacturing (modest titanium content in skin panels) 4. **Regional Supply Dominance:** India's large aerospace market (Tejas, Rafale, F-35 procurement) creates potential for local supplier development; however, infrastructure and capital constraints limit pace

**Geopolitical Implications:** - Indian self-sufficiency in titanium sponge (if achieved) would create alternative supply hub independent of Japan-Kazakhstan-Russia nexus - India-Japan-US "Quad" framework for semiconductor and critical minerals cooperation could extend to titanium supply agreements - Pakistan's potential F-16 and JF-17 acquisition would increase regional demand but not alter global supply dynamics

### **Middle East Procurement and Regional Supply Disruption Risks**

Middle Eastern defense procurement, while significant in absolute volume, faces unique geopolitical risks that could impact global supply chains.

**Recent Developments:** - Saudi Arabia's announced F-35 acquisition (November 2025) positions Kingdom as first Arab F-35 operator - UAE demand for fifth-generation fighters (KF-21 Boramae offer, Su-57 interest) creating competitive procurement dynamics - Egypt's prolonged quest for advanced fighter jets (currently transitioning from Su-35 consideration to F-15 pursuit)

**Supply-Chain Risks:** 1. **Iran-Russia Military Cooperation:** Iran's reported procurement of Su-35 aircraft from Russia (substitution for cancelled Su-35 sale to Egypt) creates potential for sanctions-evasion supply chains through Iran-Russia axis 2. **Gulf Stability:** Regional conflicts involving Saudi Arabia, UAE, or other suppliers could disrupt logistics; however, titanium supply itself (sourced from Japan, Kazakhstan, global routes) would not be directly impacted unless major supplier nation embroiled 3. **Transshipment Hubs:** UAE and other Gulf ports serve as transshipment points for global trade; regional conflicts could create temporary logistics delays but not supply disruptions

**Strategic Conclusion:** Middle East titanium demand is modest (<2% of global aerospace consumption) and does not represent independent supply-chain vulnerability; however, regional geopolitical escalation could create indirect supply-chain friction through port congestion or shipping route disruptions.

## **GOVERNMENT POLICY, DEFENSE BUDGETS & INDUSTRIAL STRATEGY**

### **Global Defense Budget Acceleration**

Defense spending has entered a structural growth phase driven by geopolitical recalibration, NATO rearmament, and defense-industrial sovereignty priorities.

**Global Military Expenditure Trends:** - **FY2024:** \$2.72 trillion (9.4% YoY increase); steepest annual increase since Cold War - **FY2025 Projected:** \$2.8+ trillion (3.2% YoY growth) - **FY2028 Estimated:** Approaching \$3.0 trillion - **Geographic Distribution (FY2024):** - North America (US-Canada): \$1.05 trillion (38%) - Europe (NATO): \$454 billion (17%) - Asia-Pacific: \$550+ billion (20%) - Russia: \$88+ billion (3%) - China: \$314 billion (12%) - Others: ~\$240 billion (9%)

**Policy Drivers:** 1. **NATO Rearmament Imperative:** Post-Ukraine war acceleration toward 2% GDP defense spending threshold; Germany, Poland, Denmark, UK, France all increasing budgets 10–16% YoY 2. **Indo-Pacific Security Concerns:** Japan (+15% 2025), South Korea, Australia all accelerating procurement in response to China’s military modernization 3. **Defense Industrial Sovereignty:** Governments linking procurement to domestic manufacturing; “Make-in-country” policies driving localized aerospace production

### **“Make-in-Country” Initiatives and Industrial Policy**

Nations are prioritizing indigenous aerospace capabilities as strategic autonomy enabler.

**Key Programs:** - **India:** Tejas Mk1A, AMCA development; target 64%+ indigenous content - **Japan:** F-X sixth-generation development; target 100% domestic design and manufacture (with Lockheed Martin subsystem involvement) - **South Korea:** KF-21 Boramae; fully indigenous design and manufacture - **Turkey:** KAN fighter development; domestic design, phased industrial participation - **UK-Italy-Japan:** GCAP sixth-generation; distributed manufacturing across allied nations - **Russia:** Su-57 production despite sanctions; forced toward complete domestic supply chains - **EU:** Increasing intra-European defense industrial integration (Eurofighter, FCAS/Tempest) to reduce external dependency

**Titanium Supply-Chain Implications:** - Localization drives demand for certified titanium sponge and forging capacity within or near manufacturing nations - Japan and Europe are expanding capacity; India and South Korea seeking capacity development - China benefits from integrated supply chains; less reliant on external titanium sourcing - Global supply chains increasingly bifurcating: NATO-aligned (Japan-Kazakhstan-Saudi Arabia-US), China-aligned (domestic), Russia (forced autarky)

## Titanium as Strategic Material: Classification and Stockpiling

Titanium's formal designation as "critical" or "strategic" material varies by jurisdiction, creating policy asymmetry.

**United States:** - **Formal Status:** Titanium not explicitly designated as "critical mineral" under Defense Production Act (DPA) - **Defense Prioritization:** DoD designates titanium as "strategic material" requiring domestic supply assurance; IperionX facility expansion funded via DPA authorities - **Sanctions Architecture:** November 2023 OFAC/State Department sanctions on Russian titanium suppliers elevated titanium to strategic sanctions target - **Domestic Capacity Initiative:** Target to achieve 10,000 tonnes/year US titanium sponge production within 5 years (IperionX); currently <200 tonnes/year

**European Union:** - **Formal Status:** Titanium not yet listed in EU Critical Raw Materials Regulation (as of January 2026) but under strategic review - **RESourceEU Framework:** €3 billion allocation to critical minerals includes potential titanium stockpiling - **Designation Timeline:** EU Critical Raw Materials Act determination expected 2026–2027 - **Strategic Stockpiling:** If designated critical, EU would establish 3–6 month strategic reserve (~2,500–5,000 tonnes)

**China:** - **Supply Assurance:** Domestic dominance in titanium mining and sponge production provides supply security; no formal "critical materials" designation needed - **Export Control Potential:** Could weaponize titanium supply if geopolitical tensions escalate; currently no export restrictions

**Implications:** - Formal designation of titanium as critical material would trigger government-coordinated procurement, strategic reserves, and domestic capacity investment - Current informal strategic prioritization (DoD focus, DPA authorities, sanctions targeting) achieves supply-assurance objectives without formal designation - If titanium is formally designated critical in EU/NATO, supply-chain fragmentation between NATO-aligned and China-aligned sources would accelerate

## MAJOR GLOBAL PRODUCERS OF INDUSTRY-GRADE & AEROSPACE-GRADE TITANIUM

### Mining and Primary Production

#### Titanium Mineral Mining:

Company	Country	Ore Type	Primary Market	Public/Private	Defense Exposure
<b>Tronox Limited</b>	USA	Ilmenite, rutile mining	Pigment, titanium sponge feedstock	Public (NYSE: TROX)	Indirect (sponge feedstock)
<b>Iluka Resources</b>	Australia	Rutile, zircon mining	Aerospace-grade sponge feedstock	Public	Indirect
<b>Rio Tinto (mineral sands)</b>	Australia	Ilmenite, rutile mining	Pigment, aerospace feedstock	Public	Indirect
<b>China Titanium Industrial Group</b>	China	Ilmenite mining	Domestic sponge production	State-owned	Indirect
<b>Kin Minerals</b>	Mozambique	Ilmenite mining	Export to processors	Private	Indirect
<b>Kumba Iron Ore (formerly Kumba)</b>	South Africa	Mineral sands division	Pigment, industrial	Public	Indirect
<b>Vietnam Titanium Limited</b>	Vietnam	Ilmenite mining	Domestic and export	Private	None identified

**Notes:** Mining represents upstream feedstock; direct defense exposure limited. Strategic importance lies in ore supply security to sponge producers. China's dominance (35% global ilmenite production) creates upstream leverage; however, multiple secondary suppliers limit single-source risk.

## Titanium Sponge Production (Aerospace-Certified)

### Critical Constraint Manufacturers:

Producer	Country	Facility Location	Capacity (t/yr)	Certification	Customers (Public)
<b>Toho Titanium Co., Ltd.</b>	Japan	Taoka, Ehime	40,000	AS9100, NADCAP, AMS	Boeing, Airbus, Lockheed Martin, Rolls-Royce (reported)
<b>Osaka Titanium Manufacturing Co.</b>	Japan	Amagasaki	25,200	AS9100, NADCAP	Similar (OEM-specific contracts confidential)
<b>Ust-Kamenogorsk Titanium and Magnesium Plant (UKTMP)</b>	Kazakhstan	Ust-Kamenogorsk	~21,000	AS9100, NADCAP	Boeing, Airbus, US-allied defense contractors
<b>AMIC Toho Titanium Metal Co.</b>	Saudi Arabia	Yanbu	15,600	AS9100, NADCAP	General aerospace OEMs
<b>VSMPO-AVISMA Corp.</b>	Russia	Verkhnyaya Salda	Estimated 20,000 (post-2022 reduction)	GOST-certified; not US/NATO aerospace-approved (post-2023 sanctions)	Domestic (Rostec group); limited export (traceability concerns)

**Second-tier Producers (Limited Aerospace Certification):** - **Indian Titanium Sponge Plant (TSPI)** (India): ~300 tonnes/year; developing aerospace certification - **Aeroalloy Technologies** (India): Emerging capacity; aerospace certification in progress

**Emerging/Development-Stage:** - **IperionX Limited** (USA, Virginia): 125 tonnes/year demonstrator facility; targeting 10,000 tonnes/year within 5 years; aerospace-grade specification target - **Kronos Worldwide** (Luxembourg-based titanium pigment/feedstock producer): No direct titanium sponge production; supplies feedstock to sponge manufacturers

**Policy Observation:** Four-producer constraint on aerospace-certified sponge creates structural scarcity and pricing power for incumbent producers. Barriers to entry (certification, capital, technical expertise) are high; new capacity addition takes 5–10 years minimum. This oligopolistic structure underpins recommendations for supply-chain diversification and domestic capacity investment.

**Titanium Ingot, Forging, and Mill-Product Manufacturers**

**Integrated Producers (Sponge through Finished Components):**

Company	Country	Capabilities	Defense Exposure	Notes
<b>VSMPO-AVISMA</b>	Russia	Sponge, ingots, forgings, mill products	Russian defense (Su-57, Mi-series helicopters)	Sanctioned; Western customers discontinued 2023
<b>Howmet Aerospace Corp.</b>	USA	Castings, forgings, mill products	F-35, F-22, Boeing 787, military engines (Pratt & Whitney, GE)	Transitioned away from Russian sourcing; expanded alternative suppliers
<b>PCC (Precision Castparts Corp.)</b>	USA	Forgings, castings, superalloys	F-35, Boeing 787, military engines	Leading US capacity; publicly traded (subsidiary of Berkshire Hathaway)

**Specialized Forging and Mill-Product Producers:**

Company	Country	Primary Products	Defense Programs	Scale
<b>Aubert &amp; Duval</b>	France	Ingots, forgings, mill products	Rafale, FCAS/Tempest	Modernized 60,000-tonne press (2024)
<b>ATI (Advanced Titanium Industries)</b>	USA	Advanced titanium alloys, mill products	F-35, defense engines	Specialty alloys; high-margin products
<b>Otto Fuchs KG</b>	Germany	Forgings, rings, precision components	Eurofighter Typhoon, FCAS/Tempest	European-focused; strong NATO ties
<b>Kobe Steel Ltd.</b>	Japan	Forgings, mill	F-35 (assembly),	Japanese capacity;

Company	Country	Primary Products	Defense Programs	Scale
		products, superalloys	civil and military	export-oriented
<b>Nippon Steel &amp; Sumitomo Metal Corp.</b>	Japan	Forgings, mill products	F-35, civil aerospace	Diversified aerospace supplier
<b>Forgital Group</b>	Italy	Forgings, precision machined components	Eurofighter Typhoon, FCAS/Tempest, defense contractors	Acquired by Stonepeak Infrastructure Partners (Dec 2024) for capacity expansion
<b>Mettis Aerospace</b>	USA	Forgings, machined components	F-35, Boeing 787, military programs	Established supplier; capacity sufficient
<b>Baoti (Baoji Titanium Industry Co.)</b>	China	Sponge, ingots, forgings, mill products	Domestic (J-20, J-31); export via export-control channels	Largest by volume globally; non-aerospace-grade dominance
<b>Scot Forge</b>	USA	Custom forgings, aerospace/defense-specific	Defense contractors, military aircraft	Specialized capacity; long lead times
<b>Mattco Forge</b>	USA	Aerospace and defense forgings	Defense programs (specific programs confidential)	Mid-tier capacity

**Downstream Integration (Machining, Assembly): - Howmet Aerospace (USA):** Integrated casting, forging, and machining for jet engines and airframes - **Various aerospace suppliers** (Lockheed Martin, Boeing, Northrop Grumman, Airbus, Dassault, BAE Systems): In-house machining and assembly of titanium components

## Titanium Recycling and Scrap Processors

Titanium recycling provides secondary supply stream; efficiency gains reduce primary sponge demand.

Company	Country	Process	Capacity Status	Defense Exposure
<b>IperionX Limited</b>	USA	Titanium powder from aerospace scrap	125 tonnes/year demonstrator	AFRL contracts; DoD interest
<b>Commercial Metals Company</b>	USA	Scrap collection and processing	General scrap; limited titanium focus	Indirect
<b>Various regional recyclers</b>	Global	Scrap collection, reprocessing	Limited published capacity data	Indirect

## REAL-TIME & RECENT PUBLIC DEVELOPMENTS

### Aerospace Production Announcements (2025–2026)

**F-35 Lightning II Record Deliveries: - January 7, 2026:** Lockheed Martin announced 191 F-35 deliveries in 2025, setting all-time program record - **Production tempo:** 5× faster than any other allied fighter; global fleet approaching 1,300 aircraft - **International expansion:** Italy (+25), Denmark (+16) expanding programs of record; Finland and Belgium receiving first domestic deliveries - **Financing:** Lots 18–19 contract finalized September 2025 for up to 296 F-35s over \$24 billion; demonstrates sustained procurement commitment through 2030s

**Chinese Fighter Production Acceleration: - October 2025:** Changchun Air Show displayed 300th J-20 aircraft as symbolic production milestone - **Production rate:** Estimated 70–120 J-20 units annually; cumulative 300+ by October 2025 - **Export interest:** FC-31 variant marketed for export; 30–50 units in various development stages - **Structural capacity:** CAC pulse-line production enables 15–20 simultaneous airframe assembly; digitalized factories and AI quality control achieving consistent output

**European Fighter Demand Surge: - November 2025:** Eurofighter consortium announced intention to increase production from 12 to 20 aircraft annually, with potential to reach 30/year dependent on export orders - **Rafale backlog:** Dassault closed 2025 with 220-aircraft backlog (45 French, 175 export); 26 delivered in 2025; current delivery rate 2.3 aircraft/month - **Recent export wins:** Iraq (14 potential F4s, late-stage negotiations), India (114 additional, MRFA program), Ukraine (100 potential, letter of intent November 2025)

**South Korea KF-21 Boramae Transition: - May 20, 2025:** First production model KF-21 entered final assembly at Korea Aerospace Industries (KAI) Sacheon facility - **Delivery timeline:** First aircraft scheduled delivery to ROKAF 2026 - **Program scale:** 12 aircraft in

various assembly stages as of May 2025; 20-aircraft initial contract; 120 total planned by 2032 - **Capability acceleration:** Air-to-ground combat capability accelerated to 2027 (originally 2029), demonstrating confidence in technical maturity

**India Tejas Mk1A Procurement: - September 25, 2025:** Ministry of Defence and Hindustan Aeronautics Limited signed contract for 97 Tejas Mk1A (₹62,370 crore, approximately \$7.5 billion) - **Deliveries:** 2027–28 through 2033 (six-year manufacturing window) - **Industrial impact:** 105 Indian suppliers supporting ecosystem; estimated 11,750 jobs annually over contract period; 64%+ indigenous content - **Total IAF commitment:** Combined with 2021 order of 83 aircraft, IAF will operate 180+ Tejas Mk1A by 2033

### Supply Chain and Strategic Sourcing Developments

**Russia-Ukraine War Supply Chain Adaptation: - January 2025:** European aerospace firms (Airbus, Safran, Rolls-Royce) report successful completion of supply-chain transition away from Russian titanium suppliers - **VSMPO-AVISMA Impact:** Russian titanium sponge production estimated at ~17,000 tonnes annually (down from 32,000 pre-2022); majority output now serves domestic Russian military and civilian aircraft programs - **Western Diversification:** Boeing and Airbus transitioned to 100% and 80% non-Russian sourcing, respectively, by 2024–2025; Japanese (Toho, Osaka), Kazakhstani (UKTMP), and Saudi Arabian (AMIC Toho) capacity absorbed demand

**US Domestic Titanium Capacity Initiative: - November 2023:** DoD announced support for IperionX Limited (Virginia facility) to scale up titanium powder production - **Initial Phase:** 125 metric tons annual capacity (demonstrator) - **Target Scale:** 10,000 metric tons annually within five years; timeline to full aerospace certification 2027–2030 - **Technology:** Novel calcium hydride reduction process; zero-emissions target; recycled scrap feedstock capability - **Strategic Rationale:** Reduce US dependency on Russian, Japanese, and Kazakhstani titanium; establish domestic surge capacity for wartime scenarios

**European Industrial Consolidation: - December 2024:** Stonepeak Infrastructure Partners acquired Italian Forgital Group (titanium and aluminum forging specialist) - **Strategic Intent:** Consolidate European titanium forging capacity; support FCAS/Tempest (sixth-generation fighter) supply chain - **Capacity Expansion:** Post-acquisition plans include modernization of Forgital facilities and potential acquisition of complementary suppliers - **Defense Integration:** Coordination with Leonardo (GCAP prime contractor) expected to optimize supply chain for future platforms

**EU ResourceEU Action Plan (December 2025): - Funding:** €3 billion allocated to support critical raw materials sector development and stockpiling - **Governance:** European Commission to establish central procurement authority coordinating across 27 member states - **Critical Materials Review:** Titanium explicitly under evaluation for designation as critical raw material; determination expected 2026–2027 - **Strategic Reserves:** Target 3–6 months of consumption stockpile for designated critical materials - **Supply Agreements:** Long-term offtake agreements with allied producers (Japan, Kazakhstan, Saudi Arabia) prioritized

## Titanium Market Developments

**Price Movements and Market Dynamics (2025–2026):** - **Aviation Titanium Alloy Market:** Forecast to grow from \$4.7 billion (2025) to \$9.15 billion (2035), representing 6.9% CAGR - **Military Titanium Alloy Market:** Expected to expand from estimated \$12.34 billion (2024) to higher levels through 2034 (7.2% CAGR) - **Global Titanium Market:** Projected growth from \$28.58 billion (2024) to \$30.44 billion (2025) and \$53.65 billion by 2034 - **Supply Pressure:** Continued aviation industry production ramps (Boeing 787 targeting 8–10 per month by 2026; Airbus A350 accelerating) maintaining demand pressure on aerospace-certified sponge

**Capacity Announcements:** - **Toho Titanium (Japan):** Announced 10,000 tonnes additional capacity; total capacity to reach 50,000 tonnes annually (25% increase) - **AMIC Toho (Saudi Arabia):** Operating at 96% of 15,600-tonne capacity; limited expansion headroom - **UKTMP (Kazakhstan):** Maintaining 19,000-tonne output; expansion plans not publicly announced - **China:** Continued capacity growth to 260–320 tonnes annually; certification barriers prevent aerospace supply contributions

## Sanctions and Geopolitical Developments

**Russia-Titanium Sanctions Debate (September 2025):** - **Pressure for Extension:** Policy advisors and defense analysts argue for extending US/EU sanctions to Russian titanium following successful Western supply-chain diversification - **Current Position:** Titanium remains excluded from post-2022 Russia sanctions despite pressure - **Industry Position:** Boeing and Airbus report reduced reliance on Russian titanium (Airbus now <20%); inventory buffers provide transition cushion - **VSMPO Status:** Annual sponge output declined to ~17,000 tonnes; exports constrained by sanctions; traceability concerns for China-routed shipments

**Saudi Arabia F-35 Announcement (November 2025):** - **Historic Significance:** Saudi Arabia announced as first Arab nation to acquire F-35 fighter jets - **Defense Integration:** Complements existing 70 Eurofighter Typhoons and 150+ F-15 aircraft - **Implications:** Increases global F-35 demand; adds 50–80 aircraft to potential future procurement - **Regional Impact:** Signals expanded US military partnership; potential trigger for UAE and other regional air-force modernization announcements

**Ukraine Defense Procurement (November 2025):** - **Rafale Letter of Intent:** Ukraine and France signed letter of intent for potential acquisition of up to 100 Rafale F4 fighters over next decade - **Implementation Timeline:** Actual procurement contingent on war conclusion and defense budget allocation - **Titanium Demand:** 100 Rafale aircraft would require ~160 tonnes of aerospace-grade titanium (assuming 1.6 tonnes per aircraft)

## SCENARIO ANALYSIS (NON-FINANCIAL)

This section presents qualitative scenarios for global titanium demand expansion through 2030 and 2035, reflecting different geopolitical and strategic trajectories.

### Base Case: Gradual Defense Escalation with Supply-Chain Stabilization

**Assumptions:** - Global defense spending continues 5–7% annual growth through 2030, moderating to 3–4% through 2035 - Fighter jet production increases as scheduled: F-35 to 190/year by 2026, sustained through 2035; J-20 to 100/year by 2027; Typhoon to 20/year by 2026, potential 30/year by 2030 - NATO rearmament drives European fighter procurement; no major war or proxy escalation - Taiwan strait remains stable; China continues military modernization without crisis - US-China tech competition continues; sanctions framework stable (no new Russia sanctions extensions) - Titanium supply chain stabilizes with Japanese capacity increase (Toho +10,000 tonnes/year by 2027) and IperionX US domestic capacity (5,000 tonnes by 2029) - Commercial aviation (Boeing 787, Airbus A350) normalizes to 70–90 aircraft per month by 2028

**Projected Titanium Demand (2030 and 2035):** - **Military aviation:** 1,200–1,400 tonnes annually by 2030; 1,400–1,700 tonnes by 2035 - **Commercial aerospace:** 35,000–45,000 tonnes by 2030; 45,000–55,000 tonnes by 2035 - **Marine/Naval/Industrial:** 5,000–7,000 tonnes by 2030; 6,000–8,000 tonnes by 2035 - **Total demand:** 41,000–53,000 tonnes annually by 2030; 52,000–65,000 tonnes by 2035

**Supply-Chain Response:** - **Total aerospace-certified capacity by 2030:** 115,000–125,000 tonnes/year (Japan +10,000; US +5,000; others stable) - **Supply-demand balance:** Moderate utilization 36–46% by 2030, potentially tightening to 42–54% by 2035 - **Price trajectory:** Modest increases (3–5% annually in real terms) driven by demand growth; no sharp spikes

**Risks/Sensitivities:** 1. **Commercial aviation upside:** If Boeing 787 or A350 production exceeds base case (100+ aircraft/month combined), demand could reach 60,000+ tonnes annually by 2030, creating capacity pressure 2. **Fighter production acceleration:** If China J-20 production reaches 120+ units/year and F-35 reaches 200/year, military demand could reach 1,500–1,800 tonnes, expanding total to 42,000–56,000 tonnes by 2030 3. **IperionX delay:** If US domestic capacity adds only 2,000–3,000 tonnes by 2030 (vs. 5,000-tonne target), supply pressure increases 4. **China aerospace sponge certification:** If Chinese producers achieve aerospace-grade certification by 2030, global capacity could increase by 50,000+ tonnes, eliminating supply constraints

### High Defense-Escalation Case: Geopolitical Crisis Scenario

**Assumptions:** - Taiwan strait military confrontation or NATO-Russia escalation in Eastern Europe (2026–2028) triggers acute defense spending surge - Global defense budgets accelerate to 8–10% annually through 2030; fighter procurement prioritized - F-35 production escalates to 250+ aircraft annually by 2028 (wartime mobilization pace) - Eurofighter Typhoon production increases to 30+ aircraft/year by 2027; additional export orders for Rafale and Gripen - China accelerates J-20/J-31 production to 150+/year in

response to perceived threat - Russia Su-57 program accelerates (sustained Russian defense spending); export demand increases if sanctions ease - Commercial aviation demand declines as global travel disruption occurs; Boeing 787 production falls to 5/month; Airbus A350 production constrained - Supply-chain disruptions: Shipping delays, logistics congestion; geopolitical supply restrictions (e.g., Kazakhstan-Russia tensions)

**Projected Titanium Demand (2030 and 2035):** - **Military aviation:** 2,000–2,500 tonnes annually by 2030; 1,800–2,200 tonnes by 2035 (post-crisis normalization) - **Commercial aerospace:** 15,000–25,000 tonnes by 2030 (depressed); 35,000–45,000 tonnes by 2035 (recovery) - **Marine/Naval/Industrial:** 8,000–10,000 tonnes by 2030 (elevated military spending); 6,000–8,000 tonnes by 2035 - **Total demand:** 25,000–37,500 tonnes annually by 2030; 41,000–55,000 tonnes by 2035

**Supply-Chain Response:** - **Shortfall scenario:** Available aerospace-certified capacity (100,000–110,000 tonnes) insufficient to meet 2030 military + commercial peak demand of 27,000–36,500 tonnes (24–33% utilization surge) - **Strategic stockpile drawdowns:** NATO and allied nations release strategic reserves to bridge supply gaps (2,000–5,000 tonnes annually, 2026–2029) - **Russian titanium re-entry:** Potential sanctions waiver on Russian titanium if geopolitical tensions require supply surge; VSMPO-AVISMA production increases to 25,000–30,000 tonnes annually within 12–18 months (requires extraordinary effort) - **Emergency capacity activation:** IperionX and other emerging suppliers accelerate timelines; potential 2,000–3,000 tonnes of emergency capacity by 2027–2028 - **Price trajectory:** Sharp increases (15–30% annually in nominal terms, 2027–2029); supply allocation mechanisms favored toward defense; commercial aviation supply rationing

**Risks/Sensitivities:** 1. **Military demand explosion:** Fighter orders far exceeding production capacity; backlog extension to 15+ years 2. **Supply-chain fracture:** Geopolitical split between NATO-aligned (Japan-Kazakhstan) and China-Russia supply chains; dual-track development required 3. **Certification gaps:** Acceleration of non-aerospace-certified Chinese sponge to 50,000+ tonnes within 2–3 years (unlikely but potential emergency measure) 4. **Post-conflict oversupply:** If crisis resolved 2028–2030, rapid demand destruction creates capacity over-supply and price collapse 2030–2035

#### **De-escalation and Substitution Case: Technology Disruption Scenario**

**Assumptions:** - Geopolitical tensions ease 2026–2027; global defense spending plateaus at 2–3% growth through 2035 - Advanced composite and alternative material research accelerates; titanium content per aircraft declines 15–25% by 2030 through design optimization - Additive manufacturing (3D printing) of titanium components scales to 20–30% of small-part manufacturing by 2030; reduces titanium scrap waste and per-unit consumption - Unmanned aircraft and drone production accelerates, partially substituting for manned fighter demand; UAVs use ~30–50% less titanium per unit than manned fighters - Electric and hybrid aircraft development (commercial focus) reduces conventional engine titanium demand by 20–30% by 2035 - Commercial aviation demand remains stable at current levels; no acceleration - Titanium recycling infrastructure expands; secondary supply captures 15–20% of total aerospace demand by 2035

**Projected Titanium Demand (2030 and 2035):** - **Military aviation:** 900–1,100 tonnes annually by 2030 (lower per-aircraft content); 800–1,000 tonnes by 2035 - **Commercial aerospace:** 30,000–38,000 tonnes by 2030 (flatter trajectory); 32,000–42,000 tonnes by 2035 (alternative materials offset growth) - **Recycled supply contribution:** 2,000–3,000 tonnes by 2030; 6,000–8,000 tonnes by 2035 (secondary source expansion) - **Total primary titanium demand:** 30,000–39,000 tonnes annually by 2030; 26,000–35,000 tonnes by 2035 (declining trajectory)

**Supply-Chain Response:** - **Capacity surplus:** Total aerospace-certified capacity (120,000+ tonnes by 2030) significantly exceeds demand (30,000–39,000 tonnes); utilization falls to 25–32% - **Producer rationalization:** Marginal capacity closures or conversion to specialty applications; consolidation among competitors - **Price trajectory:** Structural decline in real terms (5–8% annually) driven by excess capacity; potential margin compression for incumbents - **New entrant opportunity:** Lower prices enable non-traditional suppliers or emerging markets to develop capacity; Chinese aerospace-grade sponge certification becomes viable business case

**Risks/Sensitivities:** 1. **Composite adoption faster than expected:** If alternative materials capture 35–40% of airframe weight by 2030 (vs. 15–25% base case), primary titanium demand could fall to 22,000–28,000 tonnes, creating severe overcapacity 2. **Commercial aviation surprise demand:** Unexpected surge in hypersonic or advanced aircraft programs could maintain demand despite substitution 3. **Recycling infrastructure failure:** If secondary supply development lags expectations, primary demand reduction limited to 5–10%, maintaining moderate capacity pressure 4. **Geopolitical stabilization extended:** If conflict tensions resolve earlier than assumed, military demand collapse could be abrupt (2025–2026) rather than gradual

## KEY UNCERTAINTIES & DATA LIMITATIONS

This report synthesizes publicly available information but is subject to material limitations and uncertainties that should inform any downstream analysis or policy decisions.

### Classified and Proprietary Data Gaps

**Aircraft-Specific Specifications:** - Exact titanium alloy compositions and percentage by component in modern fighter jets are typically classified or proprietary - Estimates of titanium content (25–42% of airframe weight) are derived from declassified historical documents (F-22 Raptor specifications), industry publications, and defense analyst assessments - F-35 and newer platforms contain design refinements not publicly disclosed; actual titanium content may vary from estimates by  $\pm 10\text{--}20\%$  - Chinese J-20 and Su-57 specifications are not transparently disclosed; foreign assessments rely on reverse engineering from satellite imagery and intelligence assessments with unknown confidence intervals

**Production Rates and Capacity:** - Chinese fighter production rates (J-20: 70–120 units/year estimates) reflect satellite imagery analysis, supply-chain monitoring, and analyst assessments; official Chinese figures not published - Confidence intervals for Chinese production:  $\pm 15\text{--}25\%$  (wide uncertainty range) - Russian Su-57 production is opaque due to Ukraine war disruptions and supply-chain fragmentation; estimates range 10–20 units/year with low confidence - Aerospace-grade titanium sponge capacity utilization figures are derived from industry publications; actual utilization rates may vary by facility and quarter

### Supply-Chain Attribution and Traceability

**Russian Titanium Exports Post-Sanctions:** - Estimated 20–30% of Russian titanium exports are routed through third countries (China, Kazakhstan, United Arab Emirates, Singapore) to obscure origin - Western compliance monitoring faces persistent attribution challenges; “actual” Russian export volumes may exceed reported sanctioned flows by 15–30% - This opacity complicates assessment of VSMPO-AVISMA’s true export revenue and impact

**Chinese Aerospace-Grade Titanium Certification:** - Chinese capacity to produce aerospace-grade titanium sponge is growing but not transparently reported - Estimates of non-aerospace-grade proportion (97% of 220,000 tonnes) derive from analyst assessments; actual certification status of some Chinese sponge grades remains uncertain - Potential for Chinese aerospace-grade sponge to comprise 10–20% of output by 2030 is feasible but timing and volume highly uncertain

### Data Availability Constraints

**Titanium Demand by End Application:** - Published titanium market reports rarely disaggregate demand by military vs. civil aviation, making precise military demand estimation difficult - Commercial aerospace titanium demand is better tracked (Boeing,

Airbus publicly report aircraft deliveries); military demand requires indirect inference from aircraft specifications and production rates

**Geopolitical Supply-Chain Mapping:** - Detailed supply-chain mapping of titanium value chain from mining through finished components is commercially sensitive; defense contractors protect supplier relationships - Public data available at mining, sponge, and major OEM levels; mid-tier forging and processing remains opaque

**Pricing Data:** - Titanium sponge pricing is typically negotiated long-term between producers and OEMs; spot prices are not widely published - Market reports provide estimated ranges (e.g., \$8–12 per kilogram for aerospace-grade sponge) but lack transparency on actual transaction prices or pricing trends - Price forecasts rely on analyst models incorporating demand and capacity factors; predictive confidence is moderate

### **Geopolitical Contingency Sensitivity**

**Taiwan Strait and Indo-Pacific Scenarios:** - Probability and timeline of military conflict in Taiwan strait are highly uncertain; civilian analysis relies on defense assessments with intrinsic uncertainty - Impact modeling of such conflicts on supply chains requires assumptions about escalation path, participant nations, sanctions architecture, and duration—all subject to large forecast error ranges

**NATO-Russia Escalation:** - Current Ukraine war represents subset of possible NATO-Russia confrontation scenarios; probability of broader NATO-Russia military engagement is debated among strategic analysts - Supply-chain impact modeling of different escalation paths is illustrative rather than predictive

### **Technology Substitution Uncertainty**

**Advanced Materials and Composites:** - Rate of titanium displacement by composite, ceramic matrix composite (CMC), or alternative materials depends on: - Research breakthroughs (probabilistic, difficult to forecast) - Certification timelines (5–10 years typical) - Cost competitiveness vs. titanium (currently unfavorable for many applications) - Manufacturing scale-up challenges - Substitution scenarios presented here reflect analyst consensus but are subject to  $\pm 25$ –50% error in timing and magnitude

**Additive Manufacturing (3D Printing):** - Current additive manufacturing accounts for <5% of aerospace titanium consumption - Path to 15–30% by 2030–2035 is plausible but depends on regulatory approval, cost reduction, and material property validation still under development - Some defense applications (classified stealth or performance-critical components) may resist AM adoption due to design constraints or certification barriers

### Statistical Confidence Intervals

The following ranges represent estimated confidence intervals ( $\pm 1$  standard deviation) for key metrics:

Metric	Central Estimate	Confidence Range	Key Uncertainties
<b>Global military fighter aircraft titanium demand (2025-2026)</b>	1,200 tonnes/year	950-1,500 tonnes/year	Chinese production rates, F-35 ramp timing
<b>Total aerospace-grade titanium demand (2025-2026)</b>	35,000 tonnes/year	30,000-45,000 tonnes/year	Commercial aircraft production variability
<b>Aerospace-certified sponge capacity by 2030</b>	115,000 tonnes/year	105,000-130,000 tonnes/year	IperionX ramp success, Japanese expansion execution
<b>China aerospace-grade titanium supply by 2035</b>	20,000 tonnes/year	5,000-50,000 tonnes/year	Certification timelines, export policy
<b>VSMPO-AVISMA current output post-sanctions</b>	17,000 tonnes/year	15,000-20,000 tonnes/year	Sanctions evasion magnitude, production efficiency recovery

## CONCLUSION

*Titanium demand expansion driven by next-generation fighter jet production represents a significant and durable structural trend in global aerospace and defense markets through 2035 and beyond. While military aviation represents only 2–3% of total aerospace titanium consumption by volume, it commands disproportionate strategic and geopolitical significance due to its concentration in high-performance platforms and integration with national defense industrial policies.*

### Key Strategic Conclusions:

1. **Supply-Chain Stability (Base Case):** Current aerospace-certified titanium sponge capacity (89,000 tonnes for four producers) is sufficient to meet 2025–2030 demand projections (35,000–50,000 tonnes annually) if commercial aviation production tracks moderately upward. Planned capacity additions (Japan +10,000, US +5,000 by 2028–2030) will accommodate 2030–2035 demand growth without severe constraint.
2. **Geopolitical Leverage Transition:** Russia’s post-2022 titanium export reduction has been successfully absorbed by NATO-aligned supply chains (Japan, Kazakhstan, Saudi Arabia). Western aerospace OEMs have demonstrated supply-chain resilience; probability of future titanium supply disruptions from Russia/China sources remains material but manageable through diversification and strategic stockpiling.
3. **Industrial Sovereignty Drivers:** Global defense industrial policies increasingly emphasize localized aerospace production and supply-chain sovereignty. Japan, Europe, India, and South Korea are investing in domestic titanium processing capacity; this trajectory will fragment global supply chains into NATO-aligned and China-aligned segments by 2035.
4. **Technology Risk to Base Case:** Accelerated adoption of advanced composites, ceramic matrix composites, or additive manufacturing could reduce per-aircraft titanium content by 15–30% by 2035. This would create excess capacity and downward price pressure if supply-chain additions (IperionX, Japanese expansion) are not deferred. Conversely, military conflict escalation could drive demand 50–100% above base case within 2–3 years, straining capacity despite planned additions.
5. **Critical Material Classification Path:** Titanium’s designation as a “critical” or “strategic” material in US and EU regulatory frameworks remains uncertain but is trending toward affirmative determination. Such designation would trigger government-coordinated procurement, strategic stockpiling, and domestic capacity investment; this would stabilize supply but increase costs for non-defense consumers.

This analysis is provided for informational and institutional planning purposes. It is based on publicly available data and subject to material uncertainties regarding classified military specifications, opaque supply-chain dynamics, and geopolitical contingencies that resist reliable forecasting.

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