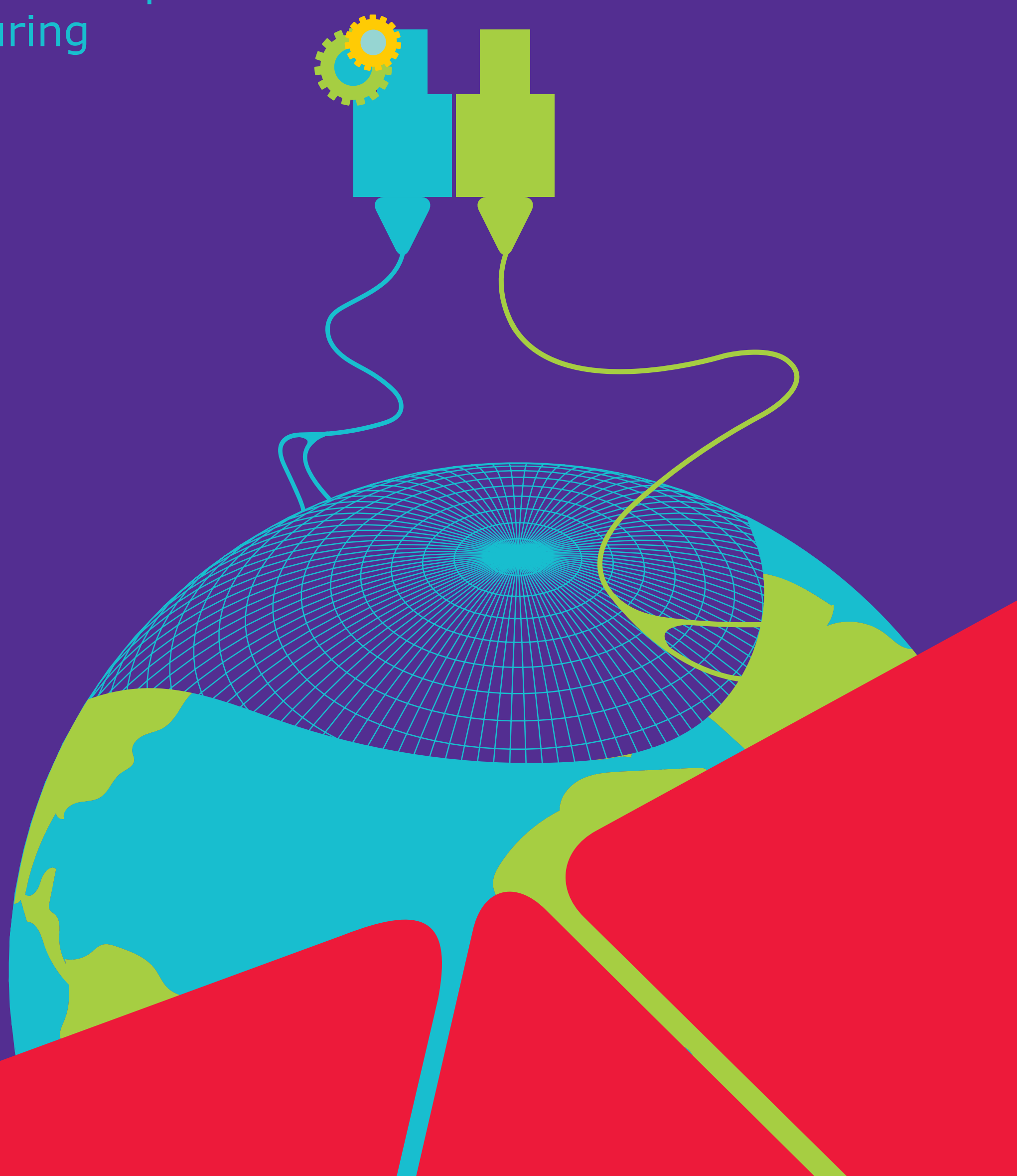
3D to 4D Printing for Added Sustainability

Minimizing Your Carbon Footprint with Smart Manufacturing



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Sigma-Aldrich®

Lab & Production Materials

3D to 4D Printing

The development of 3D printing enabled smart manufacturing by adding layer upon layer of material to build up your research. Our 3D printable portfolio provides the design flexibility (from material jetting and vat polymerization to material extrusion), energy efficiency, and allied to sustainability that this technology promises. Explore our wide range of 3D printable products for incomparable performance and economic efficiency with a lower environmental impact. Among our 3D printable offers, we highlight: (i) specialty polymers, including 4D printing precursors; (ii) inorganic-based inks, including our R&D100 awardee products; (iii) 3D printable composite enablers.

To find out more about our 3D to 4D printable solutions,
visit **sigmaaldrich.com/3dprinting**

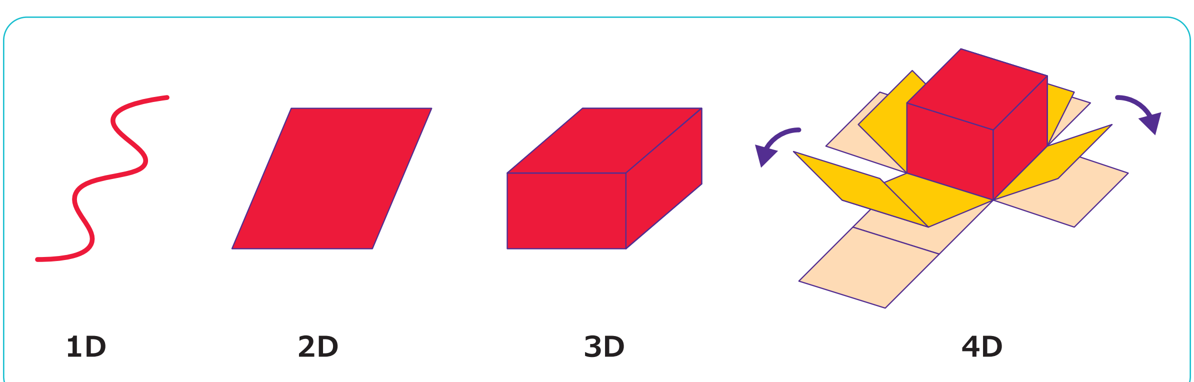
4D Printing Precursors

4D printing is the process through which a 3D printed object transforms itself into another structure over the influence of external energy input with time according to various stimuli such as heat, water, current, or light. The essential difference between 4D printing and 3D printing is the addition of smart design, or responsive materials that cause time-dependent deformations of objects.

Greener Alternative Product Characteristics: Waste Prevention, Design for Energy Efficiency

Suitable 3D Printing Techniques: Material Jetting; Vat polymerization

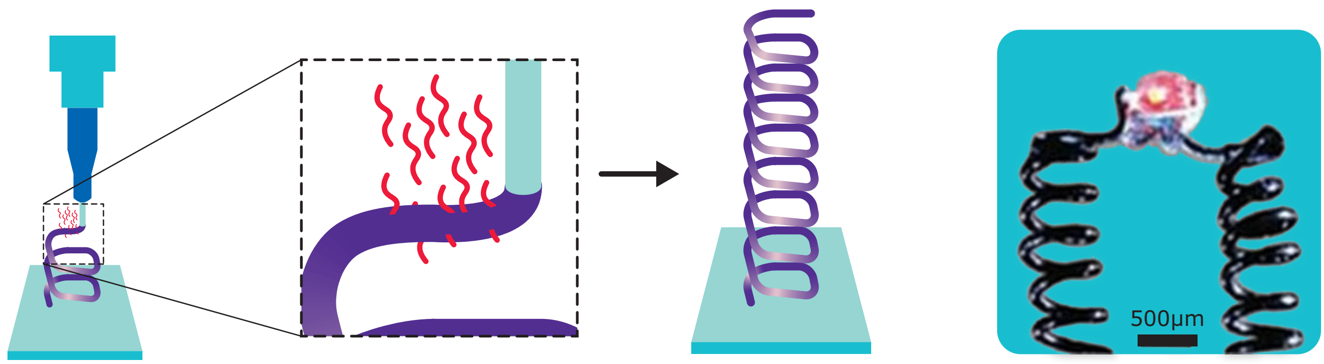
Name	Assay	Mesophase Behaviour	Cat. No.
1,4-Bis[4-(6-acryloyloxyhexyloxy)benzoyloxy]-2-methylbenzene	≥95%	$Cr_{86}N_{116}I$	**926809**
1,4-Bis[4-(3-acryloyloxypropyloxy) benzoyloxy]-2-methylbenzene	≥97%	$Cr_{64}N_{126}I$	**926841**
1,4-Bis[4-(11-acryloyloxyundecyloxy)benzoyloxy]-2-methylbenzene		$Cr_{72-75}SmX_{86}SmY_{93}I$	**926833**



Enabling 3D Printable Composites

A nanocomposite is typically defined as a mixture between a host material (e.g., polymer matrix) and nanofillers with at least one dimension of less than 100 nm. The addition of nanoparticles to a host material very often leads to significant improvements in material properties (e.g., mechanical, electrical, thermal) at relatively small loadings. The fabrication of nanocomposite structures through additive manufacturing is extremely promising for a myriad of applications such as creating aerospace, electronic and biomedical structures and devices.

Greener Alternative Product Characteristics: Design for Energy Efficiency



Composite Filaments

Suitable 3D Printing Techniques: Material Extrusion

Name	Color	Diameter (mm)	Cat. No.
3DXNANO™ ESD CNT-PETG carbon nanotube reinforced polyethylene terephthalate glycol copolymer 3D printing filament	black	2.85	**3DXCNT004**
3DXNANO™ ESD CNT-ABS carbon nanotube reinforced ABS 3D printing filament	black	2.85	**3DXCNT002**

Composite Filament Enablers

Suitable 3D Printing Techniques: Material Extrusion; Powder Bed Fusion; Material Jetting; Vat polymerization

Name	Description	Size (D x L)	Cat. No.
Carbon nanotube, single-walled	>90% carbon basis amide functionalized	4-6 nm × 0.7-1.0 μm, bundle dimensions	**685380**
	>90% carbon basis carboxylic acid functionalized	4-5 nm × 0.5-1.5 μm, bundle dimensions	**652490**
	thin, extent of labeling: >8% carboxylic acid functionalized	9.5 nm × 1.5 μm	**755125**
	80-90% carbon basis octadecylamine functionalized	2-10 nm × 0.5-2 μm, bundle dimensions	**652482**
	75-85% carbon basis polyaminobenzene sulfonic acid functionalized	1.1 nm × 0.5-1.0 μm, bundle dimensions	**639230**
	>80% carbon basis poly(ethylene glycol) functionalized	4-5 nm × 0.5-0.6 μm, bundle dimensions	**652474**
Graphene nanoribbons	alkyl functionalized		**797766**
Graphene oxide	2.0 mg/mL dispersion in toluene alkylamine functionalized		**809055**
Reduced graphene oxide	amine functionalized		**805432**
	octadecylamine functionalized		**805084**
	piperazine functionalized		**805440**
	tetraethylene pentamine functionalized		**806579**

UV-curable Resins

Greener Alternative Product Characteristics: Use of Renewable Feedstocks, Design for Energy Efficiency

Suitable 3D Printing Techniques: Material Jetting; Vat polymerization

Name	Pack Size	Cat. No.
Ultracur3D® RG 35	500 ML	925586
Ultracur3D® RG 35 N	500 ML	925578
Ultracur3D® ST 45	500 ML	925551

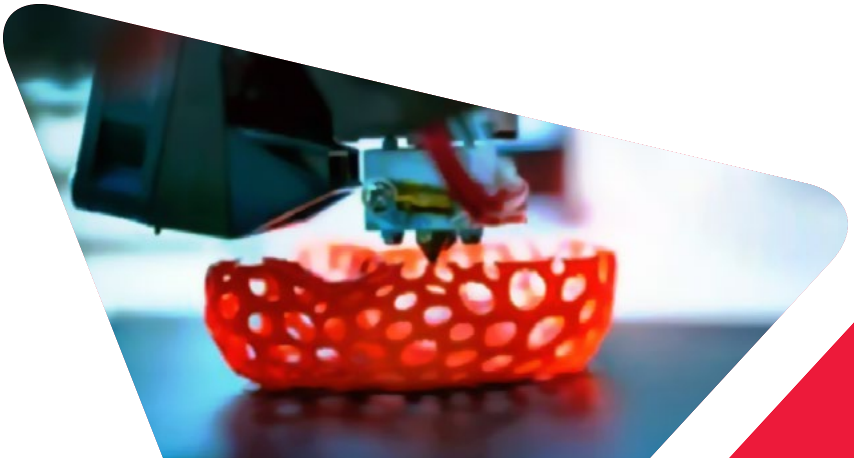
3D Printing Filaments

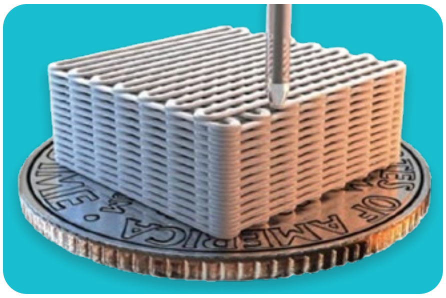
Greener Alternative Product Characteristics: Waste Prevention, Design for Energy Efficiency. PLA has additionally the characteristics of Use of Renewable Feedstocks, Design for Degradation

Suitable 3D Printing Techniques: Material Extrusion

Name	Color	Diameter (mm)	Cat. No.
ABS	black	2.85	**3DXABS002**
	blue	1.75	**3DXABS003**
	green	1.75	**3DXABS005**
	green	2.85	**3DXABS006**
	natural	2.85	**3DXABS008**
	orange	1.75	**3DXABS009**
	orange	2.85	**3DXABS010**
	red	1.75	**3DXABS011**
	white	2.85	**3DXABS014**
	yellow	1.75	**3DXABS015**
	yellow	2.85	**3DXABS016**
Caementum architectural	concrete effect	1.75	**TRD3D0063**
Clay architectural	clay effect	1.75	**TRD3D0064**
DarkStone architectural	stone effect	1.75	**TRD3D0065**
Ecogenius PLA	black hole	1.75	**TRD3D0010**
	industrial grey	1.75	**TRD3D0011**
	natural	1.75	**TRD3D0012**
	neptune blue	1.75	**TRD3D0013**
	red race	1.75	**TRD3D0014**
	signal white	1.75	**TRD3D0015**
Flexmark 7 TPU flexible	black hole	1.75	**TRD3D0041**
	signal white	1.75	**TRD3D0042**
Flexmark 8 TPU flexible	black hole	1.75	**TRD3D0043**
	signal white	1.75	**TRD3D0044**
Flexmark 9 TPU flexible	black hole	1.75	**TRD3D0045**
	signal white	1.75	**TRD3D0046**
Fusion PLA	black hole	1.75	**TRD3D0016**
	industrial grey	1.75	**TRD3D0017**
	neptune blue	1.75	**TRD3D0018**
	red race	1.75	**TRD3D0019**
	signal white	1.75	**TRD3D0020**
Gonzales High Speed PLA	black hole	1.75	**TRD3D0021**
	neptune blue	1.75	**TRD3D0022**
	red race	1.75	**TRD3D0023**
	signal white	1.75	**TRD3D0024**

Name	Color	Diameter (mm)	Cat. No.
G-PET PETG	azul variocolor	1.75	**TRD3D0036**
	black hole	1.75	**TRD3D0034**
	ruby variocolor	1.75	**TRD3D0037**
	signal white	1.75	**TRD3D0035**
Heritage Brick architectural	brick effect	1.75	**TRD3D0066**
HIRMA PMMA	transparent	1.75	**TRD3D0038**
iON™ nylon/ABS alloy	black	1.75	**3DXION001**
	natural	1.75	**3DXION004**
	red	1.75	**3DXION003**
Kyotoflex BioFlexible PLA	neptune blue	1.75	**TRD3D0025**
Longchain Nylon	black hole	1.75	**TRD3D0055**
	signal white	1.75	**TRD3D0056**
Monumental architectural	marble effect	1.75	**TRD3D0067**
P51 Polycarbonate	transparent	1.75	**TRD3D0062**
Performance ABS	black hole	1.75	**TRD3D0027**
	industrial grey	1.75	**TRD3D0028**
	neptune blue	1.75	**TRD3D0029**
	red race	1.75	**TRD3D0030**
	signal white	1.75	**TRD3D0031**
PLA	green	2.85	**3DXPLA006**
	orange	1.75	**3DXPLA009**
	red	1.75	**3DXPLA011**
	yellow	1.75	**3DXPLA015**
	yellow	2.85	**3DXPLA016**
P-LENE 4 polypropylene	black hole	1.75	**TRD3D0057**
	natural	1.75	**TRD3D0058**
	signal white	1.75	**TRD3D0059**
Sandy architectural	sandy effect	1.75	**TRD3D0068**
Shogun superior PLA	natural	1.75	**TRD3D0026**
Stiron HIPS	black hole	1.75	**TRD3D0040**
	signal white	1.75	**TRD3D0039**
Tenax PC-ABS	black hole	1.75	**TRD3D0061**
	signal white	1.75	**TRD3D0060**
UltrafleXX TPE-E	black hole	1.75	**TRD3D0052**
	signal white	1.75	**TRD3D0051**
UltrafleXX+ TPE-E	black hole	1.75	**TRD3D0054**
	signal white	1.75	**TRD3D0053**
UV729 ASA	black hole	1.75	**TRD3D0032**
	signal white	1.75	**TRD3D0033**





Inorganic-based Inks

Greener Alternative Product Characteristics:

Design for Energy Efficiency

Suitable 3D Printing Techniques: Material Extrusion

Name	Decription	Viscosity	Cat. No.
3D printable graphene oxide ink	Graphene oxide sheet size: 300-800 nm lateral size 40 mg/mL (Graphene oxide aquous ink) single layer GO	100-210 Pa.s (25 °C @ shear rate of 10 s-1)	**916579**
3D printable ultra-high temperature boron carbide ink	50 % (v/v) (Boron carbide) mean particle 1.8 µm paste form	10-103 Pa.s (25 °C @ 100 s^{-1})	**921912**
3D printable yttria-stabilized zirconium (IV) oxide ink	70 wt. % (Yttria stabilized zirconia) mean particle 120 nm paste form	2-25 Pa.s (25 °C @ shear rate of 100 s-1)	**918571**
3D printing copper ink	65 - 75 % copper content 1-10 µm particles	20-60 Pa.s	**901889**
3D printing graphene ink	25 - 30 % graphene particle size: 1-14 nm (thick) 1-20 µm (length and width)	20-60 Pa.s	**808156**
3D printing graphite ink	Graphite Content: 30-40 wt% Solid content: 20-35%	20-60 Pa.s	**901662**
3D printing hydroxyapatite ink	solid-loading as dried material = 85 vol.% hydroxyapatite, 15 vol.% PLGA	20-60 Pa.s	**902403**
3D printing iron ink	solid-loading as dried material = 70 vol.% iron, 30 vol.% PLGA 1-10 µm particles liquid	20-60 Pa.s	**901875**
3D printing nickel ink	65 - 75 % Ni	20-60 Pa.s	**901894**
3D printing zirconia ink	55 - 65 % Zr	20-60 Pa.s	**901886**
Graphene ink	for gravure printing with ethyl cellulose in terpineol	0.75 - 3.00 Pa.s (shear viscosity at 100 s^{-1}, 25 °C)	**796115**
Graphene ink	for screen printing with ethyl cellulose in terpineol	5-50 Pa.s	**798983**
Graphene oxide, non-exfoliated	≥3% C (by gravimetric analysis combined with EA) paste form	-	**900704**
Silver	particle size: 200 nm (80%), <5 nm (20%) conductive paste - 1.59 µΩ-cm 20°C	100,000-300,000 cPs (0.4 rpm, Brookfield)	**735825**

3D Printing Techniques

Additive Manufacturing is categorized in seven technology groups:

- **Binder Jetting** uses inkjet technology to selectively dispense liquid binders onto a powder bed, thereby holding the powder together into a desired cross-sectional geometry.
- **Direct Energy Deposition** is an additive manufacturing process in which focused thermal energy is used to fuse materials by melting it as they are being deposited. Focused thermal energy could be provided by a laser, electron beam, plasma arc, or other energy source that can be used to melt materials as they are deposited onto a substrate.
- **Material Extrusion*** is an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice. The material (eg: a spool of thermoplastic filament) is typically forced through a high-temperature nozzle which melts the polymer and which moves in X-Y plane relative to a platform to selectively deposit a layer of material. Then the nozzle moves up or the platform moves down to deposit the next layer. Fused deposition modelling (also called fused filament fabrication) and direct-ink-writing are extrusion-based additive manufacturing methods.
- **Material Jetting*** is an additive manufacturing process in which droplets of build material are selectively deposited and cured on a build plate. For instance, photopolymers or wax droplets that cure when exposed to light, objects are built up, one layer at a time. Examples of methods include Material Jetting (MJ), Drop on Demand (DOD).
- **Powder Bed Fusion** is an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed. The thermal energy is typically provided by a focused laser or electron beam, which selectively melts powder in a powder bed in a layer-wise fashion. Examples include selective laser sintering (SLS), direct metal laser sintering (DMLS), selective laser melting (SLM), electron beam melting (EBM), Multi Jet Fusion (MJF).
- **Sheet Lamination** is the 3D printing process in which sheet of materials are bond together to produce a part of object. The example of 3D printing technology that uses this process are laminated object manufacturing (LOM) and ultrasound additive manufacturing (UAM).
- **Vat Polymerization*** use a single-point ultraviolet (UV) laser to selectively cure layers of liquid photopolymer, or resin. The most common method: Stereolithography (SLA).

***Products to support "Material Extrusion", "Material Jetting", and "Vat Polymerization" available.**

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04/2023