Metal AM at Scale: the Closed-Loop Materials Era

An Additive Manufacturing Research | Continuum Powders White Paper

Additive Manufacturing Research

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In their struggle to secure their own futures, the world's largest economies are disrupting global supply chains more intensely and reshaping them more rapidly than ever before. Meanwhile, these geopolitical tensions are both spurring and responding to more macroeconomic variables like inflation, higher interest rates, shifting demand patterns across a wide range of sectors, and a new urgency to drastically increase investment in strategically indispensable infrastructure.

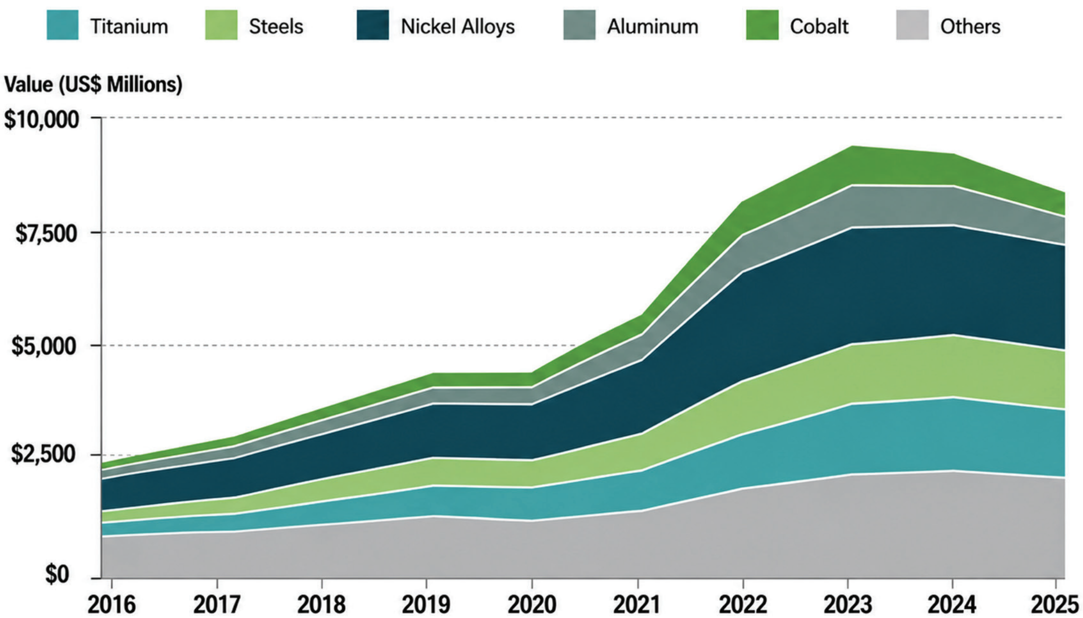
> "According to AM Research, the total value of metal 3D printed parts grew from just under $3 billion in 2016 to over $8 billion in 2025.

This is the context within which adoption of additive manufacturing (AM) and other advanced production methods have seen steady growth throughout this decade. A key thread that connects that growth cycle to the trajectory described above is the need to diversify supply sources for many critical minerals.

That connection helps explain the rising adoption rate of metal AM. According to AM Research, the total value of metal 3D printed parts grew from just under $3 billion in 2016 to over $8 billion in 2025.

Metal AM Parts Value by Metal Family

PRODUCTION PARTS, ALL PRINT TECHNOLOGIES, WORLDWIDE



2025 TOTAL VALUE

$8,009 Million

2025 VALUE BY METAL FAMILY

Nickel Alloys	$3,172M	39.6%
Titanium	$1,785M	22.3%
Steels	$1,409M	17.6%
Aluminum	$1,014M	12.7%
Cobalt	$320M	4.0%
Others	$309M	3.8%
Total	**$8,009M**	100%

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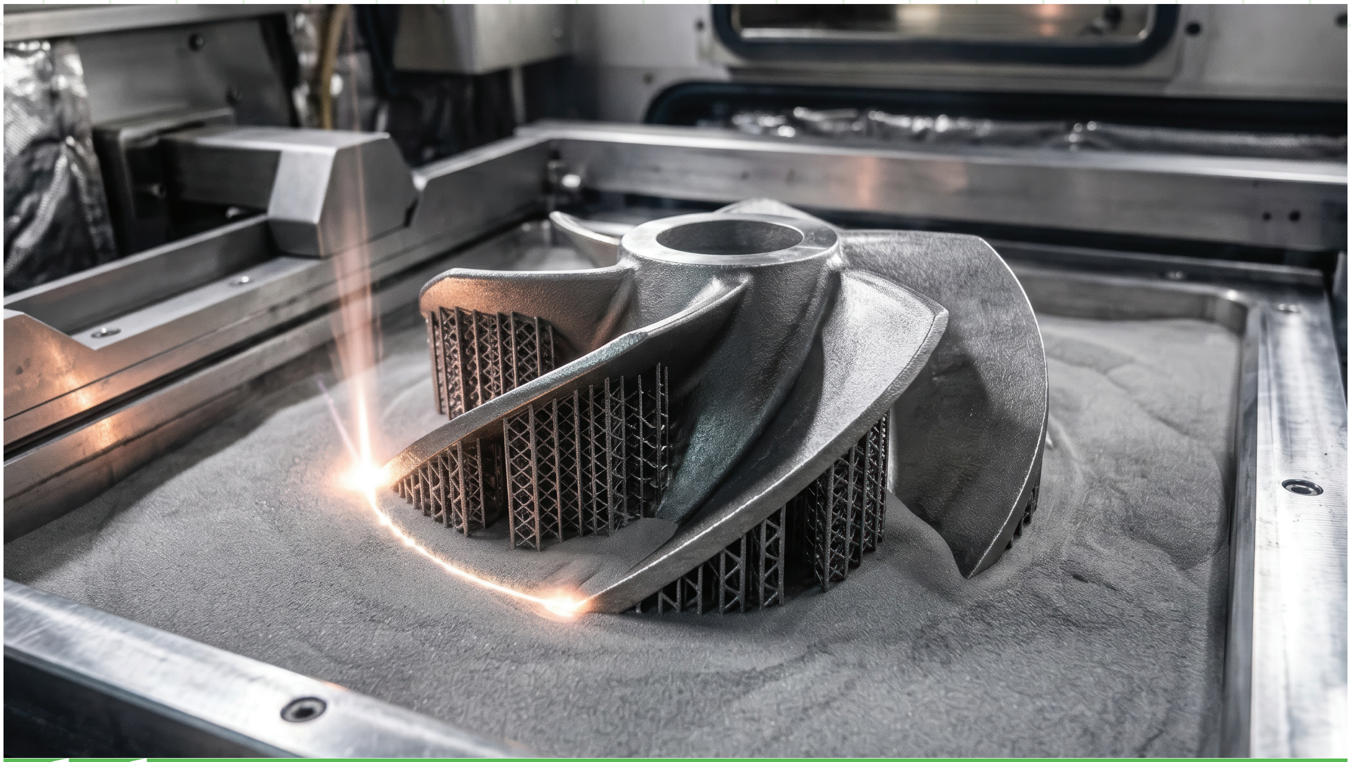
As the pace of that market growth accelerates, it will, in turn, further accentuate the need to build the sort of resilience into metal supply chains that can support the scale up of new production processes. Nations outside the currently dominant critical metal bottlenecks – primarily controlled by China and, to a lesser extent, Russia – have in recent years made critical minerals a centerpiece of efforts to tighten their frameworks for economic cooperation.

The main critical mineral bottleneck for nations outside China and Russia lies not in mining, but in the processing phase. If a nation simply increases its supply of raw ore, that does little to enhance resilience without revitalized capabilities for processing metals.

This is why a combination of expanded metal AM capacity, in conjunction with plans to raise the proportion of recycled materials in critical metals supply chains, represents the core of the economic future that reshoring nations are betting on.



> As metal AM emerged over the last couple of decades, its utilization was for some time largely limited to prototyping and relatively low levels of output, putting a natural cap on the cost benefit of recycling used AM metals into new feedstock.

Nowadays, proponents of recycling tend to be associated primarily with advocates of sustainability/ "going green", but metals recycling long predates any social concern with environmental issues. Following the widespread emergence of scrap yards in the 18th and 19th centuries during the Industrial Revolution, governments during the world wars drastically accelerated the practice of collecting scrap metal for recycling, in efforts driven equally by concerns for national security and economic resilience.

Then, following the war, the metals supply chain for markets such as automobiles quickly rebounded – and thrived – thanks in no small part to the recycling infrastructure that had emerged during the war, along with continuing innovations like the automobile shredder.

As metal AM emerged over the last couple of decades, its utilization was for some time largely limited to prototyping and relatively low levels of output, putting a natural cap on the cost benefit of recycling used AM metals into new feedstock. This was especially the case with powders, which require specialized hardware to make fresh supply out of degraded material.

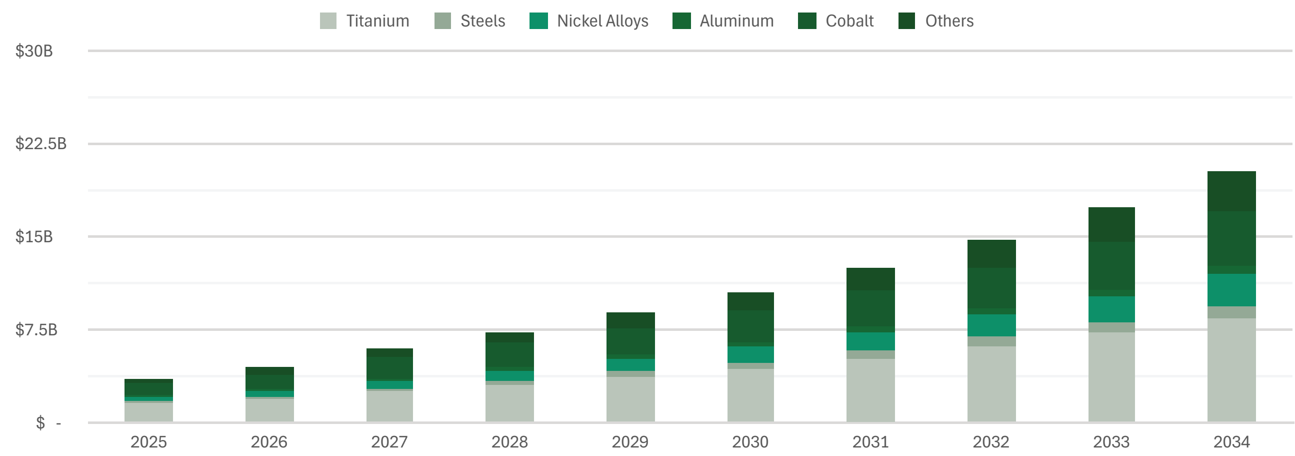
However, now that the use of powder-based metal AM for production at scale is becoming increasingly commonplace, the body of evidence shows that enterprises and organizations turning to technologies like powder bed fusion (PBF), directed energy deposition (DED), and metal binder jetting (MBJ) are leveraging recycling-enabled, closed-loop material ecosystems to secure supplies and remain cost competitive.

METAL AM MARKET GOING FORWARD:

High Value Materials for Strategic Sectors

Despite the extent to which metal AM utilization for larger runs of end-use parts has grown already, such growth is expected to be even more pronounced in the decade ahead. Focusing on PBF, the most technologically mature process, AM Research forecasts that the value of parts printed on PBF machines will rise from a total of $6 billion in 2025 to around $30 billion in 2034, representing 400 percent growth from the first year to the last year of that ten-year cycle.

Powder Bed Metal Production Parts Value by Metal Family, All Industries, Worldwide



AM Research expects the combined aerospace and defense market to be the clear leader in terms of the value of parts produced throughout that timeframe. This results from a combination of the technical maturity that aerospace/defense PBF users have already achieved, the expectations of sustained long-term demand, and the sheer mass and going market rate for components like jet turbines and rocket engines. In this vein, AM Research expects that 3D printed parts for rocket engines, currently a $254.5 million market, will grow to around $2.2 billion by 2034.

As for the total numbers of parts, medical is expected to continue to be the leader in end-use parts volume. Again, this is due to a combination of technical maturity and typical size of the relevant parts, although in this case the parts fall on the small end of the spectrum. Components for dental and orthopedics are already dominant constituents of the respective larger markets that they're part of.

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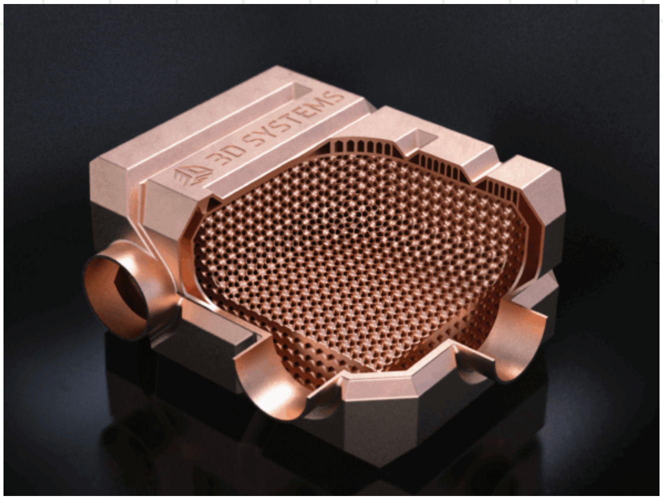
This points us to the themes we anticipate will drive demand for metal AM. The demand profile for metal 3D printed parts should continue to be characterized by the most expensive metals used in the highest value applications, for parts used in infrastructure buildouts executed by sectors at the top of national strategic priority agendas.

At the same time, within this context, there are sure to be fluctuations based on the broader drivers for the economy in general. For instance, we're already seeing a shift in the sense that, in its *AM Applications Analysis: Parts Produced 2025-2034*, AM Research projects that 2026 represents the pivot where aerospace/ defense is likely to take the top spot as the highest value applications category, replacing spinal and trauma applications.

With that in mind, it's certainly possible that other shifts which are only now in their earliest phases could change the market again in years ahead, in ways that are currently unforeseen. Bloomberg Intelligence predicts that over the next decade, the global economy could see a stunning $20 trillion n infrastructure investment, quantifying the opportunity that many different voices have said is 'the greatest CapEx cycle in history'. The catalysts there are dominated by compute and energy, rather than defense and medical.

The scale of this investment cycle will place unprecedented demand on high-value materials such as nickel, titanium, copper, and specialty alloys. As AM adoption expands across the full range of strategic sectors, manufacturers will increasingly require material strategies that improve feedstock availability, reduce exposure to supply disruptions, and enable greater reuse of valuable metals. In this environment, closed-loop material ecosystems move from being sustainability initiatives to becoming core manufacturing capabilities.



The part features complex internal geometries only achievable through additive manufacturing to optimize thermal management. Credit 3D Systems

Continuum Powders Greyhound Atomization Platform. Credit: Continuum Powders.

Already, a growing number of examples show that data center stakeholders view metal additive manufacturing (AM) as a strategic enabler for AI infrastructure. TDK's acquisition of Fabric8Labs and Johnson Controls' acquisition of Alloy Enterprises were both driven by data center hardware supply chain needs. While neither company uses powder-based AM, many powder bed fusion (PBF) manufacturers are producing data center cooling components. Conflux Technology, using EOS and AMCM systems, and industry pioneer 3D Systems are leading examples.

As adoption accelerates, so does the need for closed-loop material ecosystems, particularly because many of the required alloys are also in high demand across aerospace, energy, and defense. Copper remains especially important. Although pure copper presents challenges for PBF, advances in copper-chrome alloys and shorter-wavelength lasers are improving manufacturability. The next phase of growth will depend less on proving feasibility and more on scaling production, making applied research and reliable material suppliers increasingly important.

Siemens Energy, one of the world's largest PBF users, has significantly expanded its U.S. manufacturing footprint to support data center demand. In 2024, the company partnered with Houston-based Continuum Powders to recycle nickel superalloy scrap into new AM feedstock. During the final five months of 2024, Continuum processed roughly one ton of scrap per week using its proprietary Greyhound Melt-to-Powder (M2P) technology under its Powder-as-a-Service model.

Building on that experience, Continuum recently introduced Custom Foundry Runtime (CFR), enabling flexible production runs of 50kg - 1T per day for R&D and low-volume manufacturing. This capability is particularly valuable as emerging applications such as PBF copper cold plates transition from development to commercialization, where small and mid-sized manufacturers will play a critical role. At the same time, expanding power generation and grid infrastructure may prove an even greater constraint on AI growth than data center hardware itself.

These trends reinforce the need for localized manufacturing supported by resilient, closed-loop material supply chains. Solutions like CFR allow manufacturers to integrate circular material strategies from the outset, ensuring specialty powder production scales alongside demand. As high-volume applications such as data center cooling continue to emerge, success will depend not only on expanding manufacturing capacity, but also on securing dependable sources of specialty powders and efficient pathways for recovering and reusing high-value materials.

AM, DEFENSE, & RESOURCE AUTONOMY

As with countless other disruptive technologies, militaries and defense contractors have been among the earliest adopters of metal AM, a factor that throughout this decade has been increasingly instrumental in shaping the nature and pace of AM industry growth.

> Among the military adopters of metal AM, the US Department of Defense (DoD) and its suppliers are of course the standouts thus far.

Here, we arrive at the most direct manifestation of metal AM's status as a tool helping national and international ecosystems adjust to the fluctuating nature and heightened importance of geopolitical factors. Among the military adopters of metal AM, the US Department of Defense (DoD) and its suppliers are of course the standouts thus far.

That fact can't be separated from another fact: the US currently supplies almost none of its own processed critical minerals. In 2025, the US Geological Survey (USGS) provided its second update to the Critical Minerals List (CML) that was first issued in 2018 (the list is updated every few years). This illustrates just how much geopolitical considerations have moved beyond a purely national security context and extend directly into shaping strategies for supply chain resilience and economic competitiveness.

The 2025 list included about a dozen new additions compared to the one released in 2022, which itself included one new addition, nickel. Due largely to the US Navy's robust AM adoption efforts, there has been surging interest in qualification efforts surrounding copper-nickel powders in recent years – making the updates to the 2022 and 2025 CMLs doubly relevant, as copper was one of the 2025 CML additions.
Copper and nickel are notable examples because, while

Materials like Copper-Nickel, and Nickel-Copper are vital to the Industrial Marine Industry due to their corrosion resistance.

the US is around 50 percent import-dependent on each of them, this nonetheless puts the nation in far better shape regarding both copper and nickel than it is in regarding its supply of many other critical minerals, with the US being 100 percent import-dependent on a dozen of those minerals (a list that includes titanium sponge).

Moreover, the US's copper and nickel imports come largely from friendly nations including Chile and Norway, respectively, as well as Canada (for both minerals). This highlights how, even though every nation must act to secure its own resource supply chains, that still can't be a solo effort, which largely explains all the critical mineral agreements the US is forming, mentioned in the introduction. Indeed, in the recent critical minerals agreement deal struck by the G7, nickel was chosen as one of the pilot minerals (along with lithium) to serve as the basis for a systematic stockpiling and traceability network amongst the members. To reiterate, while mining will play a role, the strategy falls apart without recycling, a prominent feature of all those same international agreements.

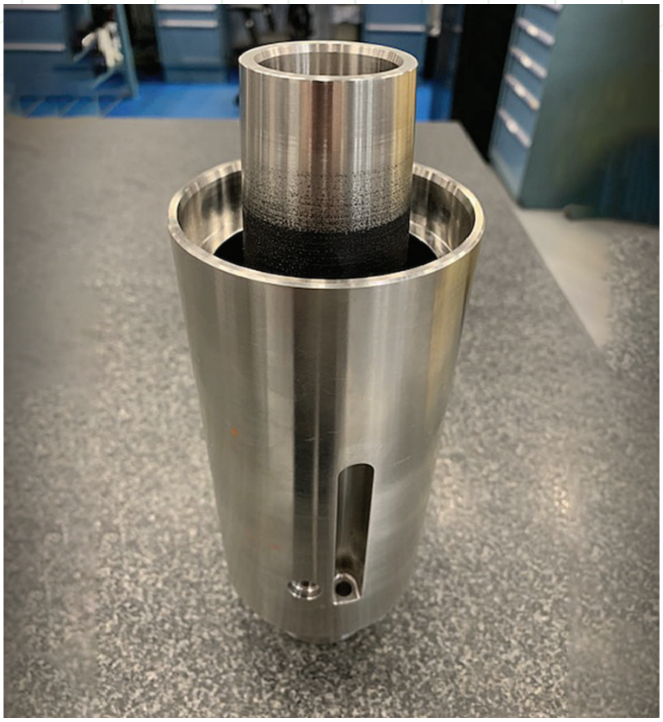
This is among the reasons why DoD is turning its attention towards large-scale recycling efforts surrounding defense hardware scrap, a central component of the US Navy's AM-centered industrial base program. Depending on the growth rate over the next decade for 3D printed metal parts for the maritime market (both defense and the commercial), that catalyst alone could be instrumental in pushing recycled metal AM feedstock to scale. AM Research's projects the maritime metal parts market value for nickel alone to reach over $400 million by 2034, representing a growth trajectory of well over 10x from the 2025 estimated market value of $31 million.

Finally, everything in this section highlights how essential it is for AM businesses and customers to establish relationships with the appropriate suppliers. That extends beyond sourcing materials and parts from legally acceptable nations of origin, to finding properly credentialed, experienced manufacturers with reliable feedstock pipelines within non-sanctioned jurisdictions.

Along these lines, anyone buying AM parts or engineering them for production for the US must secure connections with a contractor that is International Traffic in Arms Regulation (ITAR) certified. Additionally, for those contractors to be considered reliable long-term sources, they need their own critical mineral supply relationships with specialists located within the US or its allied nations.

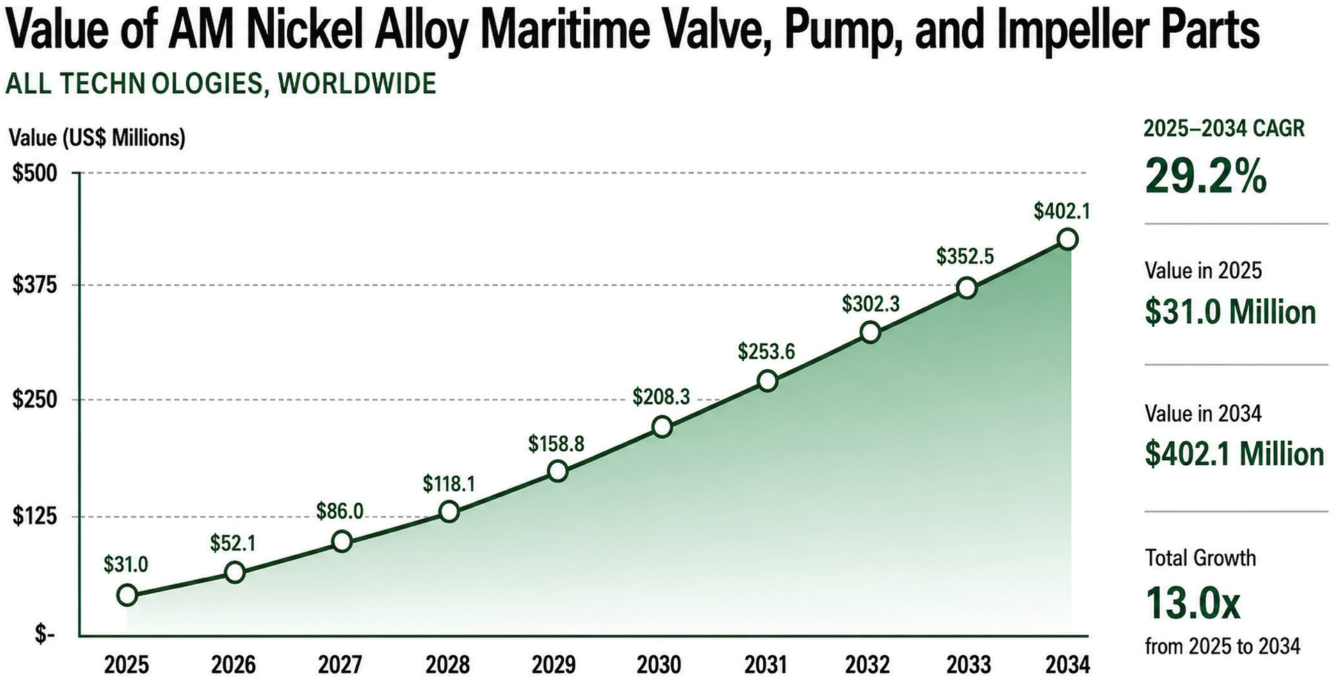
Thus, while it may not specifically involve the defense market, Continuum Powders' 2024 work with Knust-Godwin nonetheless checks all the same boxes relevant to the requirements for supplying metal 3D printed DoD hardware. Based in the Houston area, Knust-Godwin is an ITAR-certified supplier of defense equipment as well as a supplier to a range of other strategic sectors, such as oil & gas, the subject of the company's 2024 collaboration with Continuum.

One of Knust-Godwin's customers, a major oil & gas enterprise, was sitting on a large volume of Ni718 (Inconel) parts that were at the end of their life cycle. Continuum's ability to process the scrap into virgin nickel powder not only ensured Knust-Godwin nearby source of material supply, but also reduced the carbon emissions associated with the Inconel by 98.7 percent when compared to conventional sources. With an elevated baseline level in energy prices, that becomes a cost consideration, in addition to a sustainability metric.



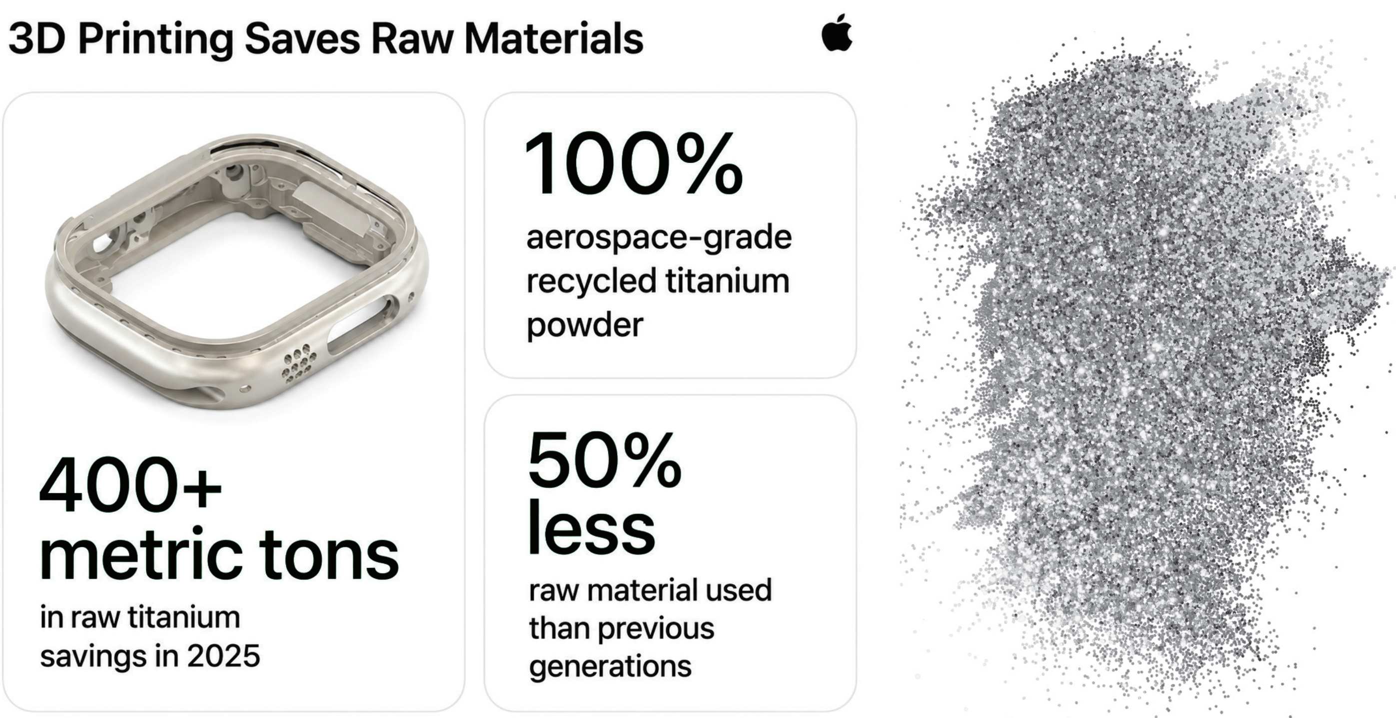
Critical additively manufactured oil & gas pump.
Credit: Knust-Godwin

Meanwhile, Knust-Godwin's initial work with Continuum evolved into a sales relationship built around monthly powder deliveries, with the potential for expansion into additional alloys. This illustrates the viability of transforming the experience gained with pilot programs into the basis for long-term business strategies.



The **INFLECTION POINT REACHES** the **CONSUMER MARKET**

At the end of 2025, Apple confirmed longstanding rumors by publicly revealing that it was using PBF to produce titanium cases for the Apple Watch. The global leader in hardware innovation noted that the design freedom and waste minimization unlocked with AM helped eliminate 50 percent of the material required to produce each case.



It's no surprise that Apple would highlight sustainability as part of a rollout: it's a pioneer and leader in corporate sustainability practices, and claims to have reduced its carbon emissions by over 60 percent since 2015.

At the same time, Apple is not a charity, nor is it an environmental R&D institute. No matter how much desire the company's stakeholders have in upholding the values of good corporate citizenship, Apple can only act on that desire so long as it does so while remaining cost competitive.

In terms of production at that scale, the waste minimization unlocked by AM isn't enough on its own to bridge the price gap against conventional manufacturing methods. Thus, one of the most noteworthy details in Apple's 3D printing announcement is that it is using 100 percent recycled aerospace-grade titanium in the watch cases, which, according to the company, amounts to 400 tons of titanium annually that doesn't have to be mined.

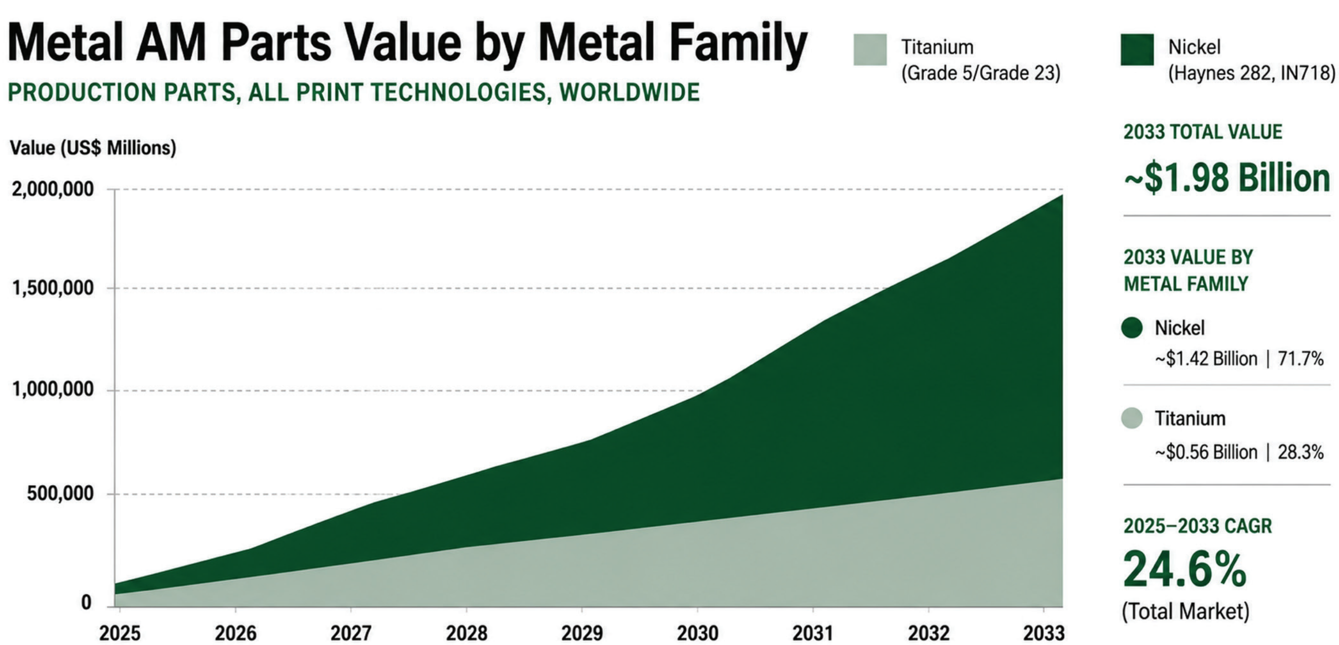
Apple procures the recycled, grade 23 titanium powder from multiple different suppliers. But the key to the supply chain strategy behind the company's titanium 3D printing workflow is the vast quantity of grade 5 titanium scrap that Apple controls thanks to the material discarded from machining involved in the production processes for iPhone and other hardware. The cost associated with the AM feedstock, then, is a recycling fee, serving as a strategic basis for Apple to trend towards long-term price-parity with conventional manufacturing methods.

Apple's adoption of recycled titanium illustrates a broader trend extending beyond consumer electronics. As additive manufacturing enters higher-volume production environments, the economic advantages of material recapture, reuse, and localized feedstock production become increasingly compelling. The ability to maintain access to strategic materials may ultimately prove just as important as the manufacturing technology itself.

Meanwhile, Chinese AM OEMs like BLT are succeeding at making tiny parts for emerging applications in the smartphone supply chain, such as hinges for foldable devices. As Apple and other device manufacturers look to diversify their sourcing networks outside of China, emulating China's incorporation of AM to the heart of the workflows will become a requirement.

Additively manufactured suppressor. Credit: INDO-MIM

While not typically viewed as a consumer market, the US market for firearm suppressors is in fact dominated by demand for civilian recreational use, with AM Research estimating that military demand for firearm suppressors accounts for just 3 to 5 percent of demand. On the other hand, the consumer market, which accounted for 750,000 suppressors sold in 2025, is expected to double in 2026, and AM Research expects that by 2032, metal AM will account for 30 percent of production in the market. Once again, titanium and Inconel are thus far the biggest beneficiaries.



CLOSING THE LOOP

Perhaps the most exciting aspect of the current changes in manufacturing is that we're seeing new products and new production methods evolve together. The inherent challenge raised by that twin evolution is a need for manufacturers to plan to be as resilient and agile as possible.

> Access to a circular metals supply chain is among the handful of solutions that every manufacturer must prioritize.

Manufacturers may not be able to predict what problems will arise, but they can put themselves in positions that are most constructive for responding to as many kinds of challenges as possible. Access to a circular metals supply chain is among the handful of solutions that every manufacturer must prioritize.

As with the scaling of metal AM itself, the scaling of recycled metal powders is no longer just an idea, but very few organizations exist on a scale that supports creating a closed-loop metals ecosystem wholly independently. That's why companies such as Continuum Powders have entered the market.

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