# Powder Arc Fusion (PAF): An Arc-Based Powder Bed Fusion System Concept for Low-Cost Metal Additive Manufacturing

Lukas Vogl
NeoFuse3D, Munich, Germany
lukas.vogl@neofuse3d.com

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**Abstract**

Metal additive manufacturing has seen rapid growth, yet access remains limited by the high cost of established processes such as Selective Laser Melting (SLM), where entry-level systems typically require investments exceeding $100,000 USD. This paper introduces Powder Arc Fusion (PAF), a powder bed fusion concept that replaces the laser with a controlled electric arc as the energy source for metal powder melting, targeting system costs below $5,000 USD and a desktop-compatible form factor. The PAF concept consolidates powder deposition, arc-based melting, and layer handling into a single integrated machine rather than a laboratory arrangement. The process is designed to operate within a sealed protective atmosphere and to allow layer thickness and melt track width to be varied within a single build, so that fine features and bulk volumes can be produced in one uninterrupted job. An analytical assessment of the melting energy requirements across more than 50 industrially relevant alloys indicates that the required thermal power is expected to remain within the range of a compact, low-cost power supply. The arc stability required for powder bed operation is intended to be provided by a proprietary arc control architecture developed at NeoFuse3D; its technical implementation is the subject of a dedicated forthcoming publication. The work presented here is at concept stage; no prototype has yet been built. The paper positions PAF against established powder bed fusion, wire arc additive manufacturing, and bound metal deposition, and identifies the application areas in which the concept is expected to be viable. PAF targets small and medium-sized enterprises, prosumer users, and research institutions that are currently excluded from metal additive manufacturing by cost and infrastructure barriers.

**Keywords:** metal additive manufacturing; powder bed fusion; arc-based melting; Powder Arc Fusion (PAF); low-cost additive manufacturing; desktop metal production; process architecture

## Abbreviations

| | |
|---|---|
| AM | Additive Manufacturing |
| PAF | Powder Arc Fusion |
| DARC | Dynamic Adaptive Arc Control |
| PBF | Powder Bed Fusion |
| SLM | Selective Laser Melting |
| DMLS | Direct Metal Laser Sintering |
| EBM | Electron Beam Melting |
| WAAM | Wire Arc Additive Manufacturing |
| BMD | Bound Metal Deposition |
| GTAW | Gas Tungsten Arc Welding |
| HAZ | Heat-Affected Zone |
| SME | Small and Medium-sized Enterprise |

## 1 Introduction

Additive manufacturing of metal components has emerged as a transformative technology across industries including aerospace, automotive, and medical device manufacturing [1]. Among the available processes, powder bed fusion techniques such as Selective Laser Melting (SLM) and Electron Beam Melting (EBM) have established themselves as the dominant approaches for producing high-density metal parts with complex geometries [1]. However, despite their technical maturity, these systems remain largely inaccessible to small and medium-sized enterprises (SMEs), research institutions with limited budgets, and prosumer users due to their high acquisition and operating costs. Entry-level SLM systems typically require capital investments exceeding $100,000 USD, with operational costs further compounded by laser maintenance, inert gas consumption, and specialized powder handling requirements [2].

Several lower-cost alternatives have been explored, including bound metal deposition (BMD) and material extrusion-based metal printing, which reduce upfront costs but introduce additional processing steps such as debinding and sintering, negatively affecting part density, dimensional accuracy, and mechanical properties [3, 4]. Wire arc additive manufacturing (WAAM) offers another arc-based approach at reduced cost, but is primarily suited for large, low-resolution components [5].

This paper introduces Powder Arc Fusion (PAF), a powder bed fusion concept that replaces the laser with a controlled electric arc as the energy source for powder melting. PAF is being developed at NeoFuse3D as a complete desktop-compatible machine rather than a laboratory apparatus: powder handling, build chamber, motion system, arc generation, and process control are designed as a single integrated unit. The arc stability required for operation over a loose powder bed is provided by the Dynamic Adaptive Arc Control (DARC) architecture, an arc control system developed at NeoFuse3D. The technical implementation of DARC is deliberately not the subject of this paper and will be presented in a dedicated publication.

PAF differs from the arc-based approaches reported in the literature in two respects, both of which are examined in Section 3. First, it is conceived as an integrated machine rather than a laboratory arrangement, covering powder handling, motion, atmosphere management, and process control within a single unit. Second, arc-based melting of a powder bed is strongly influenced by the working distance between electrode and powder, which changes as the build progresses; PAF accordingly treats the arc as a continuously regulated energy source rather than a fixed process parameter.

This paper is structured as follows. Section 2 reviews the established metal additive manufacturing process families and identifies the unaddressed position that PAF is designed to fill. Section 3 summarises prior work on arc-based powder bed processing and delimits the contribution of this work. Section 4 describes the PAF process and system architecture at concept level. Section 5 briefly addresses the arc control requirement. Section 7 discusses advantages and limitations, Section 8 covers application areas and market potential, and Section 9 concludes.

# 2 Background: Metal Additive Manufacturing Process Families

Metal additive manufacturing encompasses a diverse range of established processes, each optimized for specific applications, scales, and material requirements. The three dominant process families — Powder Bed Fusion (PBF), Wire Arc Additive Manufacturing (WAAM), and extrusion-based metal printing — have each earned their place in the manufacturing landscape and continue to see active industrial and research adoption [6]. However, each process family carries inherent limitations that restrict its applicability to specific contexts, leaving a significant gap for users who require a combination of part quality, process simplicity, compact footprint, and low system cost.

## 2.1 Powder Bed Fusion (SLM, DMLS, EBM)

Powder bed fusion processes, including Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS), and Electron Beam Melting (EBM), represent the current gold standard in metal additive manufacturing. These processes achieve exceptional part density, geometric complexity, and mechanical properties, making them the preferred choice for high-performance applications in aerospace, medical, and tooling industries [6].

However, this performance comes at a significant cost. Entry-level SLM and DMLS systems require capital investments in the range of $100,000 USD and above, with higher-end multi-laser configurations costing substantially more [2]. EBM systems carry comparable or higher acquisition costs due to the vacuum chamber and electron beam infrastructure required. These figures place PBF technology firmly outside the reach of SMEs, prosumer users, and research institutions with limited budgets.

Beyond acquisition cost, PBF systems impose substantial infrastructural requirements. Their physical footprint — including powder handling stations, inert gas supply systems, and depowdering units — typically requires a dedicated room-sized installation, making deployment in small workshops or office-adjacent environments infeasible. Operational complexity adds a further barrier: laser calibration, powder sieve management, atmosphere monitoring, and build parameter optimization require specialized training that is typically only available in well-staffed industrial or academic AM facilities [2, 7].

A less frequently discussed but practically significant limitation is optical degradation during extended print jobs. Metal spatter and process condensate progressively coat the protective window separating the laser optics from the build chamber, degrading laser power transmission and beam quality over time. In long-duration builds, this fouling can cause print failures or dimensional inconsistencies that are difficult to detect until the build is complete, resulting in significant material and time losses [8, 7].

## 2.2 Wire Arc Additive Manufacturing (WAAM)

Wire Arc Additive Manufacturing uses an electric arc as the energy source to melt a continuously fed metal wire feedstock. WAAM systems are significantly more affordable than PBF systems and are capable of producing very large metal components at high deposition rates [5]. For applications requiring large near-net-shape metal parts — such as structural aerospace components, marine hardware, or large tooling — WAAM offers a compelling combination of material efficiency, scalability, and cost effectiveness that no other process can match at comparable scale.

However, WAAM's strengths are closely tied to its limitations. The wire-based deposition process operates at relatively low resolution, with typical layer heights in the range of 1–3 mm and surface roughness values that almost always require post-process machining to achieve functional surface quality [5]. This makes WAAM fundamentally unsuitable for producing small, geometrically complex, or dimensionally precise components without significant additional processing.

## 2.3 Bound Metal Deposition and Extrusion-Based Metal Printing

Extrusion-based metal printing processes, most notably Bound Metal Deposition (BMD) as commercialized by Desktop Metal and Markforged, represent the most accessible entry point into metal additive manufacturing from a system cost and footprint perspective. These processes extrude a metal-polymer composite filament or rod, building a "green" part that subsequently undergoes debinding and high-temperature sintering to produce a fully metallic component [4, 3].

However, the apparent accessibility of BMD is substantially offset by the realities of its multi-stage process chain. The sintering step requires a separate high-temperature furnace, representing a significant additional capital investment and a large thermal energy requirement that contradicts the desktop-friendly premise of the printing stage [9]. Total cycle times from print completion to finished sintered part commonly exceed 90 hours, severely limiting throughput and making BMD poorly suited for iterative prototyping or time-sensitive production [9].

Dimensional accuracy is a further systemic limitation. Sintering-induced shrinkage of approximately 15–20% must be pre-compensated in the CAD model, requiring iterative calibration runs when processing new materials or geometries [10]. The resulting parts also exhibit residual porosity compared to directly melted counterparts, which limits their suitability for structurally demanding applications [3, 4].

The multi-stage nature of the process chain also presents a barrier to automation. Each transition between printing, debinding, and sintering requires manual handling, introducing opportunities for part damage and quality variation that are difficult to eliminate in a low-staffing environment.

## 2.4 The Position Addressed by PAF

The preceding analysis reveals a consistent pattern. PBF delivers exceptional part quality but remains locked behind industrial-scale cost and complexity. WAAM offers affordable arc-based metal deposition but is confined to large, low-resolution components. BMD achieves desktop accessibility but sacrifices cycle time, dimensional accuracy, and part density through its inherently multi-stage process chain. No established process simultaneously combines powder bed fusion quality, arc-based energy delivery, single-step direct melting, and a compact low-cost system architecture.

PAF is designed to occupy precisely this position. By transferring the arc-based energy deposition principle into a controlled powder bed environment, PAF achieves direct powder melting without laser infrastructure and without the multi-stage debinding and sintering chain. Table 1 summarises the intended positioning of PAF relative to the established process families. The values given for PAF are system design targets at the current stage of development, not measured results; the corresponding figures for the established processes are taken from the literature cited above.

Table 1: Comparative positioning of metal additive manufacturing process families. PAF column: design targets of the current development programme, not yet experimentally validated.

| | **PBF (SLM/EBM)** | **WAAM** | **BMD** | **PAF (target)** |
|---|---|---|---|---|
| System cost | >$100k | $20–50k | $10–20k | <$5k |
| Footprint | Room-sized | Large | Desktop + furnace | Desktop |
| Part density | High | High | Medium | High |
| Geometric complexity | High | Low | Medium | High |
| Single-step melting | Yes | Yes | No | Yes |
| Specialist personnel | Required | Required | Not required | Not required |
| Optical degradation risk | High | None | None | None |
| Entry barrier | Very high | High | Medium | Low |

## 3 Related Work: Arc-Based Powder Bed Processing

Using an electric arc as the heat source for powder bed fusion has been investigated in academic research since 2020. This section summarises that work and delimits the contribution of the present paper. The purpose is not to claim precedence for the general concept of arc-based powder bed melting, which is established in the published literature, but to identify what remains unaddressed at system level.

Dong et al. introduced Powder-bed Arc Additive Manufacturing (PAAM) for a pseudo-eutectic $AlCoCrFeNi_{2.1}$ high-entropy alloy, demonstrating that a free-burning arc can be used to melt powder in a bed configuration [11]. Moreira et al. investigated a tungsten inert gas (TIG) torch as the heat source for additive manufacturing, using a single-axis moving system over powder [12]. Wang et al. examined inter-layer remelting strategies in Powder-Bed Arc Additive Manufacturing (PBAAM) for a CoCrFeNiMn high-entropy alloy [13]. More recently, Balcı and Alibeyoğlu characterised the influence of layer thickness and scanning parameters on melt pool geometry and track continuity [14], and Çelikel and Balcı applied interpretable machine learning to process parameter analysis in arc-driven powder bed fusion of 316L stainless steel [15]. Reported layer thicknesses in this body of work are in the sub-millimetre range, and the influence of the electrode-to-powder stand-off distance on the result is identified as a dominant process variable [15].

A related but distinct family uses a plasma arc with coaxial powder injection rather than a powder bed, in which powder is fed into the arc and deposited onto a substrate [16]. This approach shares the arc energy source but not the powder bed configuration, and is therefore not directly comparable in terms of geometric capability.

Three observations follow from this literature. First, the reported work establishes that arc-based melting of a powder bed is physically feasible and that layer thickness and track continuity can be controlled. Second, the reported setups are experimental: single tracks, limited layer counts, and simple moving systems, with build volumes on the order of a few dozen millimetres. Third, and most significantly for the present work, the arc is operated as a fixed or pre-programmed parameter set. The arc itself is not used as a feedback source, and the electrode-to-powder distance — identified in the literature as the dominant process variable — is not actively controlled during the build.

The contribution of this paper is accordingly not the principle of arc-based powder bed melting. It is the description of an integrated machine concept for this process family: a system that combines powder deposition, arc generation, motion control, atmosphere management, and process monitoring in a single desktop-compatible unit, and that treats the arc as a controlled, continuously regulated energy source rather than a fixed process parameter. The control architecture that implements this is described in Section 5.

# 4 The PAF Process

## 4.1 Process Principle

Powder Arc Fusion is a powder bed fusion process in which a tungsten electrode is traversed over a stationary powder bed surface by a two-axis gantry, selectively melting metal powder layer by layer to produce a consolidated metal component. The process operates within a sealed chamber under a protective atmosphere and requires no debinding or sintering stage; the part is retrieved directly from the powder bed upon build completion, with surface finishing and tolerance-critical features subsequently addressed by conventional machining where required.

The complete process cycle consists of repeated sequences of powder deposition, electrode traversal and melting, and build platform lowering, continuing until the full part geometry has been consolidated. The build platform forms the chamber floor and is moved vertically between layers. Powder is supplied from a reservoir and distributed across the build area by a wiper system in a single pass; excess powder falls clear of the build area and is returned to the reservoir, forming a closed powder handling loop that minimises material waste and reduces manual intervention between layers.

The electrode is mounted on the gantry above the build area and traverses the powder surface at a controlled working distance. Because the arc is the energy source rather than a focused beam, the melt track geometry is determined by the combination of arc energy input and traversal speed rather than by optical focusing, and the process does not involve beam delivery optics.

## 4.2 Adaptive Resolution

A distinguishing feature of the PAF concept is the ability to vary both layer thickness and melt track width within a single build without hardware reconfiguration. Layer thickness is set by the build platform increment and is fully software-configurable between successive layers; melt track width is controlled through the parameters of the arc energy input and the traversal speed.

This enables a two-dimensional resolution strategy in which different regions of the same part are processed at different settings within one build. Fine features, critical surfaces, and thin-walled geometries are processed at fine resolution, while large infill volumes and bulk structural sections are processed at coarser resolution, reducing the number of passes and layers required for high-volume regions and correspondingly reducing total build time. The practical consequence is that build time scales primarily with the volume of high-resolution regions rather than with total part volume. A component with complex external geometry and simple internal structure can be produced with fine surface detail and coarse infill in a single uninterrupted build, without the fixed resolution penalty that laser-based PBF systems impose uniformly across the entire build volume [17].

## 4.3 System Architecture

The PAF system is designed as a single integrated unit that contains the build chamber, powder handling system, motion system, power electronics, and control hardware within one enclosure, with a footprint consistent with desktop operation. This is a deliberate departure from the laboratory configurations reported in the literature, which use separate motion systems, external power sources, and manual powder handling.

Process control is organised in two tiers. The lower tier is a microcontroller with direct hardware access to all time-critical components, including the motion system, the arc generation stage, and the power switching circuitry. Safety-critical functions — atmosphere interlock monitoring and arc fault detection — are implemented at this tier so that hardware-level response is independent of higher-level software state. The upper tier is a Linux-based computing system responsible for non-time-critical process intelligence, including toolpath generation and slicing, resolution zone assignment, and process parameter calculation. The upper tier also performs process monitoring using sensor data and imaging of the build surface. Communication between the tiers follows a command and telemetry model, ensuring that upper-tier computational load does not introduce timing errors into the hardware control loops [18].

## 5 Enabling Technology: Arc Control

The principal technical requirement that distinguishes PAF from a conventional powder bed fusion system is the energy source. An electric arc must be initiated without mechanical contact with the powder bed — contact-based ignition would disturb the powder layer at the start of every track — and it must be sustained in a stable state while the electrode traverses the bed, at energy levels that vary according to the local resolution setting.

Meeting both requirements simultaneously is the function of the Dynamic Adaptive Arc Control (DARC) architecture developed at NeoFuse3D. DARC is a control concept that treats the arc as a regulated system rather than a fixed process parameter: arc energy delivery is modulated continuously during the build, and the electrical behaviour of the arc is used as an input to the process control loop. This is, to the authors' knowledge, the aspect of arc-based powder bed processing that the published literature leaves open: reported work operates the arc as a pre-programmed parameter set with no active regulation during the build, whereas the dominant process variable — the working distance between electrode and powder — is inherently subject to variation as the build progresses.

The technical implementation of DARC, including its architecture, control law, and electrical design, is deliberately excluded from this document. It is the subject of ongoing development and will be presented in a dedicated publication. This paper documents the PAF system concept and the fact that a proprietary arc control architecture is a prerequisite for its operation.

## 6 Development Status and Validation Plan

The work presented in this paper is at concept and design stage. No prototype of the PAF system has been built or operated, and no experimental data on part quality, process stability, or system performance are available at the time of publication. The statements in the preceding sections describe the intended architecture and the expected characteristics of the process; they are not measurements.

The implementation of the arc control architecture described in Section 5 is deliberately withheld from this paper for intellectual property reasons, and is the subject of a dedicated forthcoming publication. The purpose of the present document is to establish the system-level concept publicly at a defined date.

The development programme proceeds in the following order, and results will be reported as they become available:

1. **Arc control verification.** Verification of the arc control architecture under powder bed conditions, including reproducible ignition and sustained operation over a loose powder layer. Reported metrics: ignition reliability over operating cycles, arc stability over track length, and the electrical operating envelope.
2. **Single-track and multi-layer trials.** Melting of single tracks and subsequently multiple layers on metal powder, characterised for track continuity and track geometry. Reported metrics: track width and depth, continuity along the track, and achievable layer thickness.
3. **Density and defect characterisation.** Metallographic analysis of built specimens with explicit quantification of lack-of-fusion defects and residual porosity as a function of track spacing and overlap. Reported metrics: relative density by the Archimedes method, cross-sectional defect distribution, and minimum achievable porosity.
4. **Dimensional accuracy and surface quality.** Geometric characterisation of built specimens against the nominal CAD geometry. Reported metrics: dimensional deviation, surface roughness, and minimum reproducible feature size.
5. **Material screening.** Extension of the process parameter window from the initial alloy to further material families, guided by the analytical assessment referred to in Section 7.

Each stage is subject to defined acceptance criteria before the following stage begins. Results will be published irrespective of outcome, including negative results.

# 7 Advantages and Limitations

The following assessment describes the intended characteristics of the PAF concept and the limitations that are expected to apply. It reflects the design intent of the current development programme; measured performance data are not yet available (Section 6).

## 7.1 Intended Advantages

**Cost and footprint.** Replacing the laser with an arc-based energy source is the single largest contributor to the intended cost advantage. Laser sources, beam delivery optics, and precision scanning systems account for a substantial portion of PBF system cost [2]; PAF removes these components and replaces them with a tungsten electrode, a two-axis gantry, and a compact power supply. The target system cost is below $5,000 USD, a reduction of more than 95% relative to entry-level SLM systems. PBF systems additionally require room-sized installations including ancillary powder handling, inert gas supply, and depowdering infrastructure; the PAF concept integrates all process components within a single enclosure and is therefore intended for small workshops, laboratories, and decentralized production settings without dedicated infrastructure.

**Scalability and adaptive resolution.** The gantry-based architecture is intended to scale in both directions: single-head desktop configurations for prosumer, prototyping, and SME use, and larger build volumes with multiple electrode heads operating in parallel for higher industrial throughput. Because layer height and track width are software-configurable, the trade-off between resolution and speed can be adjusted per region within a single build, a capability not natively available in fixed-parameter laser-based PBF systems [19].

**Energy and process chain.** Arc-based energy delivery concentrates thermal input at the point of melting and avoids the losses of beam generation, optical delivery, and powder surface reflection that characterise laser systems, where effective coupling varies considerably with material and surface condition [17]. Sintering-based processes such as BMD additionally require sustained high-temperature furnace operation over many hours [9]; PAF performs melting and consolidation in a single step, without a debinding or sintering stage, which removes the associated cycle-time penalties of more than 90 hours and reduces the number of handling steps that can introduce variation or damage.

**Material compatibility and part integrity.** Direct arc coupling into the melt pool is not subject to the optical reflection losses that constrain laser-based processing of highly reflective materials such as copper [20]. An analytical assessment of the melting energy requirements across more than 50 alloys spanning aluminium, copper, steel, stainless steel, tool steel, nickel, and titanium families indicates that the required thermal power is expected to remain within the range of a compact, low-cost power supply. Because PAF consolidates powder by direct melting, no residual porosity from incomplete sintering or binder burnout is introduced [3, 4]. The defect mechanisms that dominate laser-based powder bed fusion — keyholing and entrapped gas porosity associated with the laser coupling regime — are not directly transferable to an arc-based energy source [19, 8]. Other powder bed fusion defects, in particular lack-of-fusion between adjacent tracks and layers, remain relevant to PAF and are addressed explicitly in the validation plan (Section 6); their dependence on track spacing and overlap is documented for both laser-based and arc-based powder bed processing [13, 14].

## 7.2 Expected Limitations

**Resolution and build speed.** The arc-based energy source produces a larger melt pool than a focused laser beam, which constrains the minimum achievable feature size and surface roughness relative to high-end SLM systems [2]; post-process machining or surface treatment may therefore be required where exceptional surface finish or micro-scale features are demanded. At fine resolution settings, a single-electrode configuration processes features sequentially, which limits throughput compared to multi-laser systems; the adaptive resolution strategy partly compensates for this, and multi-head configurations are intended to address it at larger scales [17].

**Thermal effects.** Arc-based deposition produces a larger heat-affected zone than laser-based processes, which can influence microstructural properties adjacent to the melt track and may introduce residual stress gradients in sensitive materials [21]. The same thermal gradients can induce part distortion, particularly in large or geometrically asymmetric components. Both effects are common to directed energy deposition processes generally; build orientation, support structure design, and interlayer thermal management strategies established in the AM literature are directly applicable and will be evaluated during process development [21].

**Powder recovery and reuse.** The thermal environment within the build chamber may result in partial sintering or contamination of unfused powder in regions proximal to the melt track, potentially reducing reusability compared to laser-based systems, where thermal input is more spatially confined [22, 23]. Systematic powder recovery and sieving protocols have not yet been characterised for PAF and are part of the planned experimental work.

**Safety.** The target user base includes SMEs, prosumers, and private users who may lack formal training in arc processes, high-voltage systems, or metal powder handling. The combination of electrical hazards, fine metal powder with associated inhalation and combustion risks, arc radiation, and inert gas atmosphere management requires safety measures at system level: full enclosure of the build chamber, hardware interlocks preventing arc ignition outside safe operating conditions, automated atmosphere control, and user-facing safety monitoring. Bringing the operational safety profile in line with other desktop manufacturing equipment, including the applicable conformity assessment route, remains part of the development programme.

# 8 Application Areas and Market Potential

The PAF process is not designed for a single industry vertical or application domain. Rather, its combination of single-step direct melting, broad material compatibility, scalable architecture, and low system cost creates structural alignment with several of the most significant trends in modern manufacturing.

## 8.1 Industry 4.0 and Full Process Automation

The single-step direct melting approach of PAF makes it inherently compatible with fully automated manufacturing environments. Unlike multi-stage processes such as BMD — where manual handling between printing, debinding, and sintering introduces automation barriers — PAF's complete process chain occurs within a single enclosed system [24]. Build preparation, atmosphere control, arc operation, and build completion can all be managed by a central control system with no required human intervention between job initiation and part retrieval, aligning PAF units with Industry 4.0 principles of autonomous, connected, and data-driven manufacturing and enabling operation as nodes within larger automated production cells [18].

## 8.2 Lean Manufacturing and Just-in-Time Production

On-demand part production via PAF aligns with lean manufacturing and just-in-time production philosophies [24]. Complex metal components can be produced as needed, in the quantity needed, without large inventories of finished or semi-finished parts. Critically, the raw material inventory required to support a broad PAF-based production operation reduces to a small number of metal powder types: a single aluminium alloy powder can serve as the feedstock for a wide variety of geometrically and functionally distinct components. This contrasts with conventional subtractive manufacturing, where each part family typically requires its own dedicated stock of billets or forgings. The resulting reduction in raw material variety, warehouse space, and inventory capital represents a significant operational advantage for SMEs and decentralized production environments [24].

## 8.3 Geometric Freedom and Design-Driven Manufacturing

The powder bed fusion approach employed by PAF enables the fabrication of almost arbitrary geometries, including internal channels, complex lattice structures, and organic forms that are inaccessible to conventional subtractive processes. This geometric freedom shifts the manufacturing constraint from "what can be made" to "what is the optimal design", positioning the process as a platform for design-driven manufacturing across a wide range of functional applications.

### 8.4 Integration with Existing Post-Processing Infrastructure

As a powder bed fusion process, PAF produces parts that are directly compatible with established depowdering and surface treatment equipment widely used in the casting and metal processing industries [23]. Vibratory depowdering systems, shot blasting, and chemical surface treatments developed for cast and sintered metal parts can be applied to PAF-produced components without modification, reducing the infrastructure investment required to establish a complete PAF-based production workflow and allowing PAF to integrate into existing production lines rather than requiring greenfield infrastructure.

### 8.5 Hybrid Manufacturing with CNC Machining

While PAF enables the production of highly complex near-net-shape metal components, tight dimensional tolerances at critical interfaces — such as bearing seats, sealing surfaces, or threaded features — are best achieved through subsequent CNC machining operations [25]. The combination of PAF for geometry generation and automated machining centres for precision finishing creates a hybrid manufacturing workflow capable of producing end-use components with both geometric complexity and dimensional accuracy. This hybrid approach is well established in the metal AM industry and is directly applicable to PAF-produced parts [25].

## 9 Conclusion

This paper has introduced Powder Arc Fusion (PAF), a powder bed fusion concept that replaces the laser with a controlled electric arc as the primary energy source for metal powder melting, and has described it as an integrated desktop-compatible machine rather than a laboratory configuration.

The analysis of the established process families shows that no single process simultaneously combines powder bed fusion quality, arc-based energy delivery, single-step direct melting, and a compact low-cost system architecture. Laser-based powder bed fusion delivers exceptional part quality but remains confined to industrial environments by cost, footprint, and operational complexity. Wire arc additive manufacturing offers affordable arc-based deposition but is limited to large, low-resolution components. Bound metal deposition reduces upfront system cost but introduces multi-stage process chains with cycle times exceeding 90 hours, sintering-induced shrinkage of 15–20%, and residual porosity that limits structural performance. PAF is designed to occupy the intersection of these process families.

A review of prior work shows that arc-based melting within a powder bed is physically established and has been investigated academically since 2020. That work, however, is confined to test rigs, single tracks, and simple moving systems, with the arc operated as a pre-programmed parameter set. The contribution described here is the system-level concept: an integrated machine architecture for arc-based powder bed fusion, combined with active regulation of the arc as a controlled energy source rather than a fixed process parameter. Implementing that regulation is the intended function of the DARC architecture under development at NeoFuse3D, whose technical details are withheld from this paper and are the subject of a dedicated forthcoming publication.

Full experimental validation of the PAF process — including systematic characterisation of part density, mechanical properties, dimensional accuracy, and surface finish across material families — represents the primary direction of ongoing work. The validation plan set out in Section 6 defines the sequence in which these results are to be produced, and they will be reported as they become available. PAF does not seek to replace established metal additive manufacturing processes in their respective domains of excellence; rather, it aims to establish a category of desktop-compatible, single-step, arc-based powder bed fusion for users, institutions, and production environments for which existing processes remain out of reach.

## Declarations

**Competing interests.** The author is the founder of NeoFuse3D and is involved in the development of the PAF system and of the arc control architecture referred to in this paper. The author has an interest in establishing the public date of the concept described here; this does not affect the technical content of the paper.

**Data availability.** No new experimental data were generated or analysed for this work. The analytical assessment referred to in Section 7 is based on material property data available in the cited literature. The implementation details of the arc control architecture are withheld for intellectual property reasons and are not available.

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**Use of AI.** A generative AI writing assistant based on a large language model (DeepSeek) was used during the preparation of this manuscript. Its use covered language editing, stylistic refinement, LaTeX formatting, structural editing of the manuscript text, and support in literature screening for the related-work section. All scientific content — the process concept, the system architecture, the engineering assessments, and the development and validation plan — originates from the author, who remains responsible for the accuracy and integrity of the work. No experimental data, analyses, or results were generated by AI tools, and no AI tool is listed as an author or contributor.

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