Technical white paper

HP Multi Jet Fusion technology

A disruptive 3D printing technology for a new era of manufacturing

Three-dimensional printing of useful objects and machine parts is becoming a reality. 3D printing offers the ability to produce—both rapidly and at low cost—short runs or one-of-a-kind parts. HP's development of HP Multi Jet Fusion technology includes new HP Jet Fusion 3D printers and an Open Platform that will revolutionize the design, materials, manufacturing, and distribution of 3D parts to drive the digital transformation of manufacturing.

Introduction

For more than 30 years, HP inkjet technologies have disrupted and led a broad range of printing markets. HP Multi Jet Fusion technology leverages HP's deep assets in imaging and printing to take the digital transformation of printing off the page and into a three-dimensional world of highly-functional, high-value manufactured items.

HP Multi Jet Fusion technology enables high build quality up to 10 times the faster[1] and at the lowest cost relative to competitive 3D printing solutions in the marketplace today.[2] These breakthroughs in quality and speed will accelerate the widespread adoption of 3D printing to create a digital transformation of manufacturing as widespread and profound as the way HP thermal inkjet technology has changed the landscape of conventional printing markets and applications. As with other HP products, HP Jet Fusion 3D printers will offer users HP's key values of reliability, ease of use, versatility, and an end-to-end digital workflow.

This technical white paper provides details on HP Multi Jet Fusion technology and HP's strategies and vision to introduce a new era of digital manufacturing.

3D printing

Whereas manufacturing by milling, grinding, and cutting removes material from a workpiece, additive manufacturing— "3D printing"—is a digital technology that creates objects by selective material addition. This allows each 3D-printed part to be unique in the same way that each page printed by an inkjet or laser printer can have unique content. 100% customized content page-to-page and part-to-part is a capability digital technologies bring to 2D and 3D printing.

Prime applications for 3D printing include the functional and aesthetic components of machines, consumer and industrial products that are manufactured in short runs of typically less than 1000 units, highly-customized and high-value products that can be one-of-a-kind, and parts with complex internal and external 3D geometries.

Before 3D printing, parts with complex surfaces, moving elements,[3] and internal fluid passages were assembled from subcomponents that were aligned and assembled with fasteners and/or adhesives. In conventional parts—especially those designed to handle air and liquids—joints and sealing surfaces may be points where mechanical failure and leakage occurs.

Because 3D printing builds objects from a stack of thin cross-sections, complex parts can be produced either as a monolithic structure or from many fewer subcomponents. 3D printing has the potential to simplify design and manufacturing processes and to reduce processing time and costs. Parts can be made by 3D printing that cannot be made by other methods, and this creates many new possibilities for innovations in design, form, and function.

To meet the needs of a broad range of applications, a 3D printing solution should offer the desirable attributes of high productivity, low cost of hardware, low cost per part, high build quality, and choices in materials and material properties for strength, elasticity, and other properties. While commercial 3D printers have been available for more than thirty years, adoption of 3D printing has been limited to niche markets and applications because all of these attributes have not been available from a single technology or 3D printing solution. Until now.

HP Multi Jet Fusion technology was conceived to overcome the tradeoffs and constraints limiting current 3D technologies. And, HP Multi Jet Fusion has the unique ability to produce parts with controllable physical and functional properties at each point in a part. Offering speed, quality, strength, and novel functionalities, HP Multi Jet Fusion will accelerate the adoption of 3D manufacturing across a wide range of industries and applications.

HP's vision is to revolutionize part design and manufacturing with streamlined workflows and new capabilities for 3D printing. The supply chain for finished, high-value items will be fundamentally changed by the ability to manufacture parts where they are needed and on-demand. HP's Multi Jet Fusion Open Platform will bring down barriers to adoption of 3D printing through collaborative innovations in materials, printing hardware, and design and production software.

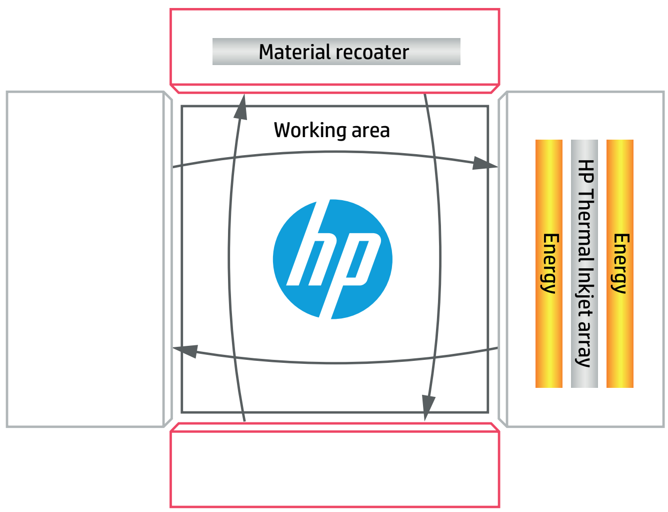
HP Multi Jet Fusion technology

HP Multi Jet Fusion technology is built on decades of HP's investment in inkjet printing, jettable materials, precision low-cost mechanics, material science, and imaging. With custom materials and innovations in how a large working area can be printed and cured rapidly, HP Multi Jet Fusion delivers advantages in build speed and control over part and material properties that are beyond the capabilities of other 3D printing processes. By jetting HP functional agents using HP printheads, material in the working area can be fused, detailed, and transformed point-by-point.

Synchronous, scalable architecture for high productivity

A key innovation in HP Multi Jet Fusion technology is a high-speed, synchronous architecture that builds parts layer-by-layer. As shown schematically in Figure 1, dual carriages scan across the Working area in perpendicular directions: one carriage recoats the working area with fresh material, and the other prints HP functional agents and fuses the printed areas. This separates the processes of recoating and printing/fusing so that each process can be separately optimized for performance, reliability, and productivity.

Figure 1. Schematic of HP Multi Jet Fusion synchronous printing architecture



In an HP Jet Fusion 3D printer, a part, or a set of parts, is built layer-by-layer over a working area inside an HP Jet Fusion 3D build unit. After job completion, the build unit is rolled into an HP Jet Fusion Processing Station for cooling, unpacking the parts, and recovery and refreshing the build material.[4] While those processes are completing, a build unit that has been refreshed by the HP Jet Fusion Processing Station can be rolled back into the printer for continuous production.[5]

The depth of the build unit and working area determine the dimensions of the largest part that can be produced. For specifications on processing speed and working area for HP Jet Fusion 3D printers, consult product data sheets at hp.com/go/3Dprint.

HP Multi Jet Fusion technology uses scalable HP thermal inkjet technology to make printbars of different widths by stacking printheads across the width of the scan. Just as this capability allows HP to scale its 2D printing solutions from the desktop to more than 100-inches wide, HP can create a range of HP Jet Fusion 3D printing solutions with working areas of different sizes. HP printheads can also be stacked along the scan direction to add more nozzles for speed, functionality, and nozzle redundancy for dependable printing quality.

Building parts by HP Multi Jet Fusion technology

The build begins by laying down a thin layer of powdered material across the working area. For example, in Figure 1, the material recoater carriage scans from top-to-bottom. Next, the printing and fusing carriage with an HP thermal inkjet (printhead) array and energy sources scans from right-to-left across the working area. The leading energy source preheats the working area immediately before printing to provide consistent and accurate temperature control of each layer as it is printed. The printheads now print functional agents in precise locations onto the material to define the part's geometry and its properties. The printing and fusing carriage now returns left-to-right to fuse the areas that were just printed.

At the ends of the scans, supply bins refill the recoater with fresh material and service stations can test, clean, and service the printheads on the printing and fusing carriage as needed to ensure reliable operation.

After finishing each layer, the surface of the work area retracts about the thickness of a sheet of office paper,[6] and the material recoater carriage scans in the reverse direction for optimum productivity.

The process continues layer-by-layer until a complete part, or set of parts, is formed in the build unit.

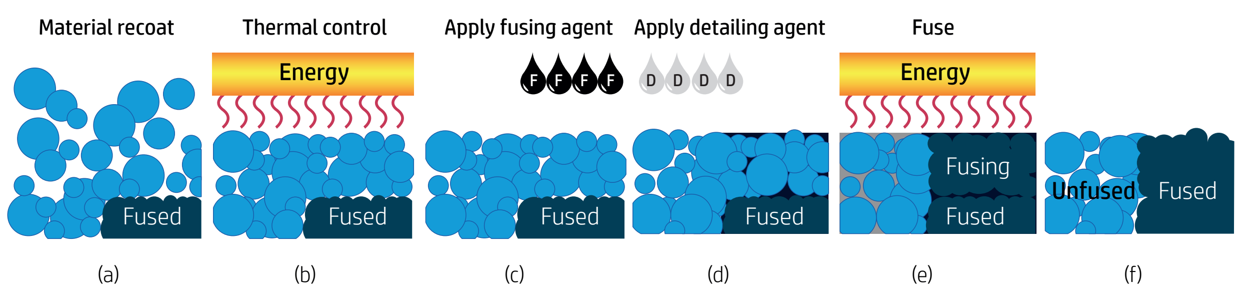
Fusing and detailing agents

With HP Multi Jet Fusion, each layer of a part is defined by an area that is fused (or transformed) surrounded by unfused powder. HP 3D high reusability printing materials are designed to minimize powder waste and can be reused in a later build.

Surplus powder reusability rates vary depending on the HP 3D printer. For specifications on surplus powder reusability, consult product data sheets at hp.com/go/3Dprint.

For high strength and surface quality, it is important that the new layer bonds to any previously fused material below it and the edges are smooth and well defined. This is accomplished with multiple agents applied by the array of HP printheads. Figure 2 takes a close-up look at the process described in Figure 1.

Figure 2. Schematic of HP Multi Jet Fusion printing process, cross-sectional views



The process begins by recoating the material in a thin layer across the work area, as shown schematically in Figure 2a.

Figures 2b-d represent what happens on the first scan of the printing and fusing carriage. Temperature at multiple points across the work area have been measured, and in Figure 2b energy is applied to the fresh layer to control the material temperature immediately before printing agents.

In Figure 2c, fusing agent ("F") is selectively printed where particles will be fused together.

In Figure 2d, detailing agent ("D") is selectively printed where the fusing action will be either reduced or amplified. In this example, the detailing agent reduces fusing at the boundary to produce a part with sharp and smooth edges.

In Figure 2e, the material is exposed to fusing energy, and selected areas now fuse. The fused material bonds to the layer below if that layer was fused on a previous cycle. Because HP Multi Jet Fusion technology can produce parts with Z-axis tensile strength comparable to the tensile strength in the X and Y planes,[7] it overcomes the limitation of reduced Z-axis strength found in some other 3D printing technologies.

Figure 2f shows the fused and unfused areas at the edge of a part. The working area now retracts in preparation for the next recoating, printing, and fusing cycle.

Figure 2 is a general overview of the process steps in HP Multi Jet Fusion technology. In specific HP Jet Fusion 3D printers, the order of steps may be rearranged and additional agents—transforming agents—may be applied during printing.

Pixels and voxels

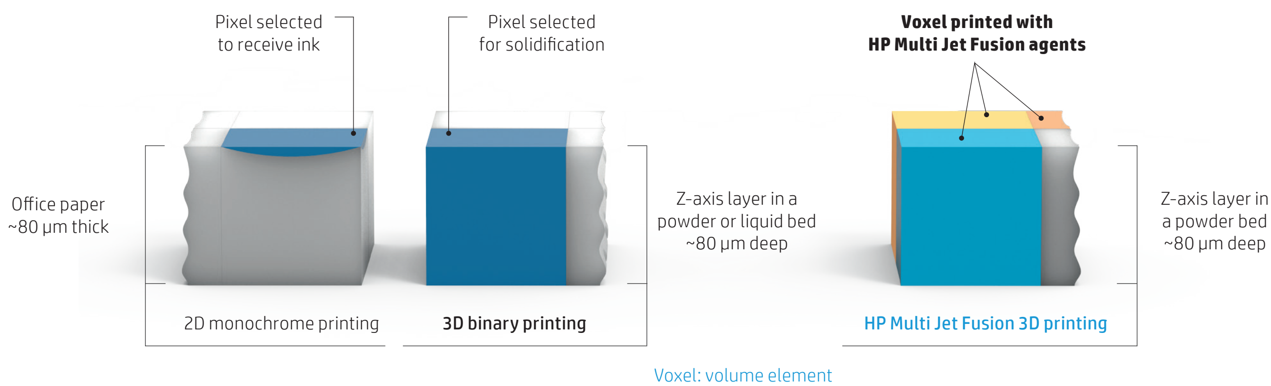
Images in conventional prints and electronic displays are formed from pixels—picture elements. Pixels are the dots that are printed (or emit light) at a specific number per inch (“dpi”), at a specific size, and with a specific color.

The 3D analog of the pixel is the voxel, for “volume element.” In 2D printing, pixels are arranged on a surface in a regular grid. In 3D printing, voxels are also printed in a regular 2D grid and a voxel has depth. The voxels form a thin layer that is the image of a part’s cross-section, and many such layers are stacked to form a 3D object. Specifying the properties of each voxel defines a 3D-printed part point-by-point over its surfaces and within its volume.

An analogy between printing pixels in a monochrome image and printing voxels by conventional 3D technologies highlights the advanced capabilities of HP Multi Jet Fusion technology. In a monochrome 2D printer, a pixel is either printed or not, and in conventional 3D printers a voxel is either fused or not. HP Multi Jet Fusion advances 3D printing in the same way that adding color to 2D inkjet printing expanded the capabilities, applications, and markets it could serve. In 2D printing, multiple inks—cyan, magenta, yellow, and black—can be combined in pixels to print an image with a wide range of colors. Using multiple agents, HP Multi Jet Fusion prints voxels with a range of physical and functional properties—including color.

Figure 3 shows a 2D pixel and two (2) 3D voxels printed in layers 80 microns thick. HP Multi Jet Fusion technology can print up to 1200 voxels per linear inch in each layer. Figure 3 illustrates the analogy between monochrome 2D pixel printing and conventional 3D binary voxel printing. HP Multi Jet Fusion voxels are shown in color to signify the potential of HP Multi Jet Fusion technology to take 3D printing to new levels. The breakthrough of printing voxels whose properties can be individually controlled is made possible using HP’s **transforming agents** in the HP Multi Jet Fusion process.

Figure 3. Pixel, binary voxel, and HP Multi Jet Fusion voxels[6]



Transforming agents

HP’s vision for HP Multi Jet Fusion technology is to create parts with controllably variable—even quite different—mechanical and physical properties within and across a single part or among separate parts printed simultaneously in the build unit. This is accomplished by the use of additional agents—called **transforming agents**—to control the interaction of the fusing and detailing agents with each other and with the material to be fused. Depositing transforming agents voxel-by-voxel across each layer allows HP Jet Fusion 3D printers to produce parts that cannot be made by other methods.

In HP Jet Fusion 3D printers, properties that HP transforming agents could control within and across a part include:

- Dimensional accuracy and detail
- Surface roughness, texture, and friction coefficient
- Tensile strength,[7] flexibility, hardness, and other material properties
- Electrical and thermal conductivity
- Opacity or translucency in plastics
- Color: embedded and at the surface

Figure 4 shows parts made by an HP Jet Fusion 3D printer that can print with color. Transforming agents print combinations of CMYK primary colors in each voxel. Color can be 3-dimensional—within the part or on its surface—to produce visible indications when material is removed by wear or damaged. This allows visual inspection to determine if a part must be replaced, and embedded color can provide anti-tampering features. In addition to visible colors, materials that emit specific colors only when illuminated by ultraviolet light (e.g., quantum dots and fluorescent dyes) can provide unobtrusive or hidden text and codes for security, identification, and other purposes.

Using HP transforming agents to modify material properties, a part can have durable, hard surfaces with a low friction coefficient where contact and wear will occur, and different properties elsewhere to meet other functional requirements.

The ability of HP transforming agents to deposit conductive traces both embedded inside the part and on its surface offers the possibility of building intelligent parts that can measure and report their state during operation. For example, advanced HP Jet Fusion 3D printers under development have built parts with embedded strain gage arrays—Wheatstone Bridges—that can accurately measure loads on the part during operation. This eliminates additional assembly operations, where strain gages must be precisely positioned and glued in place. Conductive traces can connect embedded and surface sensors with electronic circuits that process and report part status in real-time using visible indicators—such as light-emitting diodes—or by low-power wireless technologies.

Figure 4. Sample parts made by HP Multi Jet Fusion technology

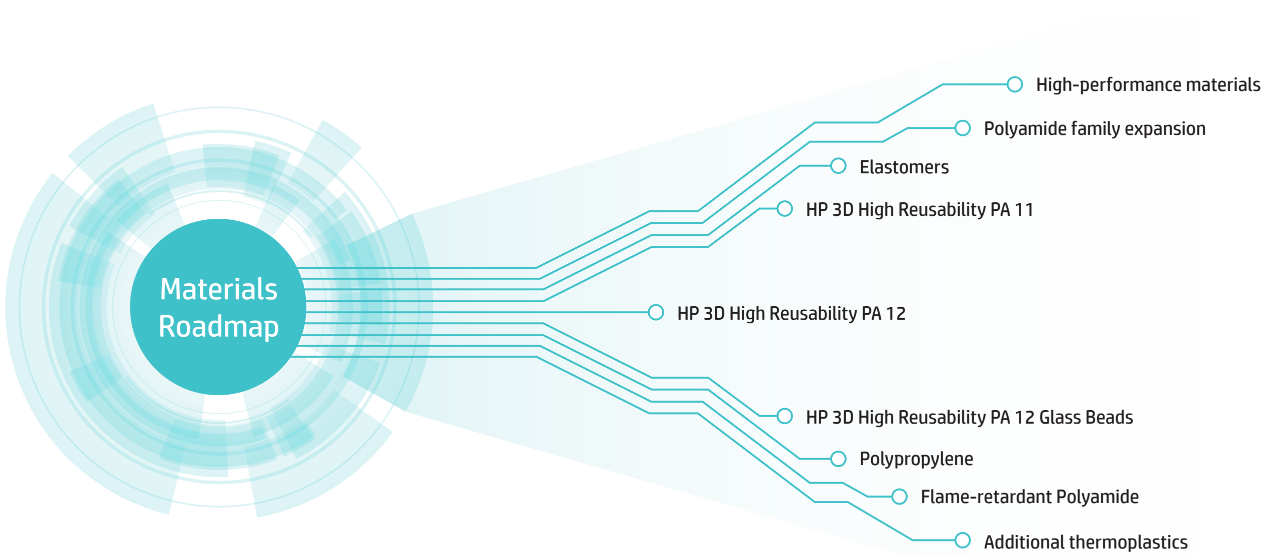
Data Courtesy of Sagtubi

3D materials

HP is working hard to enable new materials innovations that break down some of the traditional barriers to 3D printing adoption—cost, quality, performance, and diversity. We're doing this through a growing portfolio of HP-branded powders and an open platform model that encourages third-party collaboration and materials expansion.

3D materials portfolio roadmap

HP plans to continue expanding the palette of material offerings even further—delivering a wider family of thermoplastics, including those with flame-retardant properties. And we're exploring new materials, such as elastomers, polyamides, commodity plastics, and high-performance materials. The HP Multi Jet Fusion Open Platform is a critical force in the process of accelerating materials innovation. By working together, we can enable a future where even not-yet-imagined applications become possible.



HP Multi Jet Fusion Open Platform: collaborating to advance 3D printing

The goal of the HP Multi Jet Fusion Open Platform is to develop and foster industrial collaborations to drive the widespread adoption of 3D printing across industries.

Materials

The HP Multi Jet Fusion Open Platform enables materials partners including Arkema, BASF, Lehmann&Voss&Co., Evonik, and others to participate in the development of new HP Multi Jet Fusion materials. With their experience and understanding of a broad range of customer needs and applications, these partners will accelerate the development and adoption of HP Jet Fusion 3D printing solutions, and offer manufacturing economies of scale that can reduce the cost of 3D printing supplies.

Software and workflow

The STL 3D file format, first developed in 1989 for the 3D printing solutions of that era, has shortcomings with long processing times and limited dimensional precision that pose barriers to the production of complex, high-precision parts by new technologies such as HP Multi Jet Fusion. STL cannot make use of the advanced capabilities of HP Multi Jet Fusion technology because it only allows geometric representations—and not a voxel-based description—to be sent from the CAD software to a 3D printer or other applications. To realize the full potential of 3D printing, new features and capabilities are needed in 3D CAD software, and this is an area where HP is actively contributing.

HP is a founding member of the 3MF Consortium,[8] whose purpose is to define a new 3D printing format that allows 3D design software to communicate full-fidelity 3D models to other applications, services, and 3D printers.[9] Industry leaders in 3D CAD, 3D printing, software companies, and selected customers are working together through the 3MF Consortium to develop a versatile and highly-capable 3MF file format.

HP 3D printing solutions include the HP SmartStream 3D Build Manager and HP SmartStream Command Center to prepare, send to print, and monitor 3D printing jobs. For part creation, HP offers 3D design software customized for

HP Multi Jet Fusion technology from industry leaders Autodesk® (Autodesk® Netfabb® Engineer for HP) and Materialise Magics (Materialise Build Processor for HP Multi Jet Fusion).

Future potential

Just as HP's traditional printing solutions evolved from inkjet-based desktop printers in the 1980s to HP's high-speed commercial and industrial printing solutions of today, HP research and development will drive the evolution of HP Multi Jet Fusion technology beyond the materials and capabilities of HP's first-generation 3D printing products. HP is investing in long-term efforts and collaborations through the HP Multi Jet Fusion Open Platform to deliver 3D printing solutions with advanced capabilities, materials and material handling, and optimized 3D manufacturing workflows.

HP thermal inkjet technology underlies the productivity and capabilities of HP Multi Jet Fusion technology. To get a sense of the potential and scalability of HP thermal inkjet in 3D printing, HP's 2D printing solutions stack HP printhead modules to build printers with four, six, or more colors of ink and offer a wide range of printing formats from 1-inch to more than 100-inches wide. Using HP thermal inkjet, future HP Jet Fusion 3D printers will be able to deliver more kinds of functional agents and build parts in working areas even larger than today.

Summary

HP Multi Jet Fusion technology is built on HP's core competencies in precision low-cost mechanics, precision metering and placement of agents, high-volume manufacturing, material science, and imaging. Compared to other commercially available 3D printing technologies, HP Multi Jet Fusion and its 3D printing materials will define new levels of part quality and part functionality at up to 10 times faster,[1] and at the lowest cost.[2]

A unique feature of HP Multi Jet Fusion technology is its ability to modify material properties voxel-by-voxel to produce controlled variability in mechanical and physical characteristics within and across a part. This capability enables a host of new possibilities in the design and function of parts that cannot be produced by traditional manufacturing methods or other 3D printing solutions.

HP's entry into 3D printing will offer users a 3D printing ecosystem with advanced user interfaces, software for 3D part creation and production, and 3D printers optimized to deliver end-to-end productivity and economy that will drive the digital transformation of manufacturing.

Learn more at

hp.com/go/3Dprint

hp.com/go/JetFusion3Dsolutions

1 Based on internal testing and simulation, HP Jet Fusion 3D average printing time is up to 10 times faster than average printing time of comparable fused deposition modeling (FDM) and selective laser sintering (SLS) printer solutions from $100,000 USD to $300,000 USD on market as of April, 2016. Testing variables for the HP Jet Fusion 4210/4200 Printing Solutions: Part quantity: 1 full build chamber of parts from HP Jet Fusion 3D at 20% of packing density versus same number of parts on above-mentioned competitive devices; Part size: 30 cm^3; Layer thickness: 0.08 mm/0.003 inches.

2 Based on internal testing and public data for solutions on market as of April, 2016. Cost analysis based on: standard solution configuration price, supplies price, and maintenance costs recommended by manufacturer. Common cost criteria: using HP 3D High Reusability PA 12 material, and the powder reusability ratio recommended by manufacturer. HP Jet Fusion 3D 4200 Printing Solution average printing cost per part is half the average cost of comparable fused deposition modeling (FDM) and selective laser sintering (SLS) printer solutions from $100,000 to $300,000 USD. Cost criteria: printing 1 build chamber per day/5 days per week over 1 year of 30 cm^3 parts at 10% packing density. HP Jet Fusion 3D 4210 Printing Solution average printing cost per part is 65% lower versus the average cost of comparable FDM and SLS printer solutions from $100,000 to $300,000 USD and is 50% lower versus the average cost of comparable SLS printer solutions for $300,000 to $450,000 USD. Cost criteria: printing 1.4 full build chambers of parts per day/5 days per week over 1 year of 30 cm^3 parts at 10% packing density on fast print mode.

3 For example: gears, sliders, rotating joints, and other kinematic elements.

4 Fast cooling is enabled by HP Jet Fusion 3D Processing Station with Fast Cooling. HP Jet Fusion 3D Processing Station with Fast Cooling accelerates parts cooling time versus recommended manufacturer time of selective laser sintering (SLS) printer solutions from $100,000 USD to $450,000 USD, as tested in April, 2016. Fused deposition modeling (FDM) not applicable. Continuous printing requires an additional HP Jet Fusion 3D Build Unit (standard printer configuration includes one HP Jet Fusion 3D Build Unit). Material handling includes automated mixing of fresh and recycled powder, sieving, and loading.

5 Continuous printing requires an additional HP Jet Fusion 3D Build Unit (standard printer configuration includes one (1) HP Jet Fusion 3D Build Unit).

6 The retraction of the working area, on the order of 80 microns, allows a new layer to be printed. The actual range of layer thicknesses that can be produced depends on the HP Jet Fusion 3D printer. For the latest technical specifications, visit hp.com/go/3Dprint .

7 Based on the following mechanical properties: Tensile strength at 48 MPa (XYZ), Modulus at 1700-1800 MPa (XYZ). ASTM standard tests with HP 3D High Reusability PA 12 material. See hp.com/go/3Dmaterials for more information on materials specifications.

8 For more information, visit 3mf.io.

9 For more information, visit hp.com/go/3Dsoftware.

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