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Photopolymer Additive Manufacturing 2025 Workshop Report

Building a Unified Vision from Research to Regulation

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Abstract
The third biannual Photopolymer Additive Manufacturing Alliance Workshop was held on September 15-16, 2025, at the University of Colorado Boulder to continue its mission of advancing photopolymer additive manufacturing (PAM). Building on the 2023 PAMA Workshop, the 2025 iteration brought together leaders from industry, national laboratories, academia, standards organizations, and startups to assess the current state and future trajectory of PAM, also known as vat photopolymerization (VPP).

The workshop centered on four panels themed around the state-of-the-field and outlook, novel materials and metrology, and safety and standards, with a final panel focusing on an innovative VPP newcomer, volumetric additive. All panels highlighted the need to integrate material and hardware innovation with AI-driven data infrastructure, standardized metrology, and regulatory readiness to accelerate an application-driven manufacturing approach.

Keywords
Photopolymer additive manufacturing; Vat photopolymerization; Machine learning; Hybrid cure kinetics; Multimaterial AM; Degree of cure; Standardization; Metrology; Industry-Academia-Government Collaboration.

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Executive Summary

The third biannual Photopolymer Additive Manufacturing Alliance (PAMA) Workshop was held on September 15-16, 2025, at the University of Colorado Boulder to continue its mission of advancing photopolymer additive manufacturing (PAM). Building on the 2023 PAMA Workshop, the 2025 iteration brought together leaders from industry, national laboratories, academia, standards organizations, and startups to assess the current state and future trajectory of photopolymer additive manufacturing (PAM), also known as vat photopolymerization (VPP).

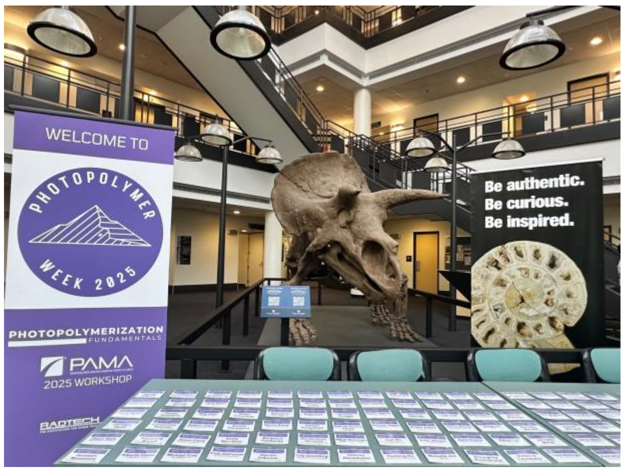

Figure 1: Welcome and registration table at the third bi-annual PAMA Workshop.

At the outset, PAMA leadership outlined a strategic framework aimed at strengthening the organization's role in supporting the responsible growth of the PAM ecosystem. Key goals include leveraging the complementary strengths of NIST and the RadTech community to advance safe materials handling and processing knowledge, improve transparency and education around material safety data (MSDS), and collaborate with stakeholders to develop standards for materials, hardware, and pre- and post-processing. PAMA emphasized its role as a trusted forum to discuss emerging global regulations and identified membership growth and broader industry engagement as priorities to increase the organization's impact.

To support these goals, PAMA introduced an action plan focused on strengthening PAM information infrastructure and outreach. Initiatives include redesigning the PAMA website to improve access to technical resources, clarifying the value proposition for membership, streamlining enrollment, and developing partnerships with other associations and PAM-adjacent conferences. These collaborations are intended to expand participation, expedite standards development, and facilitate educational activities across the field.

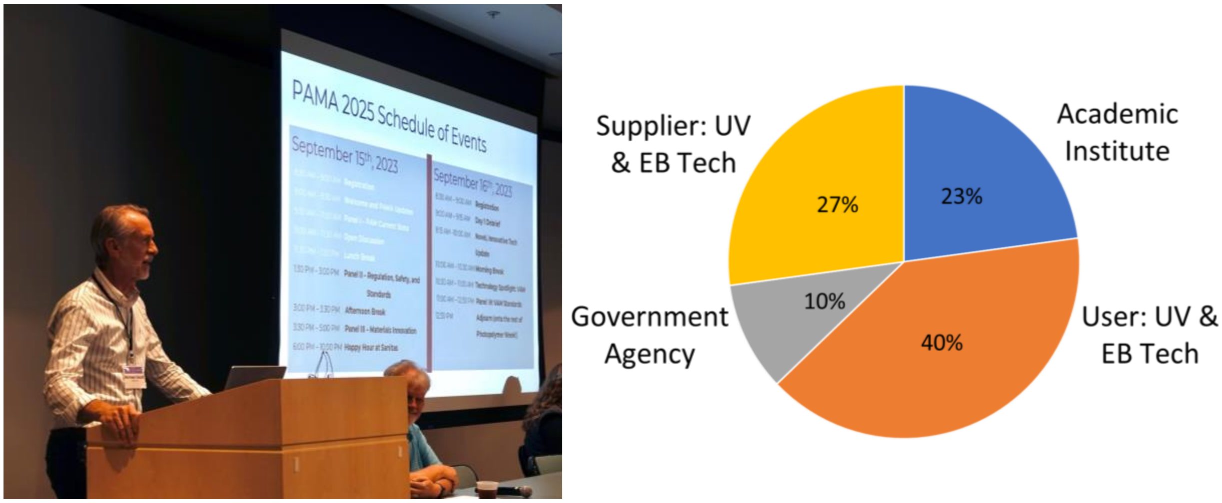

Figure 1: (left) Panel II- Regulation, Safety, and Standards moderator, Michael Gould, preparing to introduce his panelists. (right) Stakeholders participating in the PAMA 2025 by percentage.

During the four panels, participants examined barriers to adoption, evolving regulatory and sustainability pressures, materials and hardware innovation, and the urgent need for standardization, particularly in light of NIST interlaboratory studies underscoring significant discrepancies in cure depth measurements. A central theme was that PAM is transitioning from an innovation-driven field toward a manufacturing-driven ecosystem where reliability, safety, regulatory readiness, and data transparency are increasingly critical.

Panel discussions highlighted that although PAM has achieved strong adoption in applications such as dental, footwear, and sports equipment, broader industrial deployment remains limited by fragmentation, post-processing challenges, and consumer misconceptions. At the same time, advances in high-throughput experimentation, machine learning, and AI-driven materials discovery offer new opportunities for accelerated innovation, provided they are supported by shared data standards and cross-sector collaboration.

Regulatory considerations emerged as an increasingly important driver of industry direction. Growing scrutiny of photoinitiators, hazardous classifications, and photopolymer waste is increasing demand for safer chemistries, improved hazard communication, and harmonized global standards. Participants emphasized that early engagement with regulators is essential to ensure policies support both safety and continued innovation.

Discussions of the materials innovation pipeline noted that acrylate-based systems continue to dominate PAM but may be approaching the limits of incremental improvement. Future advances are likely to involve alternative chemistries, hybrid cure mechanisms, and dual-reaction systems, alongside hardware innovations that expand the feasible materials space through improved thermal control, viscosity handling, and exposure architectures.[1–6]

The workshop also featured PAMA's first focused discussion on volumetric additive manufacturing (VAM), a rapidly emerging approach that challenges conventional layer-based assumptions about exposure and resolution. Participants emphasized that measurement frameworks, terminology, and materials characterization standards must evolve quickly to support the scalable adoption of this technology.

Across all four panels, seven strategic themes (Appendix 1) emerged as foundational priorities:

1. Materials Evolution Beyond Incremental Improvement
2. Regulatory Readiness and Sustainability as Design Drivers
3. Data Infrastructure, Digitalization, and AI-Enabled Discovery
4. Standards and Metrology as Enablers of Scale
5. Hardware–Materials Co-Design and Process Integration
6. Application-Driven Commercialization and Validation
7. Collaboration as Core Infrastructure

These themes reinforced that the next phase of PAM growth will depend on coordinated progress across materials science, hardware development, regulatory science, data infrastructure, and standards development. Achieving this vision will require sustained collaboration across industry, academia, and government; an effort that PAMA aims to support by serving as a trusted platform for dialogue, education, and coordinated standards development.

Figure 2: A subset of the 2025 Workshop Attendees posing outside of the conference venue with the CU Boulder campus and Flatirons in the background.

1. Panel I – Current State of Polymer 3D Printing and Beyond

Figure 3: Panelist Johanna Schwartz discussing her research efforts in PAM at LLNL with audience members and fellow panelists.

This panel brought together leaders from industry, healthcare, national laboratories, and startups to assess the current state and near-term trajectory of photopolymer additive manufacturing (PAM). Discussions focused on persistent adoption bottlenecks, increasing sustainability pressures abroad, and the emergence of new technology platforms, such as high-throughput material screening and AI-driven discovery, that could reshape how PAM materials and processes are developed. Panelists emphasized that while application momentum is strong, broader adoption will depend on improved collaboration, standards, and trust across the field.

Moderator:

- **Vince Anewenter**, Executive Director, PAMA

Panelists:

- **Matthew Menyo, PhD**, VP of Product, Carbon
- **Johanna Schwartz, PhD**, Staff Scientist and PI, Lawrence Livermore National Laboratory
- **Katie Weimer**, CEO and Co-Founder, GenesisTissue Inc.
- **Jonathan Andersson**, Scale-up Manager, Arkema

1.1. Key Discussion Points

1. Adoption Bottlenecks and Industry Fragmentation

- PAM adoption remains constrained by material limitations, post-processing

inefficiencies, and scalability challenges
- Fragmentation between material developers, hardware vendors, and end users slows feedback loops and technology transfer
- Industry forums such as PAMA play a critical role in breaking down silos and aligning priorities

2. Sustainability as a Market Driver and Constraint
- Sustainability is no longer optional, particularly in European markets, with increasing pressure to adopt bio-based feedstocks and reduce hazardous chemistries
- Supply chain reliability and consistency remain major obstacles for scaling bio-based materials
- Photopolymers can become hazardous waste post-use, and are lacking clear and cost-effective recycling pathways compared to thermoplastics

3. Application Maturity and Commercial Momentum
- End-use adoption is accelerating in footwear, sports equipment, dental, and healthcare applications
- Dental and medical devices represent a proven success story, while bioprinting and regenerative medicine show promise but face regulatory and scale challenges
- In consumer products, adoption is often driven by aesthetics and branding, though functional benefits (e.g., ventilation, durability, customization) are emerging

4. Technology Frontiers: Automation, AI, and Post-Processing
- High-throughput platforms such as Lawrence Livermore's *Studying Polymers on a Chip (SPOC)* enable automated screening of viscous, composite, and high-performance formulations
- AI-enabled self-driving labs can leverage both successful and failed experiments to accelerate discovery and optimization
- Post-processing remains a critical weak point; solvent washing (e.g., IPA) degrades material performance, motivating interest in alternative chemistries and workflows

5. Standards, Transparency, and Collaboration
- Inconsistent terminology, limited MSDS transparency, and mismatches between lab testing and industrial practice undermine trust
- Regulatory scrutiny of photoinitiators (e.g., TPO in Europe) highlights the need for proactive industry engagement to shape workable regulations
- PAMA aims to position itself as a trusted, neutral source for safety, standards, and regulatory guidance

1.2. Action Items

- *Accelerate Adoption:* Address post-processing, scalability, and material reliability to support end-use manufacturing

- *Advance Sustainable Materials:* Develop greener, bio-based, and less hazardous chemistries with reliable supply chains
- *Enable Data-Driven Discovery:* Expand use of high-throughput screening and AI-enabled platforms to generate shared, high-quality datasets
- *Strengthen Standards and Safety:* Improve MSDS transparency, align pre- and post-processing protocols, and proactively engage regulators
- *Foster Collaboration:* Use PAMA as a neutral hub to connect material developers, OEMs, end users, and policymakers

1.3. Concluding Insights

Across the PAM infrastructure, fragmentation of data, knowledge, and metrology remains a systemic barrier to adoption, but coordinated forums and shared platforms can facilitate and accelerate industry alignment. Innovating on sustainable materials could be one such alignment strategy as pressures, particularly in Europe, mount in this space. Application-specific successes are driving PAM validation at-scale, though consumer-level adoption is still of concern due to regulatory bodies demanding stronger safety and standards frameworks, which are also foundational to ensure industry scales with technology readiness. Automation and AI-driven discovery could also assist in adoption acceleration and alignment by enabling the wealth of PAM characterization datasets to drive faster iteration on materials and design optimization.

2. Panel II – Regulations, Safety, and Standards in a Changing Landscape

Figure 4: Panelist Stephen Postle engaging the fellow panelists and audience members with his extensive experience across the photopolymer formulation world.

This panel examined the rapidly evolving regulatory and standards landscape for photopolymer additive manufacturing (PAM), with a focus on how safety, compliance, and innovation intersect. Panelists discussed tightening global regulations on chemicals, photoinitiators, waste handling, and environmental impact, particularly in Europe, and the implications for PAM materials development and commercialization. The discussion emphasized that proactive engagement with standards and regulatory frameworks is essential not only for compliance purposes but also for building trust and enabling long-term industry growth.

Moderators:
- **Michael Gould**, **MS**, Technical Key Account Manager, RAHN USA

Panelists:
- **Amanda Griffin**, Program Manager, UL
- **Phil Nagel, PhD**, VP of Polymer Materials R&D, 3D Systems
- **Dale Babcock**, Lab Manager, Henkel
- **Stephen Postle**, **PhD**, Global Director of Technology, BCH North America

2.1. Key Discussion Points

1. Escalating Global Regulatory Pressures
- Regulatory scrutiny of PAM chemistries is accelerating worldwide, with European

policies often setting de facto global standards

- Photoinitiators and acrylates (e.g., TPO) are under increasing examination, driving urgency for reformulation and substitution strategies
- Shifts in U.S. policy create uncertainty, but global supply chains effectively anchor manufacturers to stricter EU requirements

2. Safety, Hazard Classification, and MSDS Transparency

- Current MSDS documentation is often overly vague to protect IP, leaving end users without clear understanding of hazards or safe handling practices
- Insufficient transparency undermines user confidence and slows adoption in regulated environments.
- Even when accurate data exists, many users lack the training needed to interpret it consistently

3. Standards as an Enabler of Adoption

- Harmonized standards for materials testing, pre- and post-processing, and waste management are critical for PAM adoption in aerospace, automotive, and healthcare sectors
- Comparisons to injection molding and other mature manufacturing industries illustrate the importance of standardized frameworks for recycled content, hazard communication, and material qualification
- ASTM, NIST, UL, and PAMA were identified as material- and technology agnostic resource for standards development and regulatory dialogue

4. Industry–Regulator Collaboration

- Without sustained engagement from industry and research organizations, regulations risk becoming unnecessarily restrictive rather than guides to safe, responsible growth
- Early and informed collaboration can help shape “smart regulation” that balances safety, environmental responsibility, and technological advancement
- Shared language and aligned standards are necessary to avoid fragmented compliance strategies across regions

2.2. Action Items

- *Improve Regulatory Readiness:* Audit material portfolios for regulatory risk and accelerate development of safer, globally acceptable chemistries
- *Advance Standards Development:* Support harmonized standards for materials testing, processing, and waste handling through ASTM, NIST, UL, and PAMA
- *Enhance Transparency and Education:* Improve MSDS clarity and develop standardized reporting formats and training resources for end users

- *Strengthen Industry–Regulator Dialogue:* Establish ongoing mechanisms for collaboration to guide effective, innovation-friendly regulation

2.3. Concluding Insights

Across the globe, regulation of PAM materials is accelerating, and companies must transition from being reactionary to anticipatory, which will drive user trust and market expansion due to the associated increased transparency and safety practices. To facilitate this transition, proactive industry engagement on standards development and regulation is needed to ensure neither is overly restrictive or misaligned. This points toward global coordination on these efforts as supply chains and markets are inherently international.

3. Panel III – Materials Innovation and Print Reliability: Performance, Data, and Practical Challenges

Figure 5: Panelist Stefan Hinote discussing Henkel's material innovation focus areas amidst ongoing regulatory concerns.

This panel examined the technical, commercial, and regulatory constraints shaping materials innovation in photopolymer additive manufacturing (PAM). Panelists discussed why performance gains in PAM materials remain largely incremental, emphasizing that fundamental breakthroughs will require moving beyond acrylate-dominated chemistries. The discussion highlighted the tight coupling between resin chemistry, printer hardware, regulatory feasibility, and market demand, underscoring that innovation in PAM is constrained as much by economics and compliance as by chemistry itself.

Moderators:

- **Mike Idacavage**, PhD, Radical Curing LLC

Panelists:

- **Wyatt Levy, MS**, Solution Engineer, Albert Invent
- **Jeff Stansbury, PhD**, Professor, University of Colorado Anschutz
- **Stefan Hinote**, Product Development Manager-3D Printing, Henkel
- **Arminas Ilginis, PhD**, Polymer Engineer, AmeraLabs

3.1. Key Discussion Points

1. Materials as the Primary Innovation Bottleneck

- Acrylate-based systems dominate PAM and are approaching the limits of incremental

improvement
- Achieving higher toughness, temperature resistance, and durability will require new chemistries such as cationic systems, epoxies, hybrids, or dual-cure approaches
- Adoption of alternative chemistries is constrained by photoinitiator availability, exposure requirements, printer compatibility, and uncertain end-use performance

2. Regulatory and Economic Constraints on New Materials
- Registering new monomers under regulatory frameworks (e.g.; Toxic Substance Control Act (TSCA); Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH)) is slow and costly, often exceeding the revenue potential of PAM-specific markets
- As a result, PAM materials innovation frequently “piggybacks” on chemistries developed for larger markets such as coatings or adhesives, where regulatory costs are amortized quickly
- These constraints favor incremental reformulations over fundamentally new material systems

3. Hardware–Chemistry Co-Dependence
- Advances in printer hardware, such as heated chambers, improved viscosity handling, and volumetric printing, have already expanded the feasible materials space
- High-viscosity and hybrid systems offer improved performance but remain incompatible with many commercial printers
- Suppliers are reluctant to develop chemistries that function only on niche hardware platforms, slowing broader adoption

4. Performance Tradeoffs and Reliability Challenges
- PAM materials development involves persistent tradeoffs:
    - Strength vs. toughness (high crosslink density vs. low crosslink density)
    - Speed vs. fidelity (fast cure vs. resolution and stability)
    - Viscosity vs. printability (material limited vs. printer limited)
- Post-processing, rather than print speed, is often the dominant bottleneck for high-performance applications
- There is no “universal” resin; performance requirements must be matched to specific application needs

5. Commercial and Market Dynamics
- Materials development is overwhelmingly customer-driven; suppliers invest primarily when clear demand and willingness to pay for validation exist and pushes innovation toward niche, validated applications (e.g., medical, aerospace) rather than broad, general-purpose material applications
- Smaller companies and academic groups are better positioned to explore high-risk chemistries, while larger firms prioritize incremental improvements and certification

pathways

- Growing competition from lower-cost suppliers, particularly in China, is shifting differentiation toward reliability, compliance, and application-specific validation

3.2. Action Items

- *Expand the Chemistry Toolkit*: Advance cationic, hybrid, and dual-cure systems capable of thermoplastic-like performance
- *Align Hardware and Materials Development:* Promote co-design between printer manufacturers and resin developers to accommodate higher viscosities and new cure mechanisms
- *Streamline Regulatory Pathways:* Identify strategies to leverage cross-industry chemistries and reduce registration burdens for PAM materials
- *Improve Reliability and Validation:* Focus on post-processing optimization, durability testing, and application-specific certification
- *Enable Collaborative Innovation:* Encourage partnerships between academia, startups, and established suppliers to bridge early-stage research and commercial deployment

3.3. Concluding Insights

Because much of PAM adoption is now application-driven, novel chemistry and material development are needed to serve application-specific performance goals. However, coordinated regulatory strategy is required to shape which materials can realistically reach applicable markets. Hardware and software development must also align to accommodate these strategies to enable more sophisticated material systems, from viscous ceramic slurries to soft, fragile biomimetic hydrogels, appreciating that performance tradeoffs will be needed as well. Commercial validation will be the driving factor for success in novel material development, which appears to favor niche, certified materials over speculative breakthroughs.

4. Panel IV – Establishing Standards for Volumetric Printing: Lessons from the Vat Photopolymer Community

Figure 6: Panelist Alvin Li discussing his work innovating and iterating on volumetric AM algorithm considerations.

This panel examined volumetric additive manufacturing (VAM) as a disruptive evolution of vat photopolymerization, emphasizing that its technical maturation is outpacing the development of standards, shared definitions, and validation frameworks. Unlike layer-by-layer SLA and DLP processes, volumetric printing operates as a fully three-dimensional exposure and polymerization process, invalidating many long-standing assumptions about dose, resolution, and feature fidelity. Panelists stressed that early alignment on language, metrics, and material benchmarking is essential to ensure scalable adoption.

Moderators:

- **Camila Uzcategui, PhD**, CEO and Co-Founder, Manifest Technologies

Panelists:

- **Maxim Shusteff, PhD**, Engineering Research Staff, Lawrence Livermore National Laboratory
- **Chi Chung (Alvin) Li, PhD**, Postdoctoral Associate, University of Colorado Boulder
- **Martin de Beer, PhD**, Staff Scientist, Lawrence Livermore National Laboratory

- **Neil Cramer, PhD**, Global Business Development Leader, Arkema

4.1. Key Discussion Points

1. Standards Must Begin with Shared Language and Definitions

"Volumetric printing" now encompasses multiple distinct approaches, including tomographic VAM, parallax-based methods, light-sheet, and up-conversion-enabled processes

- These approaches differ significantly in hardware architecture, computational demands, materials constraints, and production readiness
- Without early consensus on terminology and classification, the field risks internal fragmentation and confusion among users, suppliers, and regulators

2. Legacy Vat Photopolymer Metrics Do Not Translate

- Traditional concepts such as working curves, Jacob's equation, and 2D radiant exposure are insufficient for describing volumetric processes
- Volumetric printing requires quantification of absorbed dose per unit volume, accounting for depth-dependent attenuation, scattering, and inhibition

3. Materials are the Primary Bottleneck (Echoing Panel III)

- Volumetric processes rely on nonlinear material response and sufficient contrast to suppress unintended polymerization outside the target volume
- Failure modes are often binary; prints fail outright rather than degrade gradually if contrast thresholds are not met
- Standardized methods for reporting absorptivity, inhibition behavior, contrast ratio, and cure kinetics are urgently needed

4. Computation Is a Core Process Step

- Volumetric printing requires the generation of tomographic projections of the desired print, fundamentally different from slicing in layer-based AM
- No standardized "slicer equivalent" exists, complicating benchmarking and inter-laboratory comparison
- Computational transparency and consistency are necessary to enable meaningful standards and performance comparisons

5. Repeatability Is Achievable; Dimensional Accuracy Is Not Yet

- Panelists agreed that volumetric printing can be highly repeatable under controlled conditions
- However, dimensional fidelity to CAD models remains a major challenge, with errors accumulating prior to reaching optimal exposure windows
- Real-time sensing and feedback mechanisms (e.g., optical scattering, refractive index changes) were identified as key future enablers

6. Performance Must Be Contextualized by Application

- Speed-versus-resolution metrics alone are insufficient to communicate value.
- Volumetric printing may be uniquely advantaged for:
    - High-viscosity materials
    - Support-free and enclosed geometries
    - Over-molding and encapsulation
    - Enhanced surface quality (no traditional layering effects)
    - Mass customization
    - Continuous or flow-based production concepts
- "Design for volumetric manufacturing" will be as critical as the printing technology itself

4.2. Action Items

- *Define Terminology and Classification:* Establish community-agreed definitions and subclasses for volumetric printing modalities
- *Develop Volumetric Metrics:* Create standards for absorbed dose per unit volume, contrast, inhibition, and depth-dependent kinetics
- *Standardize Materials Reporting:* Define minimum characterization requirements for volumetric-ready resins
- *Enable Computational Benchmarking:* Develop transparent, comparable workflows for projection generation and validation
- *Guide Early Adoption:* Identify application-specific performance benchmarks for high-value use cases

4.3. Concluding Insights

By virtue of the volumetric AM process, the nominally 2D assumptions often associated with PAM break down and require fundamentally new metrology and reporting strategies. To ensure seamless integration of these new approaches into all VAM systems, shared language needs to be standardized and prioritized, including the language and documentation surrounding computational strategies. Another consideration distinguishing VAM systems from traditional 2D PAM build strategies include how material contrast and inhibition control are essential to operation as opposed to secondary optimization parameters. While VAM is a promising technology to high-speed fabrication, adoption will be driven by repeatability and workflow integration. Engaging the broader PAM community on VAM can serve as a test case for facilitating rapid adoption of disruptive PAM technologies.

Appendix 1

Strategic Themes: Foundational Priorities Emerging from the Workshop

Across all panels, recurring patterns emerged that extend beyond individual technical topics. These themes represent the field-wide priorities required for photopolymer additive manufacturing (PAM) to evolve from a rapidly innovating technology into a robust, scalable manufacturing ecosystem. Collectively, they form a strategic framework for guiding research investment, industrial adoption, and standards development over the coming decade.

1. Materials Evolution Beyond Incremental Improvement

The workshop highlighted a broad consensus that conventional acrylate-based systems, while commercially successful, are approaching the limits of incremental optimization. Future breakthroughs in durability, thermal stability, and functional performance will likely require use of alternative chemistries such as cationic systems, hybrids, dual-cure networks, and technology-specific formulations. However, this transition is constrained by regulatory costs, supply chain realities, and printer compatibility. Strategic progress therefore requires coordinated advances in chemistry, process design, and material qualification methodologies rather than isolated formulation improvements.
Desired Outcomes: Expand the chemistry portfolio while enabling pathways for scalable validation and commercialization.

2. Regulatory Readiness and Sustainability as Design Drivers

Regulatory pressure and sustainability considerations are increasingly shaping the direction of PAM innovation. Global scrutiny of photoinitiators, hazardous classifications, and waste handling, particularly under EU frameworks, means that safer chemistries and transparent hazard communication are becoming prerequisites for market access. Sustainability is no longer a peripheral consideration but a core engineering constraint influencing material selection, lifecycle planning, and process development.
Desired Outcomes: Integrate regulatory resilience and environmental impact into early-stage material and process design.

3. Data Infrastructure, Digitalization, and AI-Enabled Discovery

Data-driven experimentation emerged as a major opportunity across panels, particularly through high-throughput screening platforms and AI-assisted laboratory workflows. However, the effectiveness of these approaches depends on data quality, reproducibility, and shared terminology. Failed experiments and process variability, traditionally underreported, were recognized as valuable assets for model training and optimization. The development of interoperable data frameworks and standardized reporting practices will be critical to unlocking the full potential of machine learning and automated experimentation.
Desired Outcomes: Build shared, high-quality datasets and digital infrastructure capable of supporting predictive and optimization-driven workflows.

4. Standards and Metrology as Enablers of Scale

From conventional vat photopolymerization to emerging volumetric printing approaches, the workshop repeatedly emphasized that standards lag behind innovation. Existing metrics and measurement frameworks often fail to capture process realities, particularly for three-dimensional exposure methods and nonlinear material responses. Early alignment on terminology, exposure metrics, material characterization, and process reporting was identified as essential to prevent fragmentation and facilitate cross-platform comparability.
Desired Outcomes: Establish common language, measurement frameworks, and validation protocols before widespread commercialization diversifies the field.

5. Hardware/Materials Co-Design and Process Integration
Advances in printer hardware, such as heated chambers, viscosity management, and volumetric exposure systems are reshaping what chemistries can be practically deployed. Conversely, material limitations often dictate hardware requirements. Panel discussions reinforced that future progress depends on integrated design approaches that consider chemistry, optics, computation, and post-processing as a single system rather than independent components.
Desired Outcomes: Foster collaborative development between material suppliers, hardware manufacturers, and process engineers to expand manufacturable design space.

6. Application-Driven Commercialization and Validation
Real-world adoption of PAM is currently strongest in highly targeted applications such as dental devices, footwear, medical tooling, and specialized industrial components. These successes demonstrate that validated workflows, rather than generalized material performance, drive commercialization. Certification, repeatability, and regulatory acceptance were repeatedly cited as stronger adoption factors than novelty or speed alone.
Desired Outcomes: Prioritize application-specific qualification and performance validation to build trust and accelerate entry into regulated markets.

7. Collaboration as Core Infrastructure
Finally, the need for coordinated collaboration across industry, academia, standards organizations, and regulatory bodies. Fragmentation between stakeholders slows innovation, while shared forums and neutral convening organizations enable knowledge exchange, consensus-building, and strategic alignment. Participants consistently identified collaboration as the mechanism through which all other strategic themes can be executed.
Desired Outcomes: Establish sustained cross-sector collaboration frameworks to align research, standards, and commercialization pathways.

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