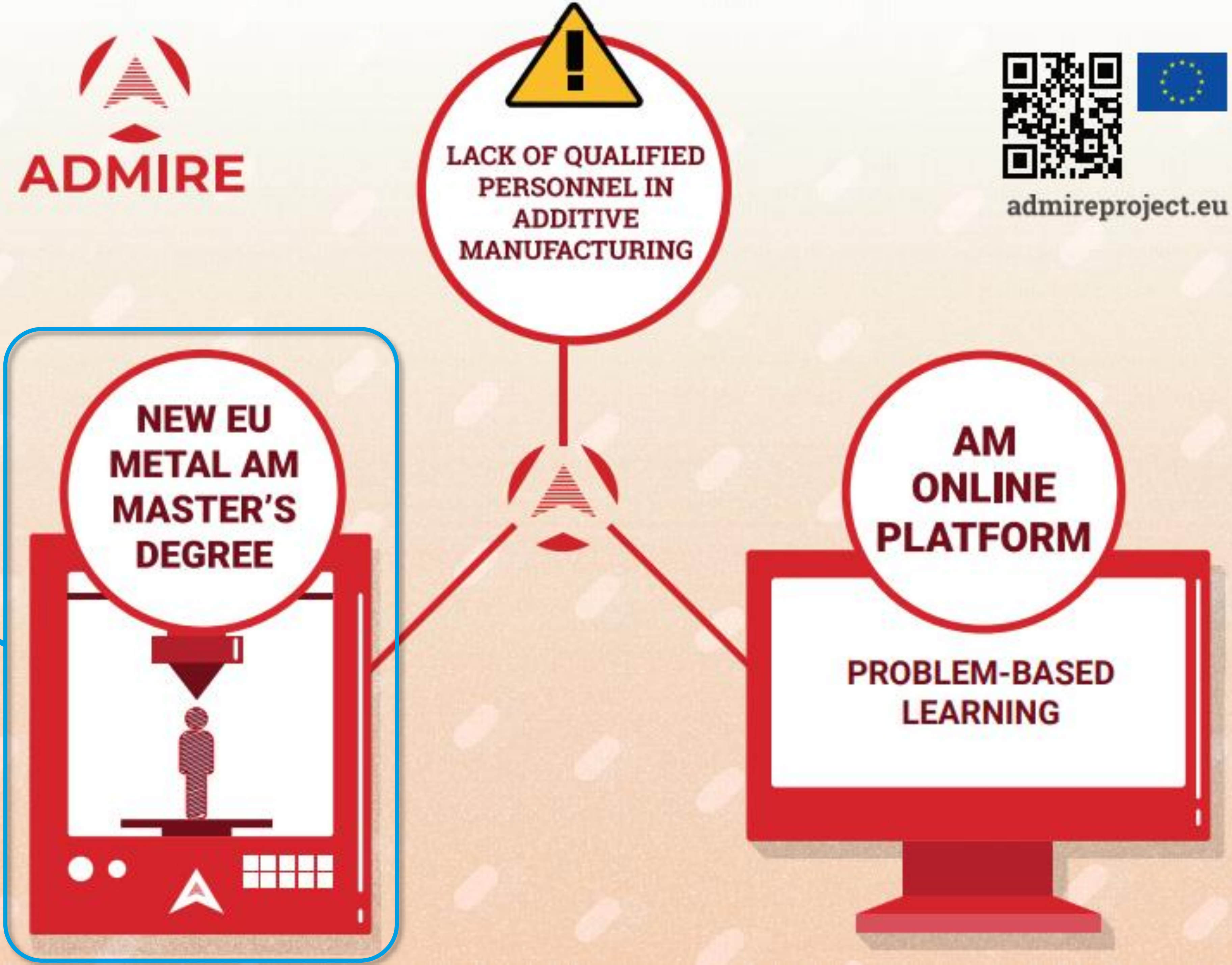
TÉCNICO LISBOA

Instituto Superior Técnico

11th March 2020

YOU!



EWF
Rita Bola
rgbola@ewf.be
www.ewf.be

TO BE PART OF A EUROPEAN NETWORK OF AM TRAINING CENTERS

TO WORK TOGETHER IN DELIVERING INDUSTRY LED COURSES

TO ALIGN THEIR COURSES WITH A EUROPEAN HARMONISED FRAMEWORK

TO ADD NEW MODULES AND ALIGN THEIR COURSES WITH INDUSTRY REQUIREMENTS

European/International Directed Energy Deposition – Arc Personnel (DED-Arc)

Qualification: European / International Process Engineer (E/IPE DED-Arc)

This Qualification is part of an harmonised European System

Course Content

#CU	Title	Recommended Hours
00	Additive Manufacturing Processes Overview	7
01	DED-Arc Process	42
08	DED-LB Process	35
15	PBF-LB Process	35
25	Post processing	14
26	Introduction to materials	14
27	AM with Steel feedstock (excluding Stainless Steel)	21
28	AM with Stainless Steel feedstock	14
29	AM with Aluminium feedstock	7
30	AM with Nickel feedstock	7
31	AM with Titanium feedstock	14
32	AM with Tungsten feedstock	3,5
33	Biomedical metallic materials	7
34	Process selection	28
35	Metal AM integration	21
36	Coordination activities	7
37	Production of DED-Arc parts	28
38	Conformity of DED-Arc parts	42
39	Conformity of facilities featuring DED-Arc	14
	TOTAL:	287 + 73,5**

*

Today

1st April

15th April

Are you looking for a different specialisation?

Powder Bed Fusion - Laser Beam Personnel (PBF-LB)

Qualification: European / International Process Engineer (E/IPE PBF-LB)

European/International Directed Energy Deposition – Laser Beam Personnel (DED-LB)

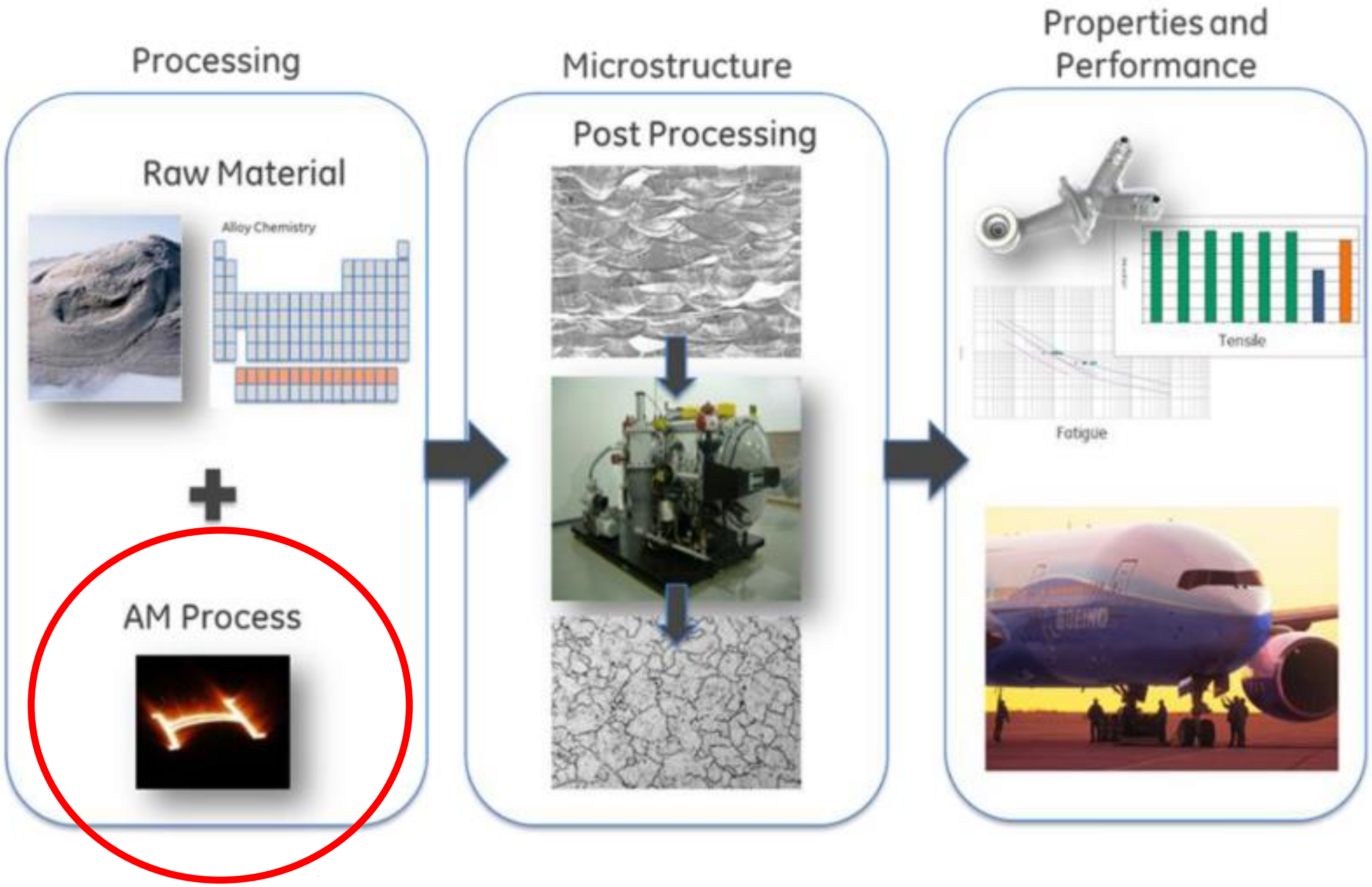
Qualification: European / International Process Engineer (E/IPE DED-LB)

You can find out more at:

www.ewf.be/additive-manufacturing

Co-funded by the Erasmus+ Programme of the European Union

Additive Manufacturing Processes Overview
Scope



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

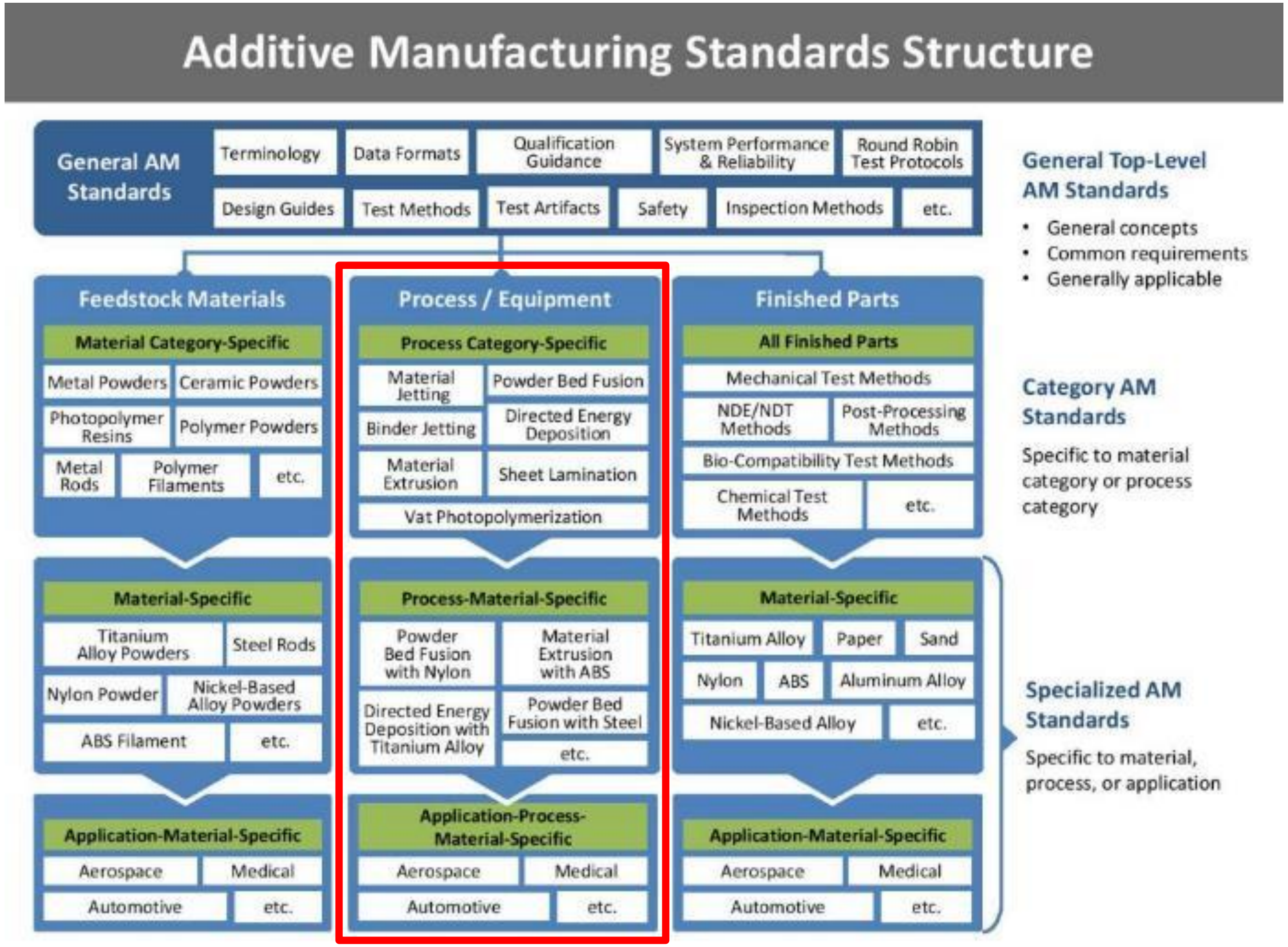
Additive Manufacturing Processes Overview
Scope

- **Knowledge:** Actual and broad knowledge of theory, principles and applicability of:
  - Directed energy deposition (DED)
  - Powder bed fusion (PBF)
  - Vat photopolymerization (VPP)
  - Material jetting (MJT)
  - Binder jetting (BJT)
  - Material extrusion (MEX)
  - Sheet lamination (SHL)
- **Objectives:**
  - Distinguish parts produced by different AM processes
  - Recognize the advantages and limitations of AM processes
  - Identify the applicability of different AM processes

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

Process defined by standards



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

Additive manufacturing technologies

	TECHNOLOGY	MATERIALS	TYPICAL MARKETS	RELEVANCE FOR METAL
Fusion	**Powder bed fusion** – Thermal energy selectively fuses regions of a powder bed	Metals, polymers	Prototyping, direct part	●
Fusion	**Directed energy deposition** – Focused thermal energy is used to fuse materials by melting as the material is deposited	Metals	Direct part, repair	◑
	Sheet lamination – Sheets of material are bonded to form an object	Metals, paper	Prototyping, direct part	◔
Sintering	**Binder jetting** – Liquid bonding agent is selectively deposited to join powder material	Metals, polymers, foundry sand	Prototyping, direct part, casting molds	◔
Sintering	**Material jetting** – Droplets of build material are selectively deposited	Polymers, waxes	Prototyping, casting patterns	○
Sintering	**Material extrusion** – Material are selectively dispensed through a nozzle or orifice	Polymers	Prototyping	○
Sintering	**Vat photopolymerization** – Liquid photopolymer in a vat is selectively cured by light-activated polymerization	Photopolymers	Prototyping	○

AM technologies for metal objects (the first four rows)

Source: ASTM International Committee F42 on Additive Manufacturing Technologies; Roland Berger | 14

AMable

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

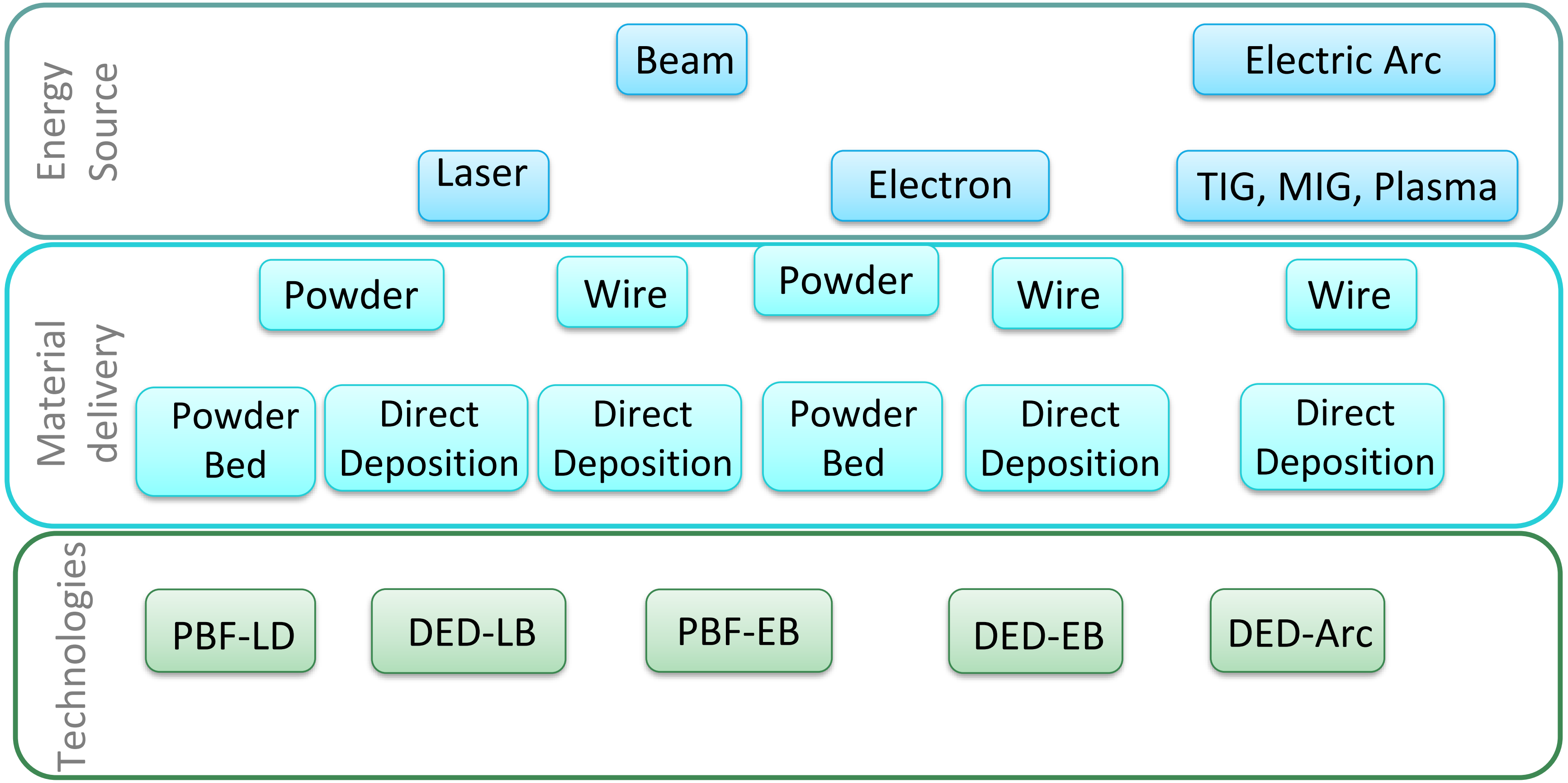
Additive Manufacturing Processes Overview
Definitions

- The standard **ISO/ASTM 52900-18: Additive manufacturing - General principles – Terminology** Defines the basic terminology to be used for everything related to additive manufacturing. This standard states for:
  - **Additive Manufacturing (AM)**
    - *"process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies".* Historical terms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, solid freeform fabrication and freeform fabrication.
  - **3D printing**
    - *"fabrication of objects through the* ***deposition*** *of a material using a print head, nozzle, or another printer technology".* Term often used in **a non-technical context** synonymously with additive manufacturing; until present times this term has in particular been associated with machines that are low end in price and/or overall capability.

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Process for Metals

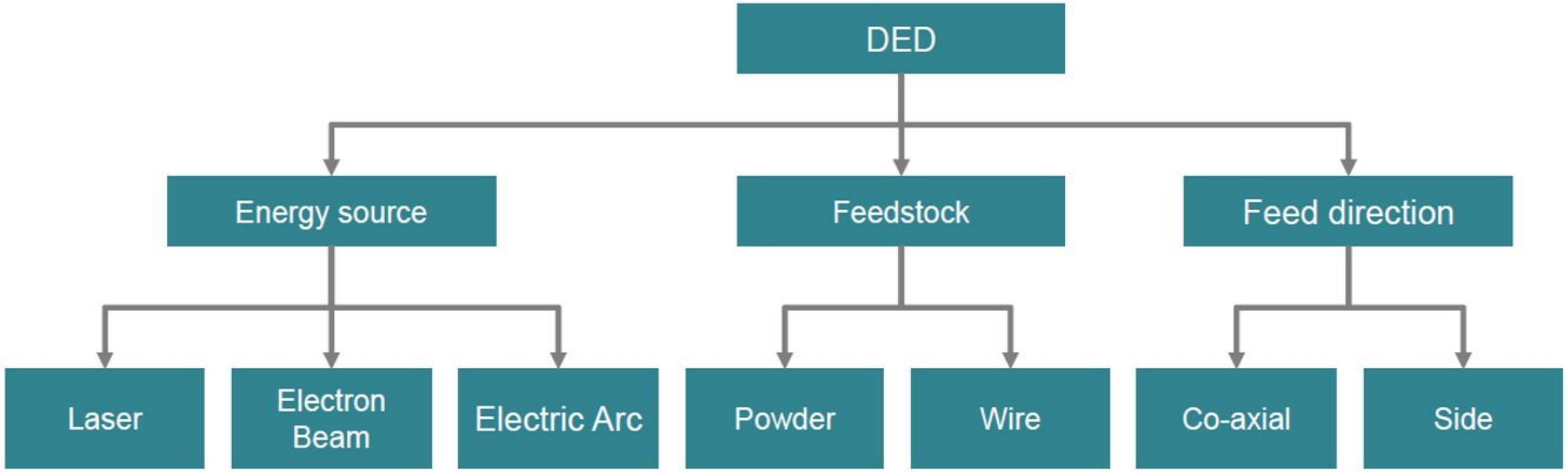
Classification of DED and Powder Bed Technologies



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Directed Energy Deposition (DED)

- “Additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited”, according to ISO/ASTM 52900-18. “Focused thermal energy” means that an energy source (for example: laser, electron beam, or plasma arc) is focused to melt the materials being deposited.



This project has received funding from the European Union’s H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

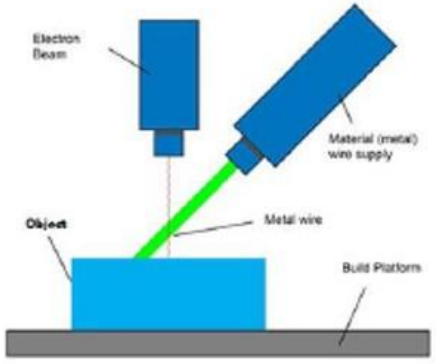
Additive Manufacturing Processes Overview
Directed Energy Deposition (DED)

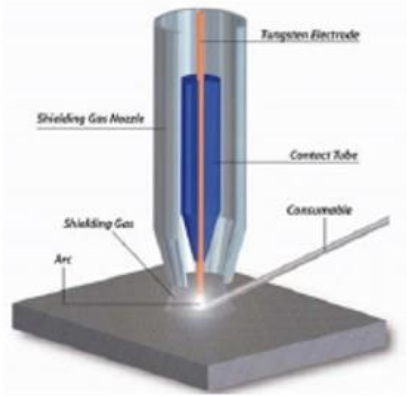
FEEDSTOCK

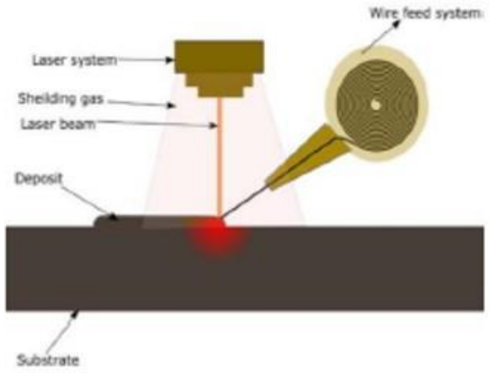
WIRE			POWDER

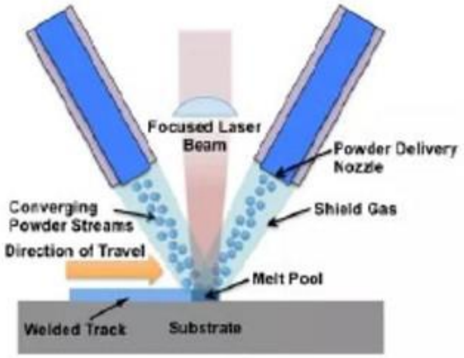
ENERGY SOURCE

ELECTRON BEAM (EB)	ARC / PLASMA	LASER	









Technology Nomenclature

DED-EB | **DED-Arc / DED-PB** | **DED-LB** | **DED-LB**

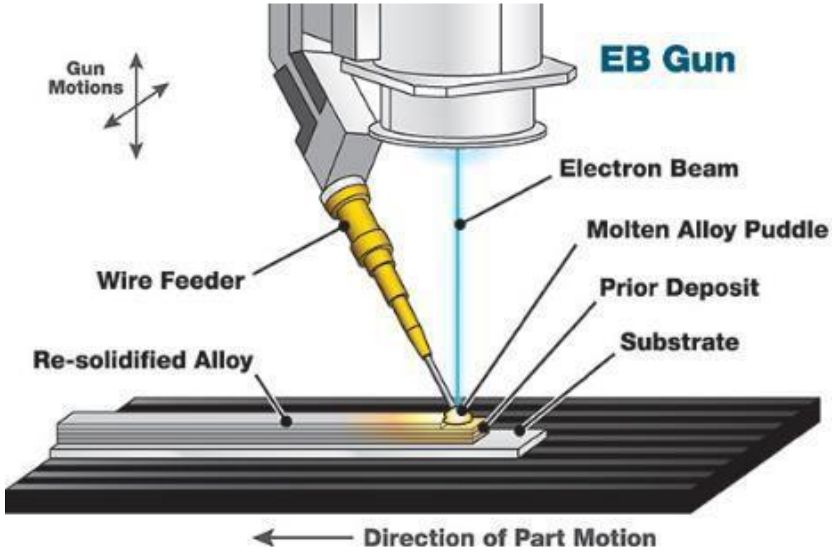
AMable

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Directed Energy Deposition – Electron Beam

- **Advantages:**
  - Higher deposition rate
  - Large pieces (larger manufacturing space)
  - Materials difficult to weld
  - Reactive metals (Ti, Al, TiAl)
  - Wire material (+ cheap, - flammable)
  - High energy efficiency (> 95%, x5-10 SLM)
  - Minor residual stress
  - Lower support requirements

- **Disadvantages:**
  - Big and complex equipment
  - High cost investment
  - High cost maintenance equipment
  - Vacuum chamber needed (+time -access)
  - Higher roughness (Ra> 40µm) (x3 SLM)



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Directed Energy Deposition – Electron Beam

- **Applications and sectors:**
  - Turbine Blades for Energy Production
  - Nuclear Components
  - Refractory Metal Components
  - Ballistic Materials
  - Industrial Pump Components
  - Semiconductor Manufacturing Equipment
  - Tooling Repair and Reconditioning
  - Aero components

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

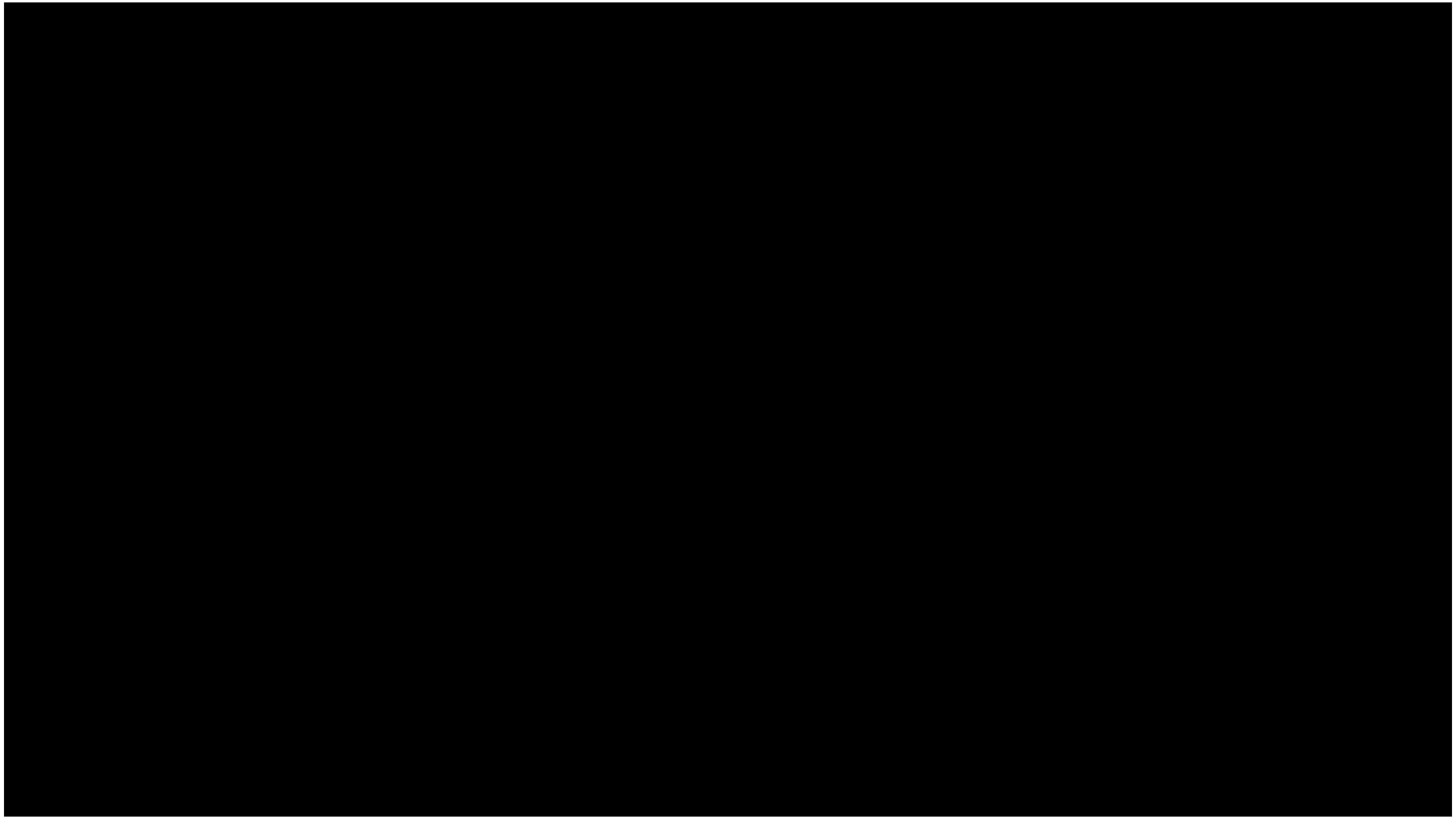
Directed Energy Deposition – Electron Beam

- **Materials:**
  - Steel, 4340
  - Stainless Steel
  - Titanium and Titanium alloys, Ti64
  - Aluminum, 2319, 4043
  - Tantalum
  - Tungsten
  - Niobium
  - Inconel 718, 625
  - Cobalt-chrome ASTM F75
  - TiAl
  - Pure copper

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

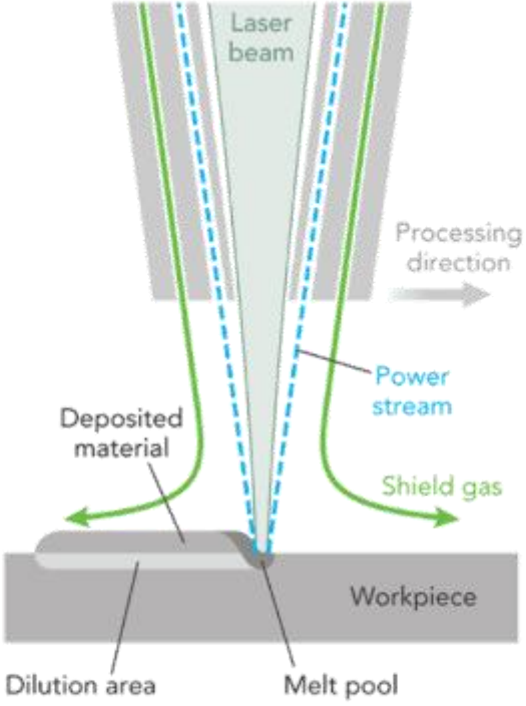
Directed Energy Deposition – Electron Beam

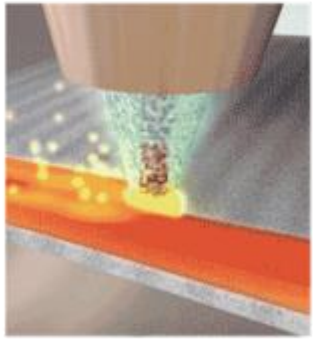


This project has received funding from the European Union’s H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

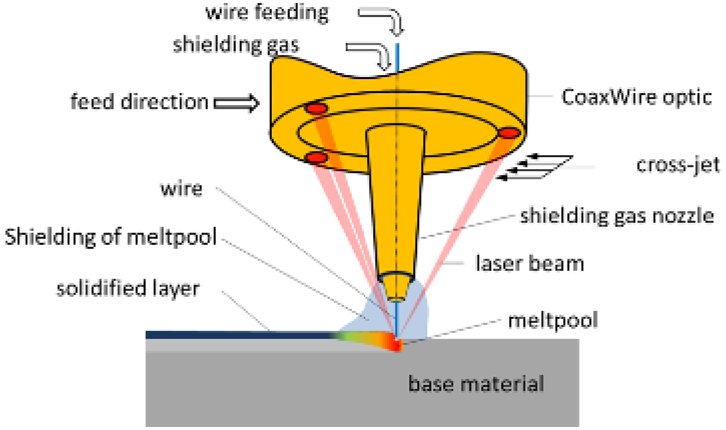
Additive Manufacturing Processes Overview
Directed Energy Deposition - Laser Beam

DED-LB

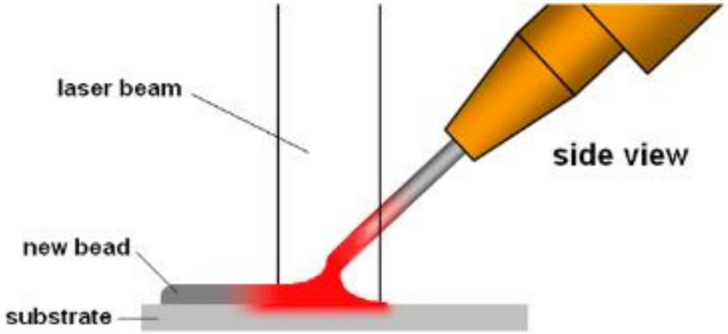


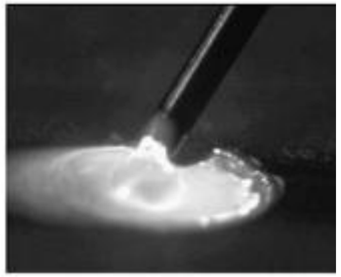


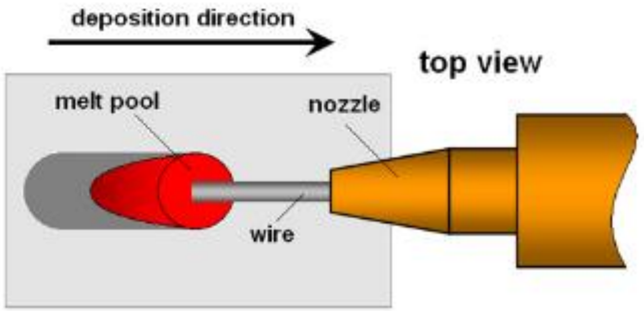
3D representation of the laser cladding process

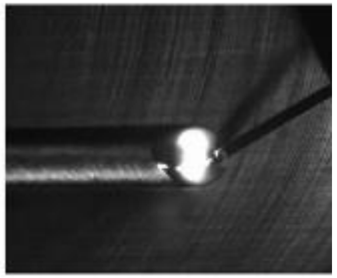


DED-LB









This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Directed Energy Deposition - Laser Beam

- **Advantages:**
  - Medium to High deposition rate
  - Medium size parts
  - near-net shape components
  - Wide range of materials
  - Multi-material and FGMs
  - Repair and remanufacturing

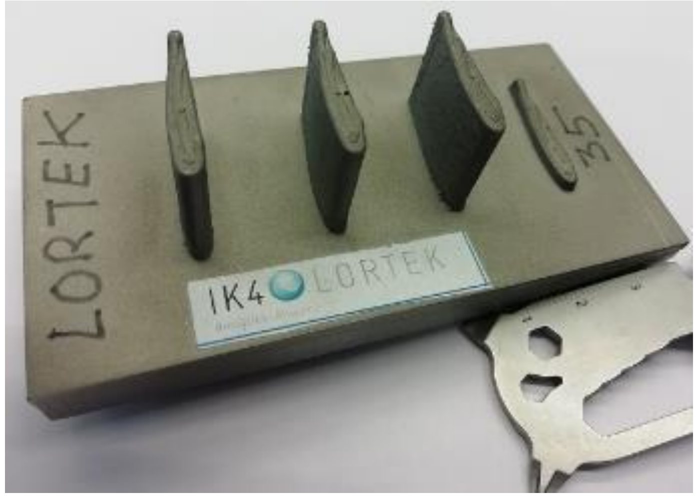
- **Disadvantages:**
  - Equipment cost
  - Low resolution
  - Needs of post-processing

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Directed Energy Deposition - Laser Beam

- **Applications and sectors:**
  - Turbomachinery
  - Aero components
  - Molds and Tooling
  - Automotive
  - Subsea and offshore

- **Materials:**
  - Steels
  - Ni-based alloys
  - Co-based alloys
  - Titanium
  - Carbides

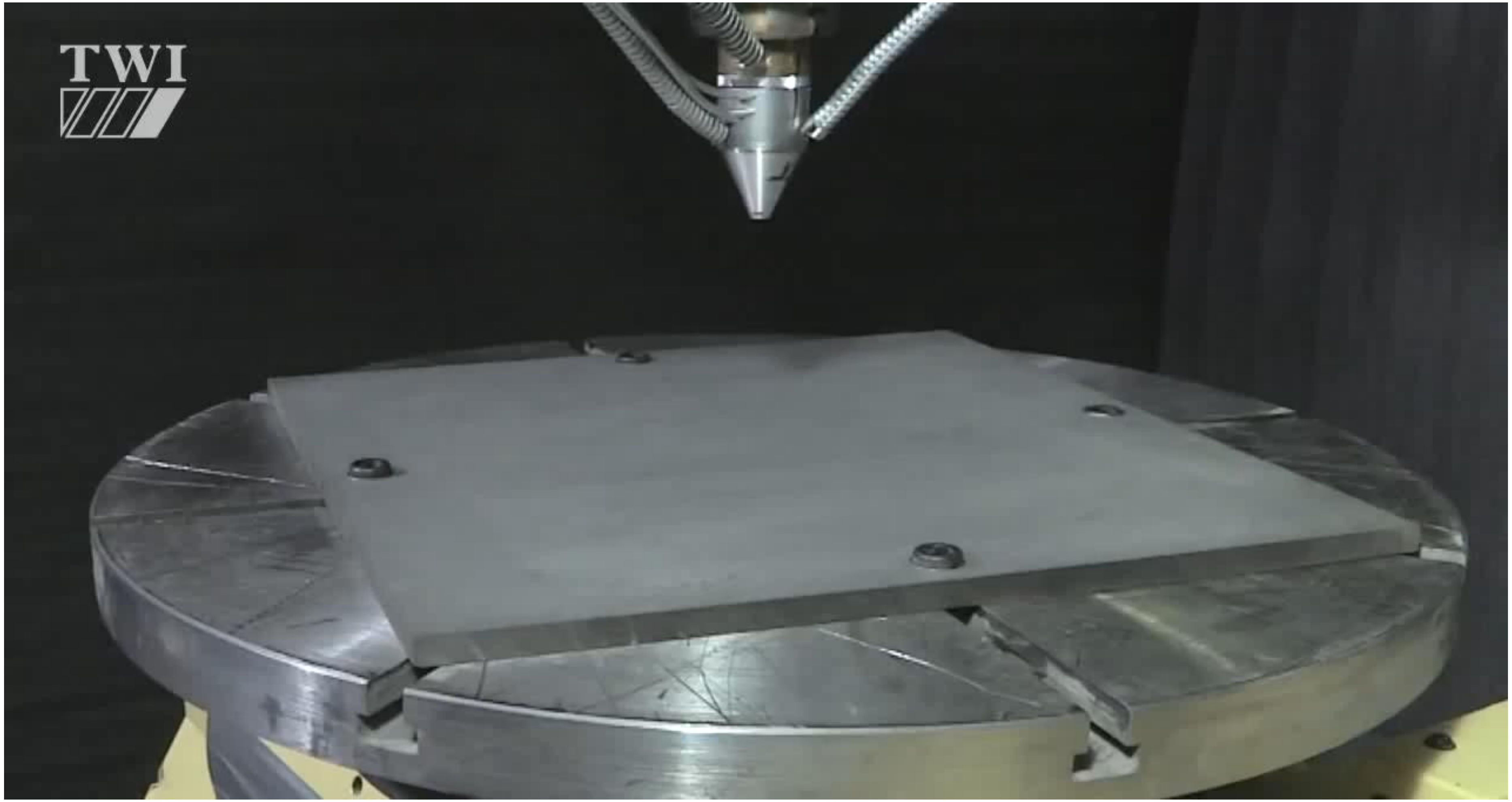


AMable

This project has received funding from the European Union’s H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

Directed Energy Deposition - Laser Beam

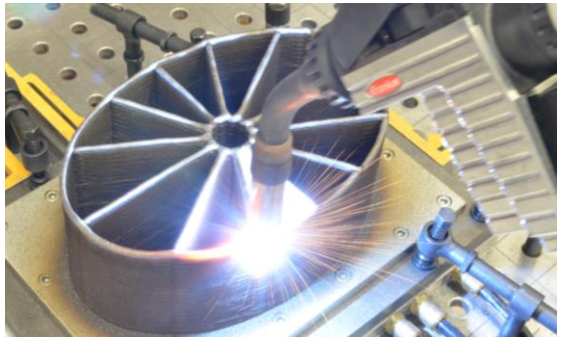


This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

Directed Energy Deposition – Arc

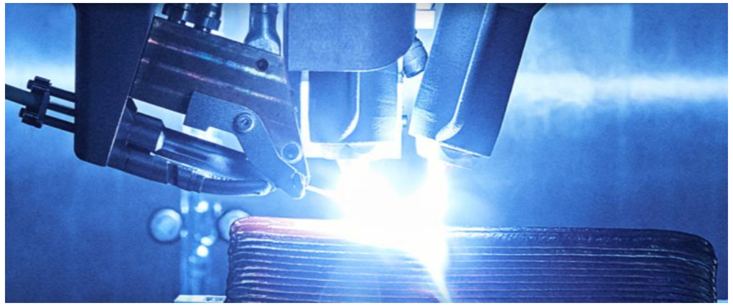
Directed Energy Deposition-Arc (DED-Arc)



[TU Ilmenau]

- GMAW and TIG processes
- feeding of wire
- low priced technical setup
- Deposition rates up to 5 kg/h and over
- little material loss compared to powder based technologies

Directed Energy Deposition - Plasma Beam (DED-PB)

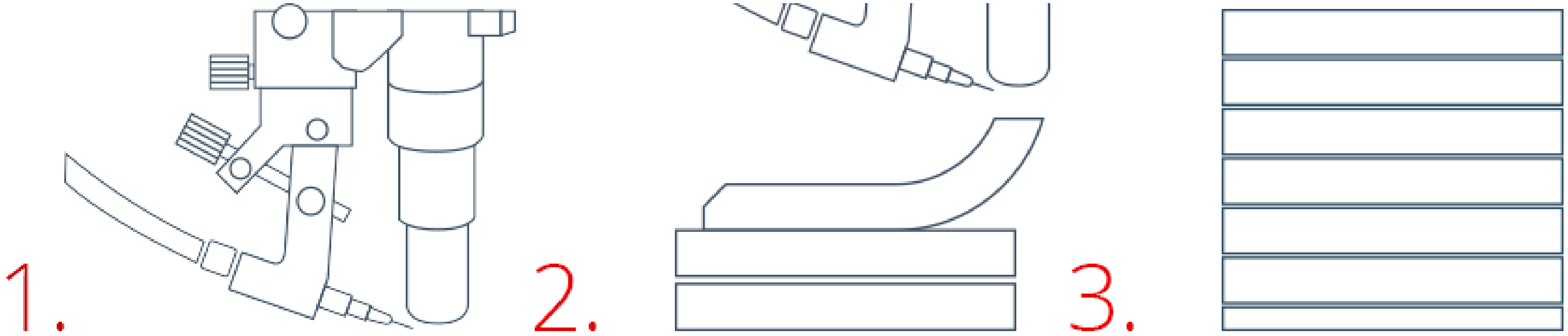


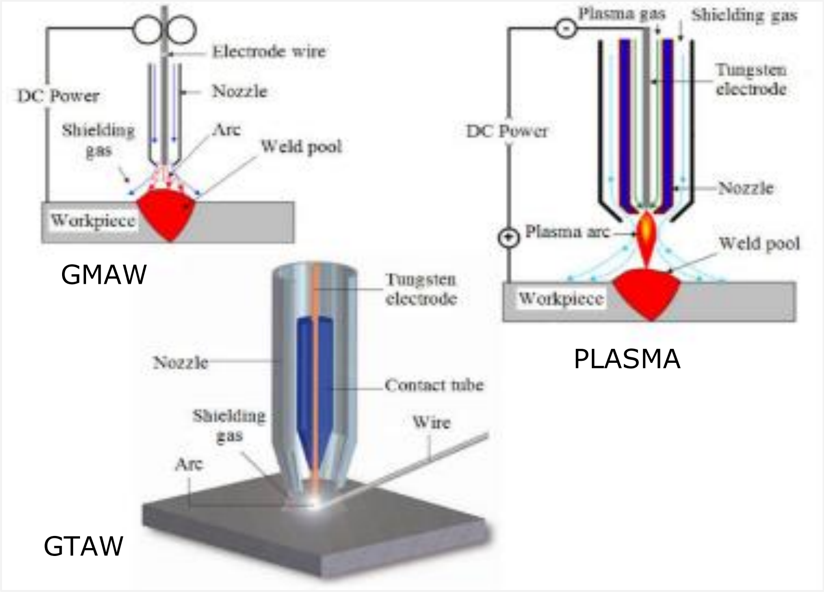
[Norsk Titanium]

- Plasma and µ-Plasma processes
- feeding of powder or wire
- Deposition rates up to 10 kg/h
- Powder availability and over spray

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Directed Energy Deposition – Arc





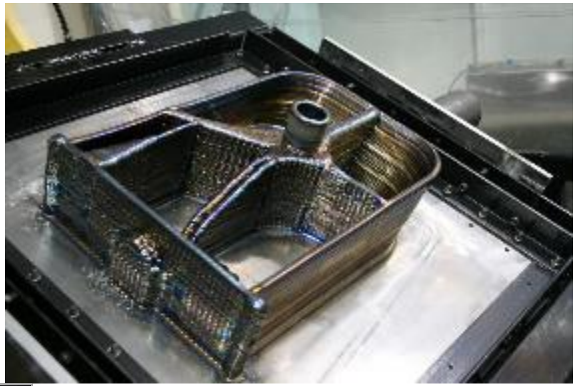
This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

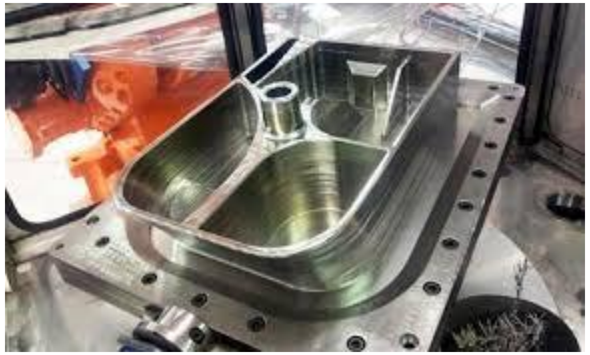
Additive Manufacturing Processes Overview

Directed Energy Deposition – Arc

- **Advantages:**
  - High deposition rate
  - High size parts
  - Good buy-to-fly ratio
  - Reduced cost for equipment
  - Wide range of materials
  - Reduced costs for wires

- **Disadvantages:**
  - Lower resolution
  - Geometric distortions
  - Needs of post-processing





AMable

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Directed Energy Deposition – Arc

- **Applications and sectors:**
  - Naval
  - Aero components
  - Energy
  - Molds and Tooling
- **Materials:**
  - Steels
  - Ni-based alloys
  - Titanium
  - Aluminum

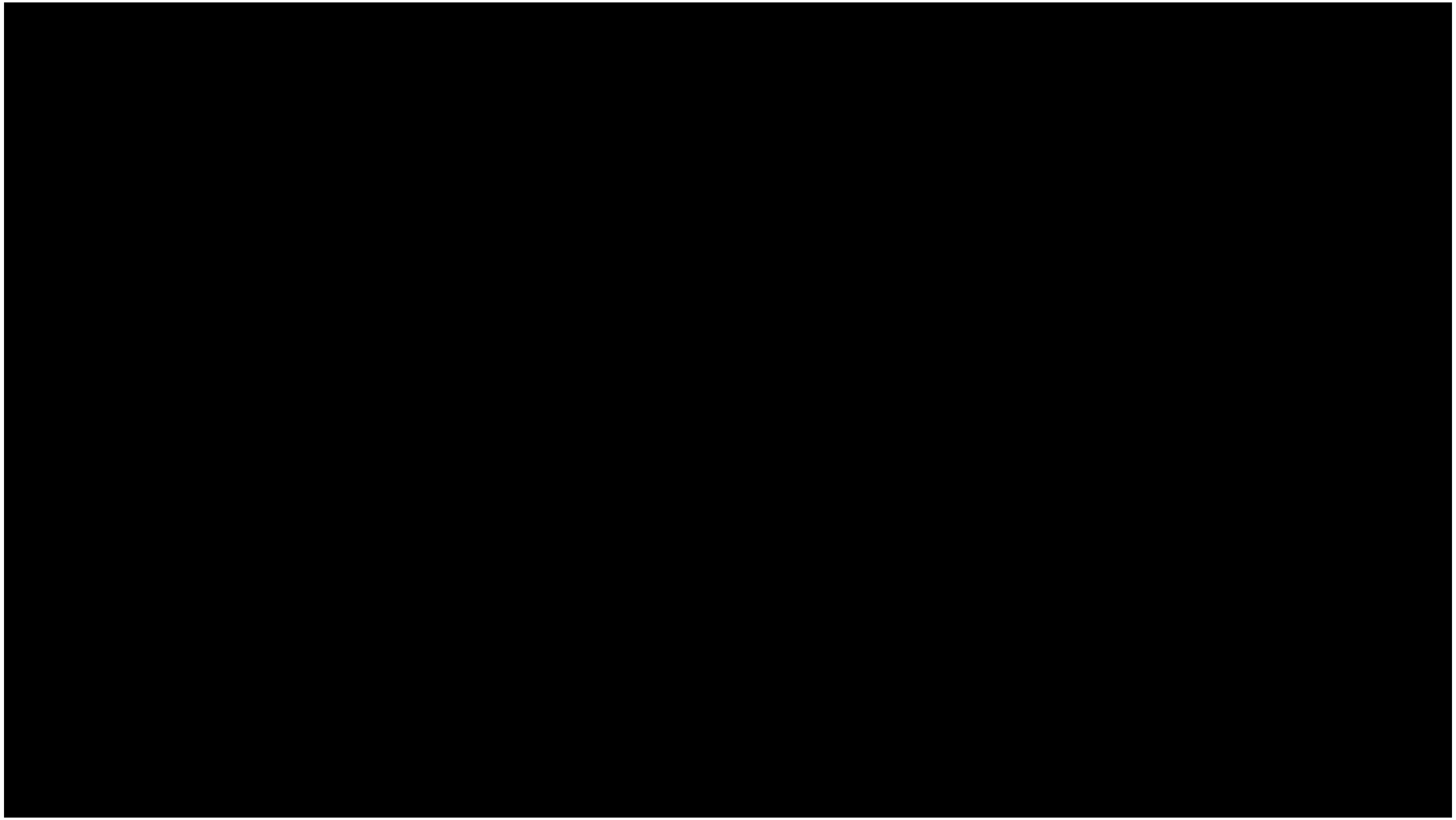
Norsk Titanium

Ramlab

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

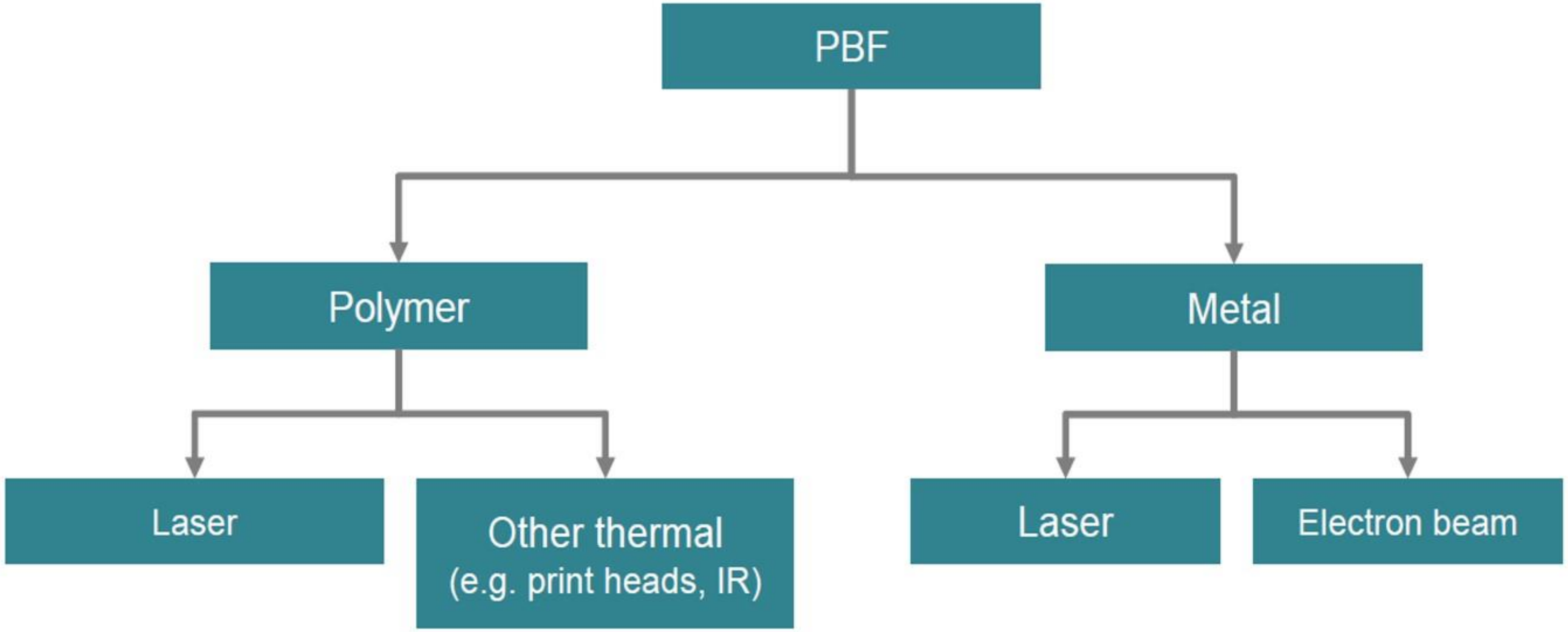
Directed Energy Deposition – Arc



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

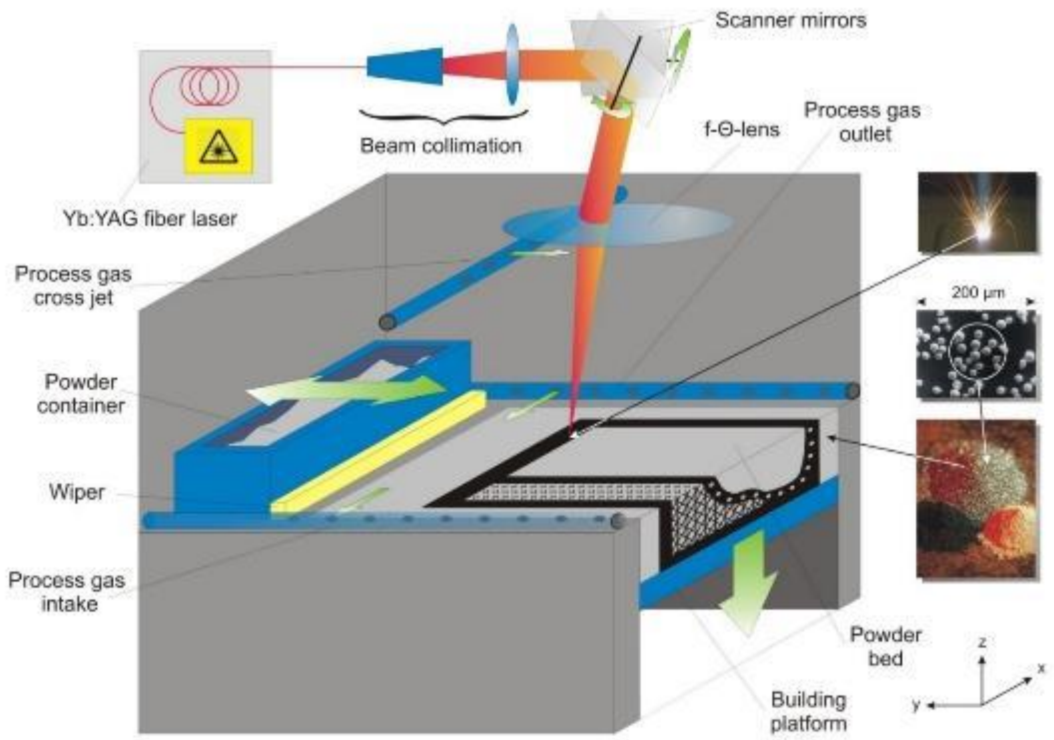
Additive Manufacturing Processes Overview
Powder Bed Fusion

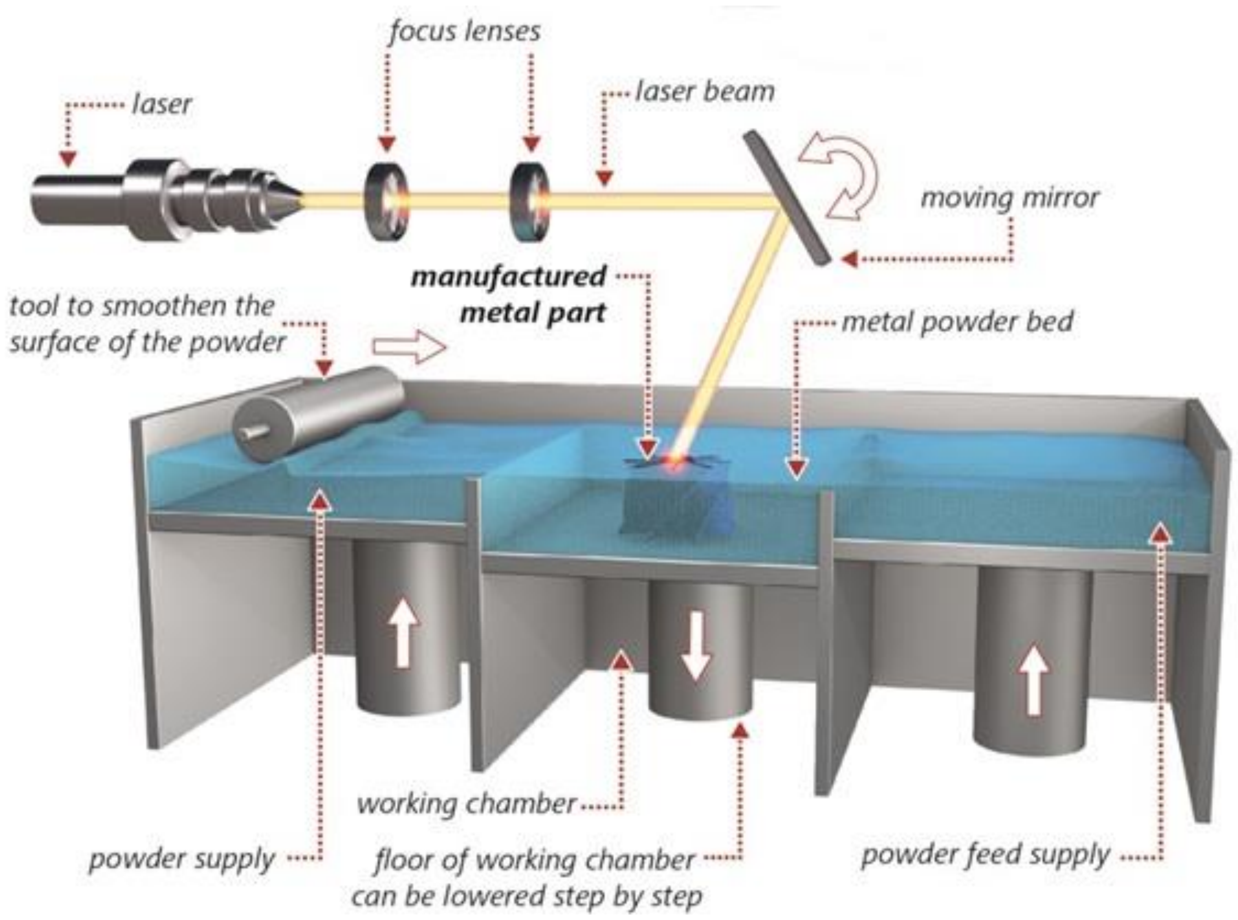
- "Additive manufacturing process in which thermal energy selectively fuses regions of a powder bed", according to ISO/ASTM 52900-18.



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Powder Bed Fusion

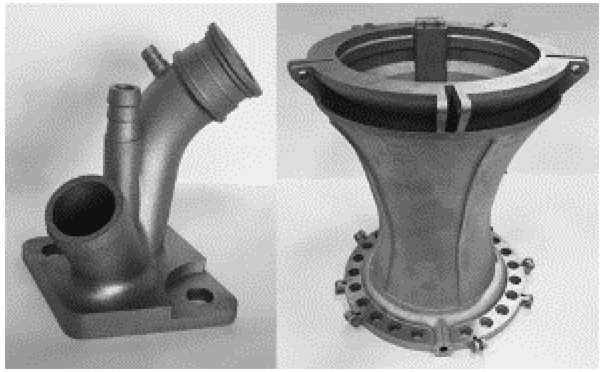




This project has received funding from the European Union’s H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Powder Bed Fusion

- **Advantages:**
  - Innovation in designs and improved functionalities
  - Integration of several pieces in one
  - Lightening in weight, less use of raw material, less material waste (green technology)
  - Individualization and complexity without added cost
  - High range of Materials (weldable materials)



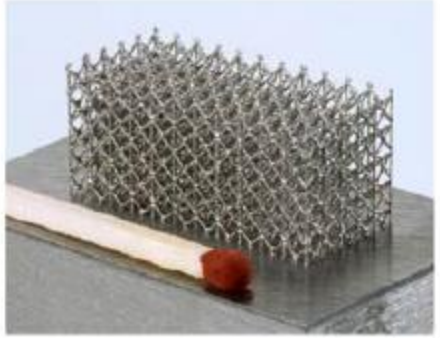
- **Disadvantages:**
  - Medium roughness (Ra> 10µm)
  - Limited parts size (< 400x400x500mm)
  - Equipment cost
  - Residual stresses and distortions in some cases
  - Low to Medium Productivity: currently series of small pieces (up to 25000 parts/year)

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Powder Bed Fusion

- **Applications and sectors:**
  - Aero components
  - Orthopedic implants
  - Automotive
  - Tooling (Molds and dies)
  - Dental
  - Goods

- **Materials:**
  - Al alloys (AlSi7Mg, AlSi10, AlSi9Cu3)
  - Ni-based Alloys (IN718, IN725, IN939, HX)
  - Titanium (grade 2, grade 23, near-alpha,
  - Cobalt-chrome (F75, CoCr28Mo6)
  - Steels (316L, 17-4PH, 1.2709, H13, Invar36)
  - Cu alloy (CuSn10)



Hydraulic Block -ADHYBLOCK

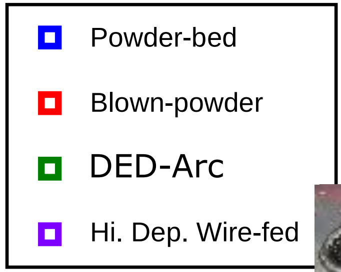
Hybrid SLM Part - FAMOLD

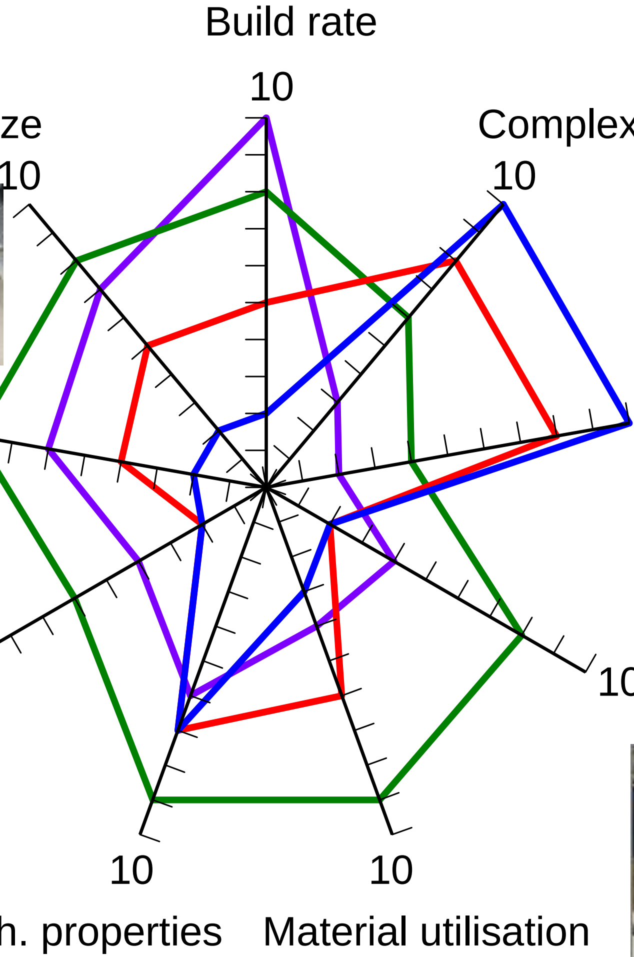
Aeronautic Bracket- ADDISPACE

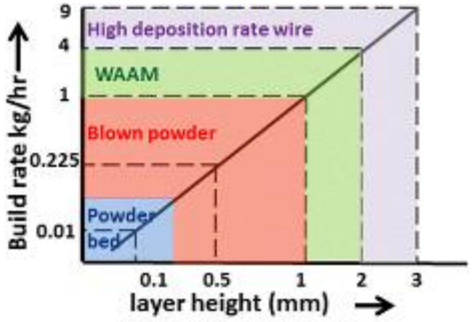
AMable

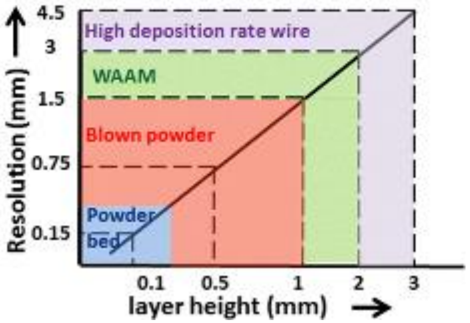
This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Metal AM – Process Comparison







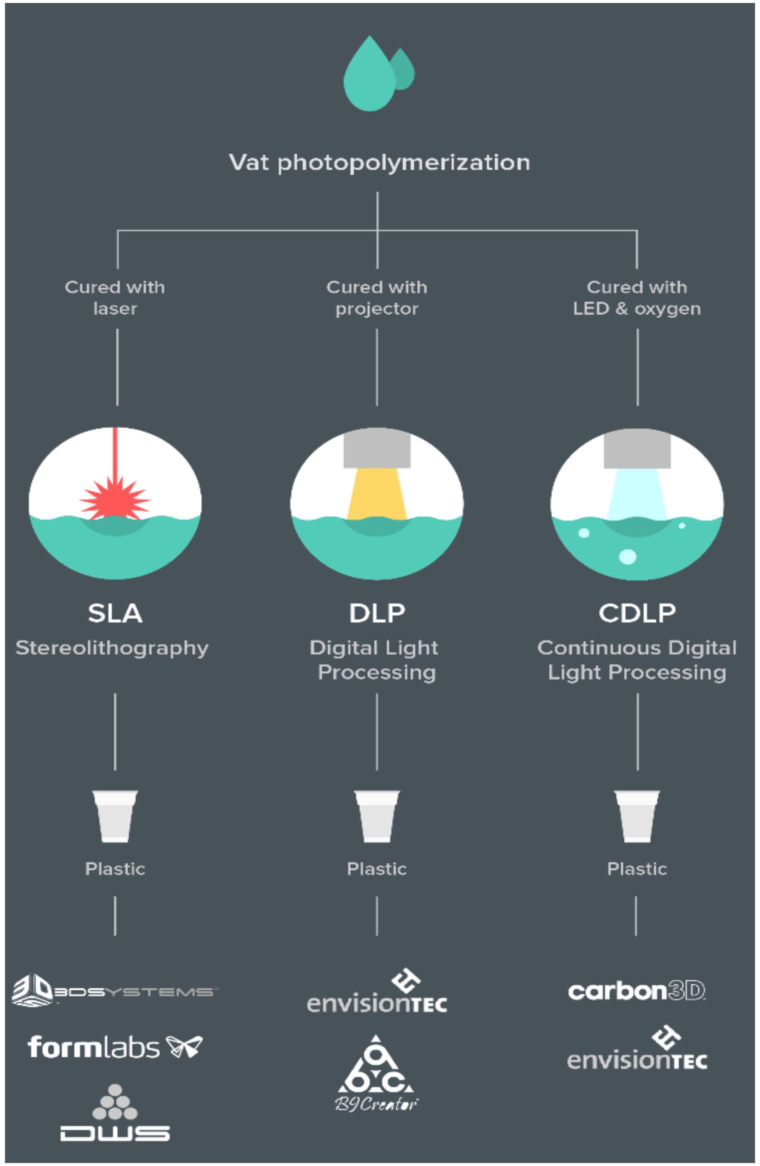


AMable

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

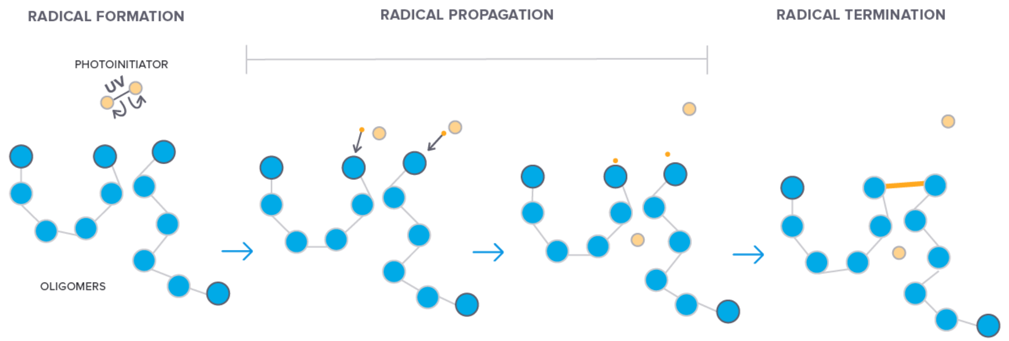
Additive Manufacturing Processes Overview
Vat Photopolymerization

- "Additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerisation", as stated in ISO/ASTM 52900-18.



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Vat Photopolymerization



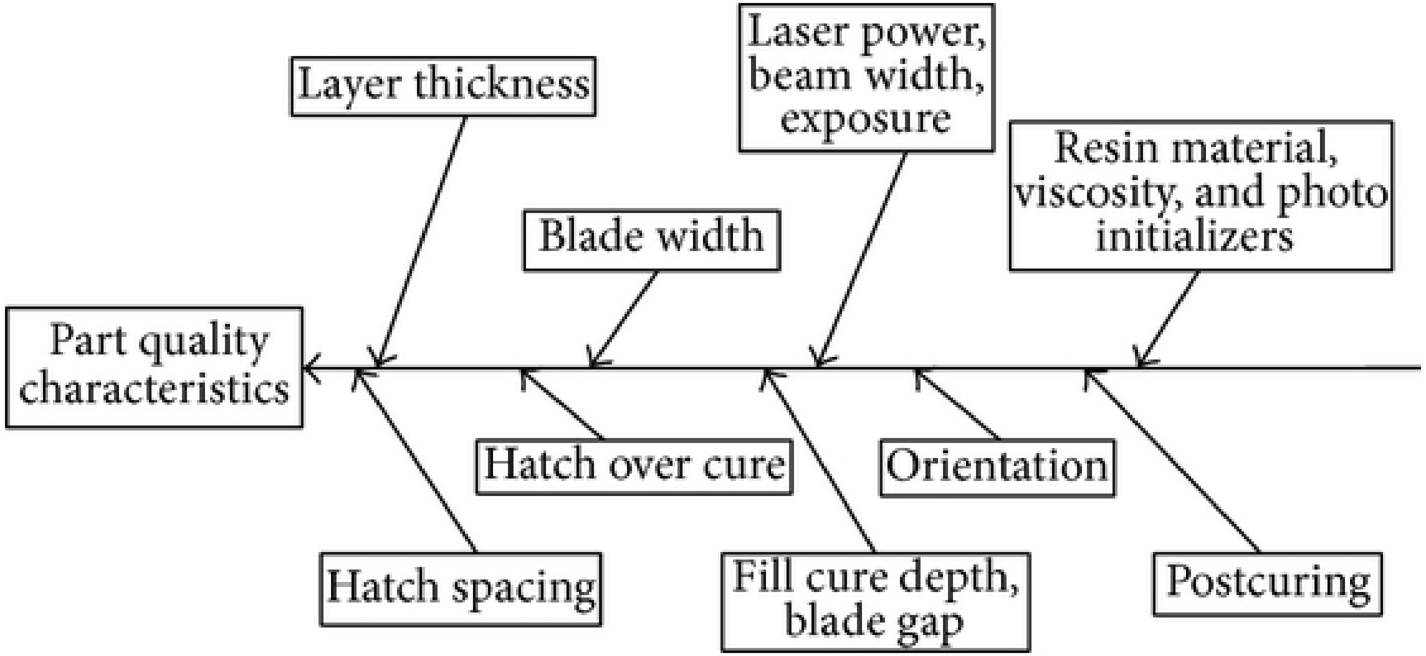
❑ **Photopolymerization process:**

- Monomer and oligomer chains have active groups at their end
- When resin is exposed to UV the Photoinitiator molecule breaks into two
- 2 very reactive radicals
- Reactive radicals are transferred to active groups which then react with other groups

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Vat Photopolymerization

- **Process Parameters:**



AMable
This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Vat Photopolymerization

- **Process Accuracy:**

- General accuracy of VPP prints is 50 to 200 microns depending on size, resin, model geometry and support generation.

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

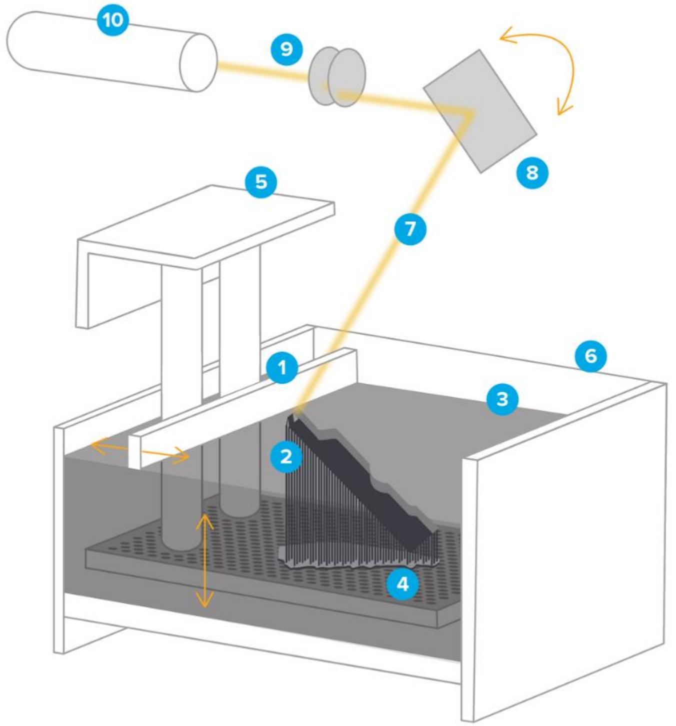
Additive Manufacturing Processes Overview
Vat Photopolymerization

❑ **Machine types:**

a)Top-down (top-cure):

- heat source above the vat
- platform is progressively dipped in the vat
- Large industrial applications

Build volume: Up to 1500x750x550mm^3



Right-Side Up VPP

1. Sweeper
2. Printed Part
3. Resin
4. Build Platform
5. Elevator
6. Resin Tank
7. Laser Beam
8. X-Y Scanning Mirror
9. Lenses
10. UV Laser

This project has received funding from the European Union’s H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

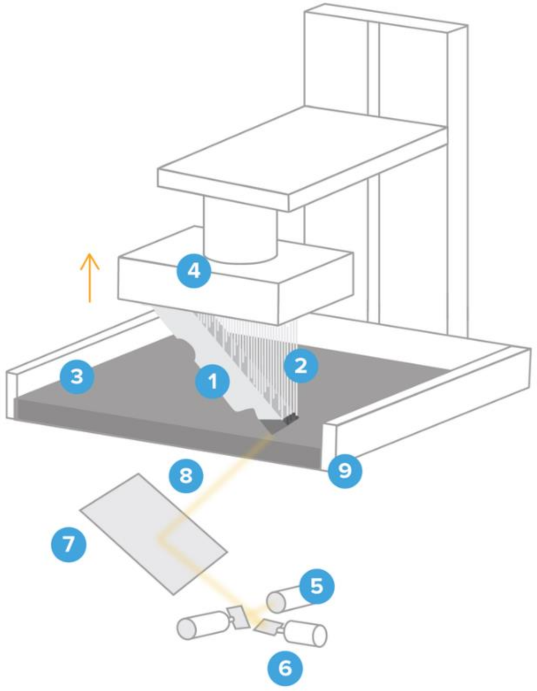
Additive Manufacturing Processes Overview
Vat Photopolymerization

❑ **Machine types:**

b) Bottom-up (bottom cure):

- heat source is placed below the vat
- platform is progressively raised
- The UV laser points at two mirror galvanometers, which direct the light to the correct coordinates on a series of mirrors
- the final part built upside down

Build volume: Up to 145x145x175mm^3



Upside-Down (inverted) VPP

1. Printed Part
2. Supports
3. Resin
4. Build Platform
5. UV Laser
6. Galvonometers
7. X-Y Scanning Mirror
8. Laser Beam
9. Resin Tank

AMable

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Vat Photopolymerization

- **Machine examples:**

FORMLABS

145 x 145 x 175 mm (xyz)

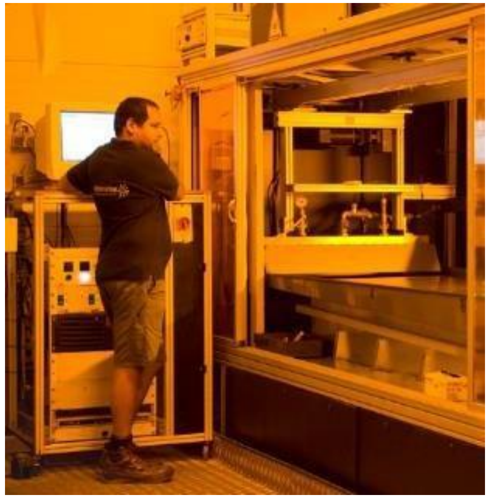
ENVISIONTEC

400 x 400 x 400 mm

3D SYSTEMS

1500 x 750 x 550 mm

MATERIALISE



2100 x 700 x 800 mm

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Vat Photopolymerization

- **Machine cost comparison:**

	Desktop SLA: Inverted	Industrial SLA: Right-Side Up
Price	Starting at $3500	$80,000-$1,000,000+
Print Volume	Up to 145 x 145 x 175 mm	Up to 1500 x 750 x 550 mm
Pros	Affordable Easy to use Low maintenance Small footprint Easy material swapping	Large build volume High production rate Extensive material options
Cons	Medium build volume	Expensive machinery High maintenance Operator required

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Vat Photopolymerization

- **Advantages:**
  - Design freedom;
  - Geometric models with great surface quality;
  - Fast process;
  - Reduced cost equipment;
  - Part isotropy is possible.

- **Disadvantages:**
  - Low range of materials available (UV curable resins);
  - Support structures required;
  - Material degradation with continued exposure to light;
  - Low working temperatures for components;
  - Some resins are toxic.

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Vat Photopolymerization

- **Applications and sectors:**
  - Rapid Prototyping;
  - Dental;
  - Healthcare;
  - Impellers and rotating devices;
  - Enclosures;
  - Investment casting.

- **Materials:**
  - Resin, typically composed of epoxy or acrylic and methacrylic monomers, will polymerize and harden when exposed to light

- **Feedstock Form:**
  - Liquid or Paste (photoreactive resin with or without filler material)

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Vat Photopolymerization

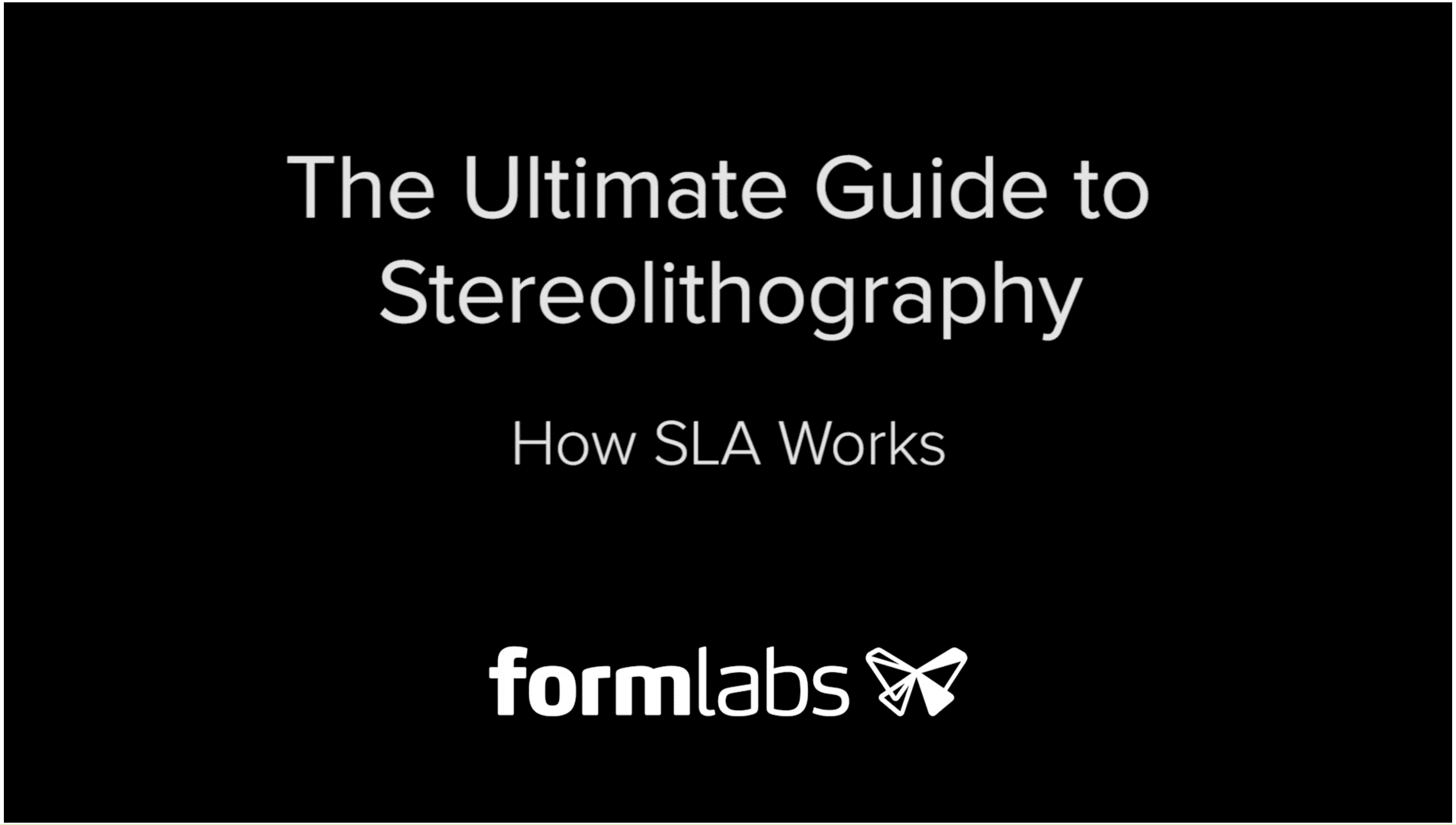
❑Processing operations (top-cure, industrial):

1. • The build platform is first positioned in the tank of liquid photopolymer, at a distance of one-layer height from the surface of the liquid
2. • Then a UV laser creates the next layer by selectively curing and solidifying the photopolymer resin
3. • The whole cross-sectional area of the model is scanned, so the produced part is fully solid
4. • When a layer is finished, the platform moves at a safe distance and the sweeper blade re-coats the surface. The process then repeats until the part is complete
5. • After printing, the part is in a green, no-fully-cured state and requires further post processing under UV light if very high mechanical and thermal properties are required

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

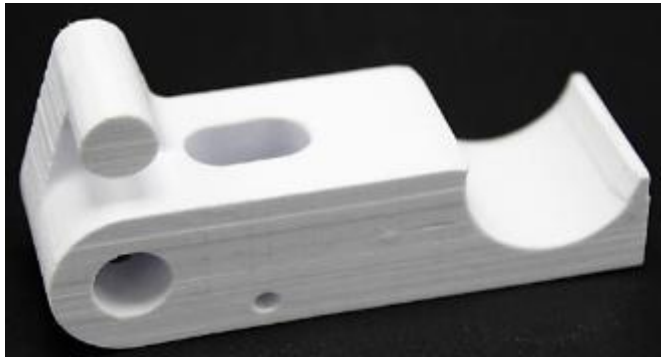
Vat Photopolymerization



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Sheet Lamination

- "Additive Manufacturing process in which sheets of material are bonded to form an object", according to ISO/ASTM 52900-18



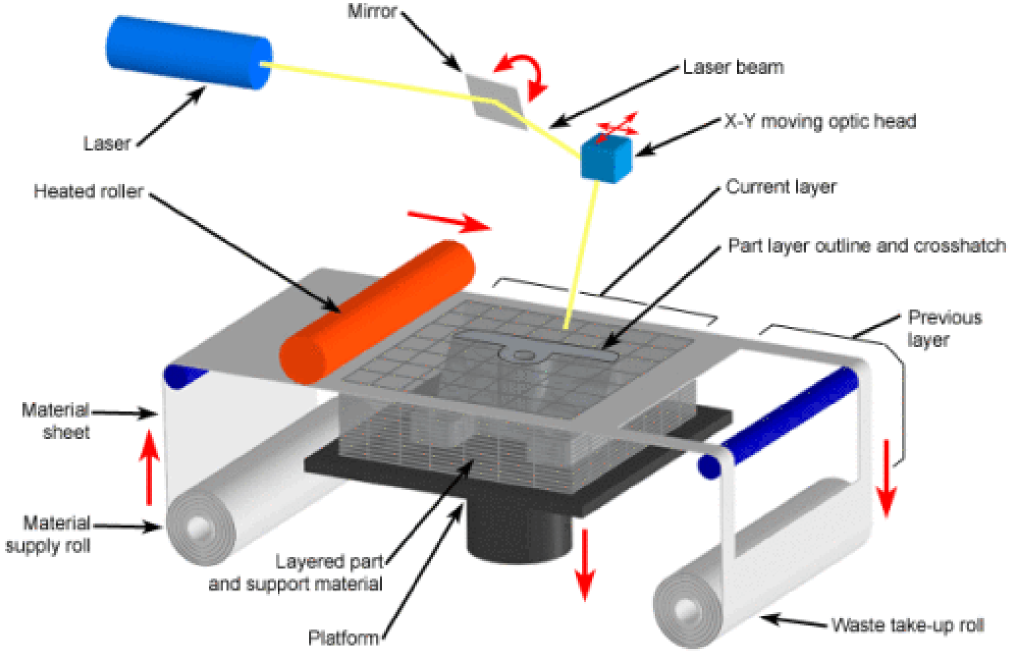
- **Processable Materials:**
  - Metals;
  - Polymers;
  - Composites;
  - Ceramics;
  - Paper.

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Sheet Lamination

- **Polymer**

- Interlayer adhesion achieved through heat/glue
- Cutting performed by laser/blade
- Can create coloured parts
- Typically for prototyping applications

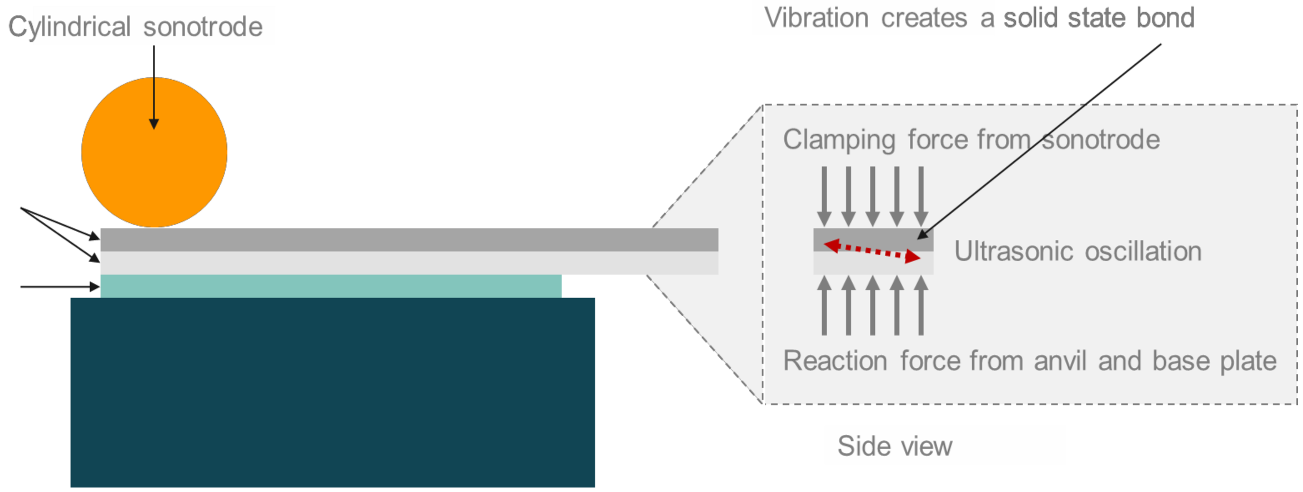


This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Sheet Lamination

Metal – Ultrasonic consolidation

- Solid state weld between 'foils'
- Multi material capability
- Ability to embed parts (low temperature)



This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Sheet Lamination

- **Advantages:**
  - High velocity
  - Non-existence of residual stress
  - Wide range of Materials

- **Disadvantages:**
  - Post-Processing are required to achieve required effect
  - Finishes can vary depending on paper or plastic material but may require post processing to achieve desired effect

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Sheet Lamination

- **Applications and sectors:**
  - Architecture models
  - Topography visualization
  - Aerospace and automotive industries

- **Feedstock Form:**
  - Sheet material, paper, metal foil, polymers or composites (metal or ceramic poder, helded by a binder)

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Sheet Lamination

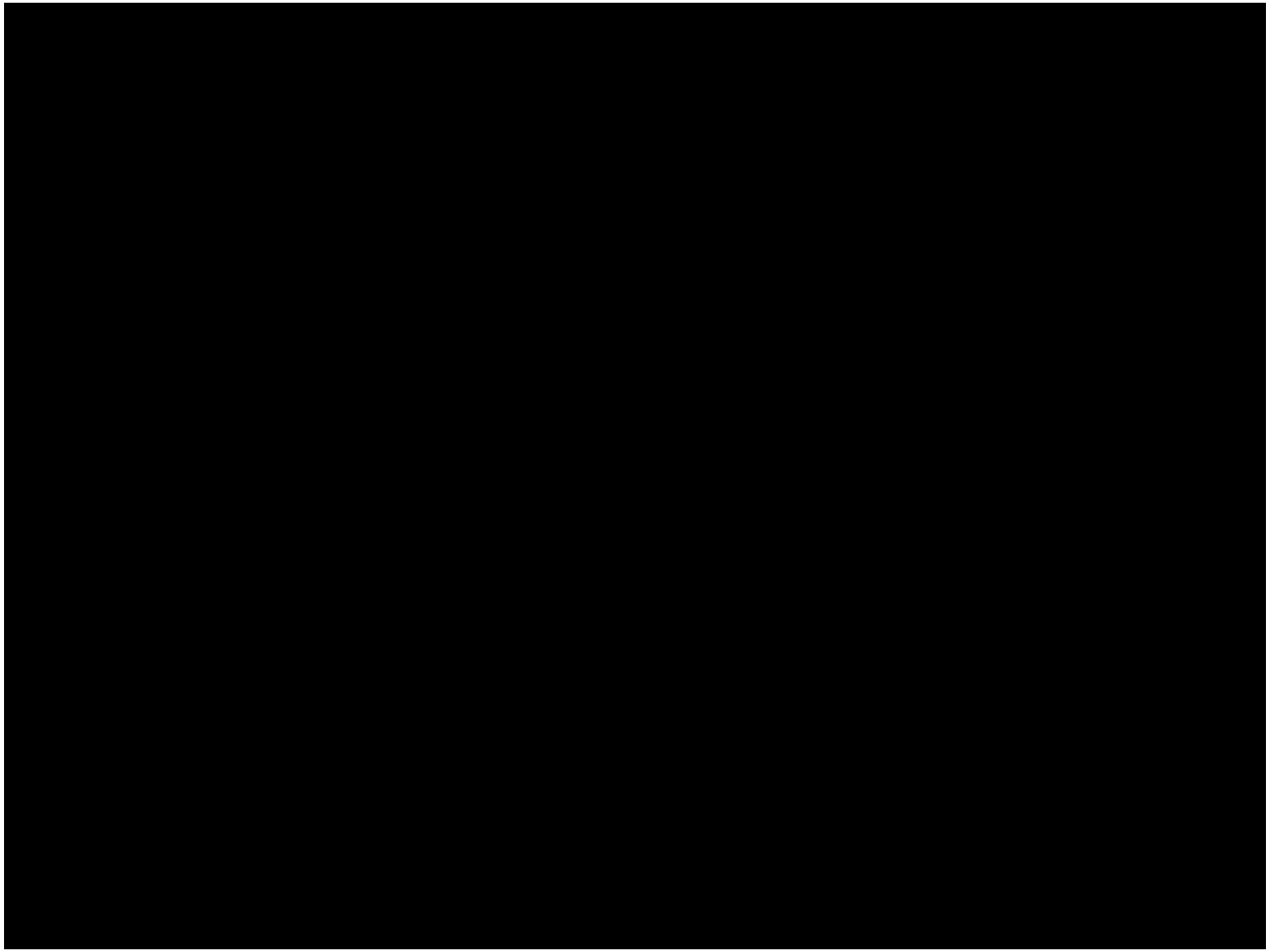
❑Processing operations (Plastic):

1. • Material is positioned in place on the cutting bed
2. • Material is bonded in place, over the previous layer, using the adhesive
3. • Required shape is then cut from the layer, by laser or knife, and next layer is added
4. • The Steps two and three can be reversed and alternatively, the material can be cut before being positioned and bonded

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview

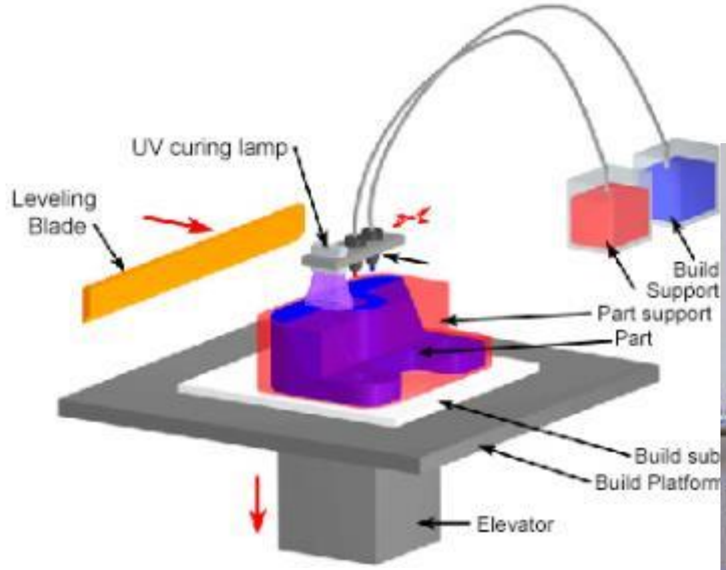
Sheet Lamination

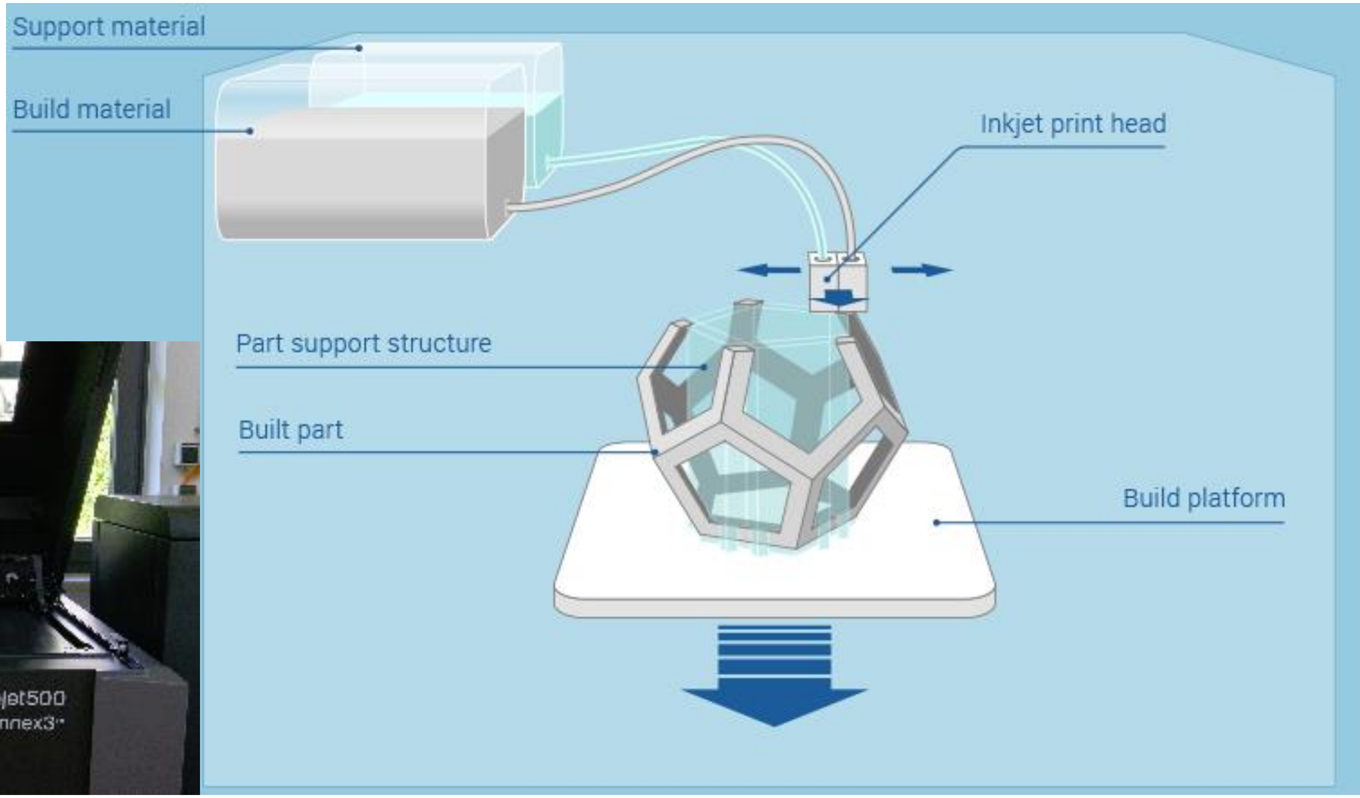


This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Material Jetting

- “*Additive manufacturing* process in which droplets of feedstock material are selectively deposited.”, according to ISO/ASTM 52900-18



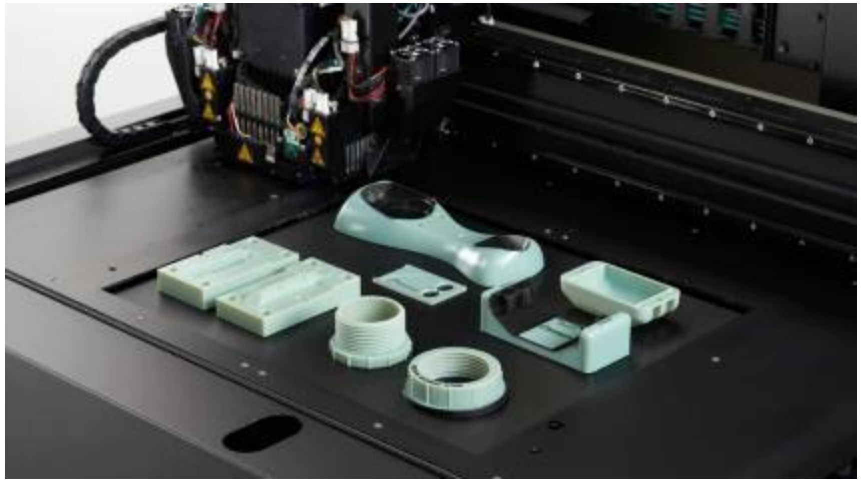


AMable

This project has received funding from the European Union’s H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Material Jetting

- **Advantages:**
  - Fast process
  - Small – medium parts
  - Good accuracy (typically ± 0.1%)
  - Allows mixture of colors and properties
  - Soft and Hard Materials
  - No post-processing required
  - Reduced cost equipment



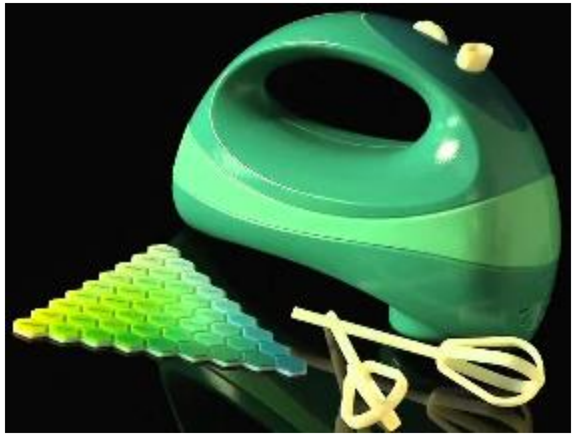
- **Disadvantages:**
  - Reduced resistance

Objects 3D Printed on Stratasys "PolyJet" Material Jetting Hardware

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Material Jetting

- **Applications and sectors:**
  - Rapid Prototyping
  - Dental
  - Healthcare
  - Prosthesis



- **Materials:**
  - UV-photosensitive resins
  - Acrylic photopolymers (thermoset)

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Binder Jetting

- "*Additive manufacturing* process in which a liquid bonding agent is selectively deposited to join powder materials", according to ISO/ASTM 52900-18

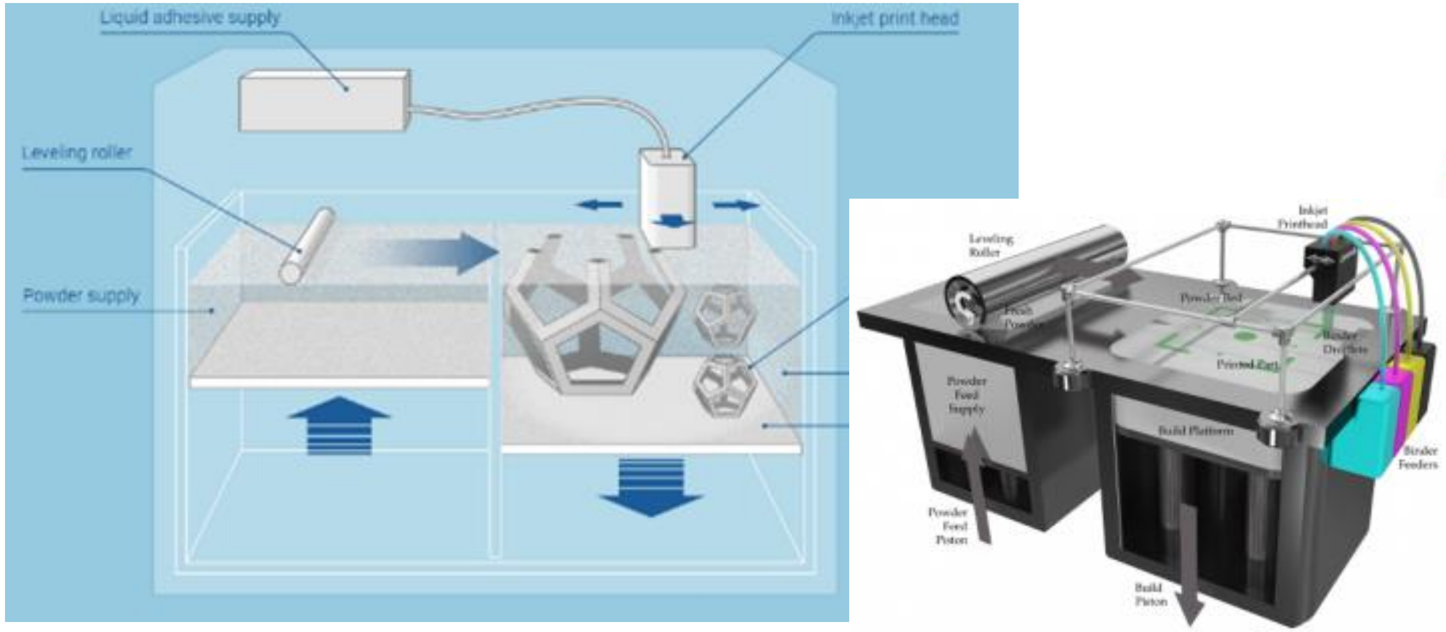
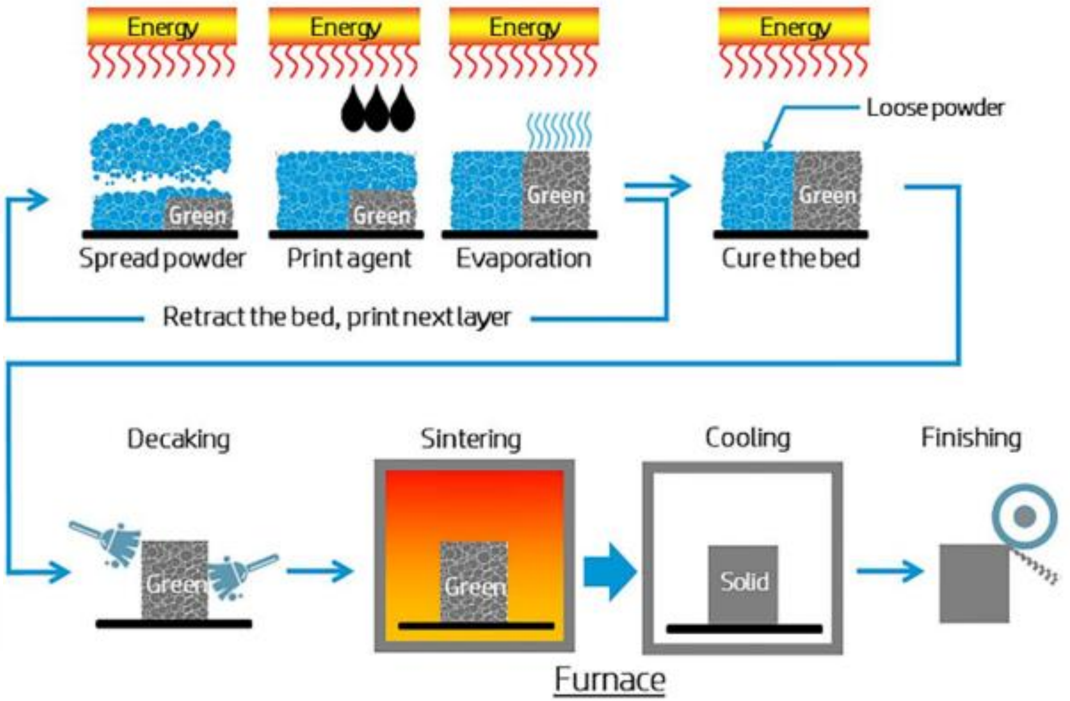


Figure 4. Schematic of HP Metal Jet printing process



AMable
This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Binder Jetting

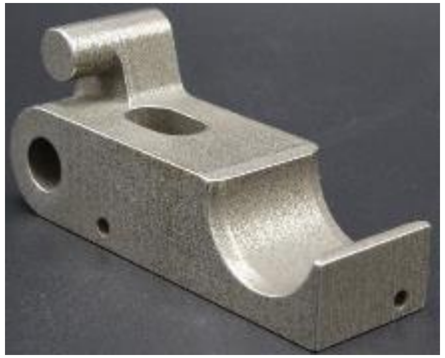
- **Advantages:**
  - X50-100 faster than PBF
  - X20 lower cost than PBF
  - No supports are required
  - Suitable for great complexity parts and large series
  - Good resolution

- **Disadvantages:**
  - Limited size (<400x300x200 mm)
  - Various processes for final part (print → debinder → sinter)
  - Complex manipulation of green parts
  - Contraction control during sintering
  - Limited wall thickness (5-10 mm)

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Binder Jetting

- **Applications and sectors:**
  - Precision engineering
  - Automotive
  - Prototyping
  - Medical



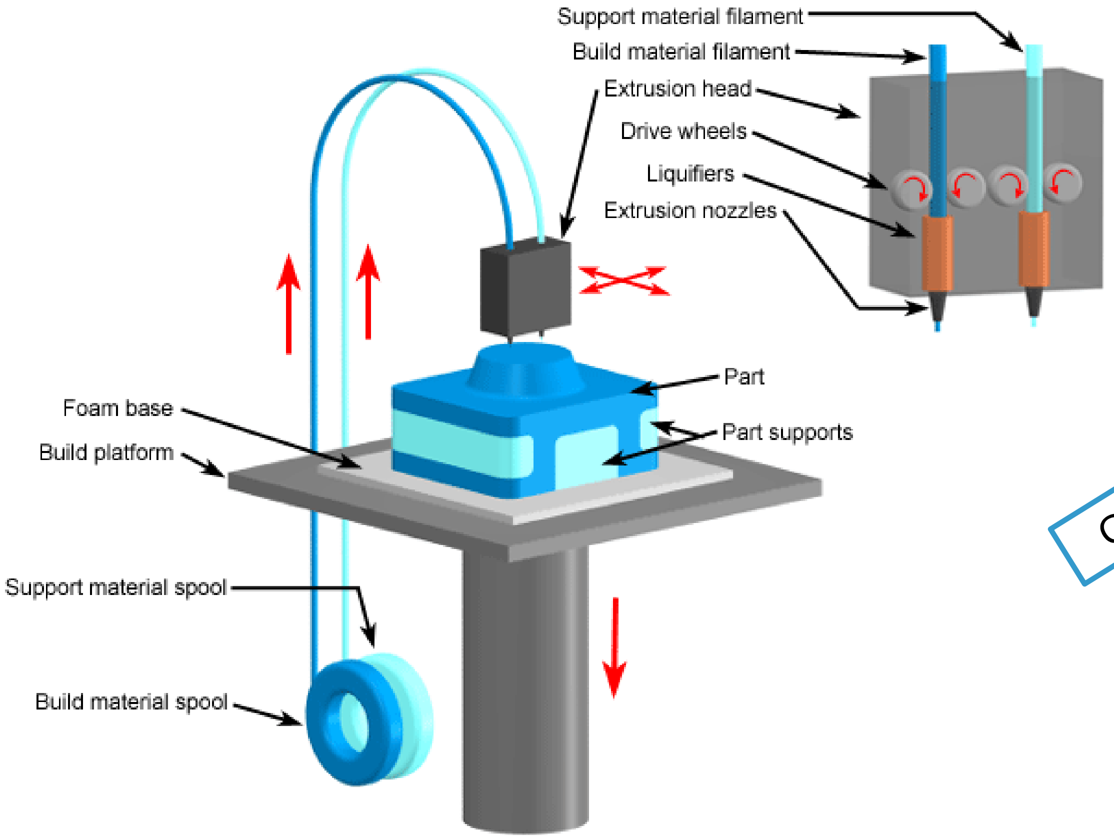
- **Materials:**
  - Steels
  - Ni-based
  - CoCr alloys
  - W, WC

AMable

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Material Extrusion

- "*Additive manufacturing* process in which material is selectively dispensed through a nozzle or orifice ", according to ISO/ASTM 52900-18



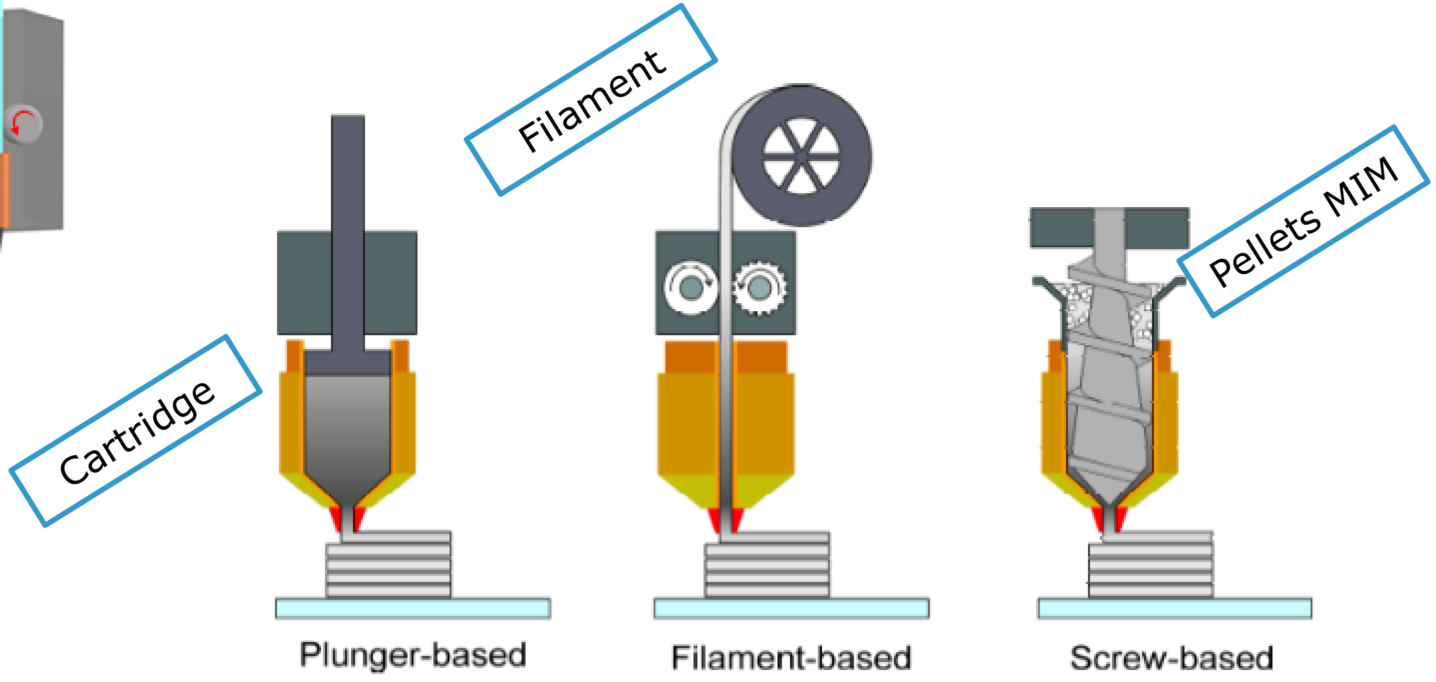


Figure 1. Different types and approaches for extrusion-based additive manufacturing.

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Material Extrusion

- **Advantages:**
  - Wide selection of print material (plastics)
  - Easy and user-friendly process (~~FDM~~)
  - Low initial and running costs
  - Small equipment size compared to other AM
  - Lower production costs (in Metals)
  - Suitable for small, highly complex parts (50 mm)
  - Suitable for small series part



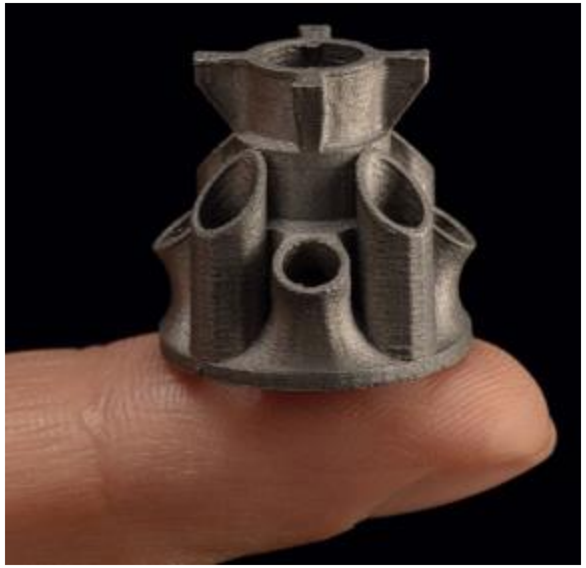

- **Disadvantages:**
  - Toxic print materials (some thermoplastics)
  - Sintered shrinkage (in metals)
  - Limited wall thickness (in metals: 5-10 mm)


This project has received funding from the European Union’s H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Additive Manufacturing Processes Overview
Material Extrusion

- **Applications and sectors:**
  - Rapid Prototyping
  - Automotive
  - Healthcare

- **Materials:**
  - Thermo Plastics (PLA, ABS, PC)
  - Composite material (Plastic reinforced)
  - Metals (Steel, Cu, Inco625)


This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Value Chain in Additive Manufacturing

Value Chain is defined as the set of activities from research to market, along a process to generate and **add value**

Figure 2.1: *Steps of AM value chain in FOFAM and AM-MOTION roadmaps*

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Value Chain in Additive Manufacturing
Added value by AM

Added value: set of additional product or service characteristics which make them more attractive for the customer against the competence

- Customization
- In-situ and on-demand production (without stocks)
- Minimum time to market
- Sustainability and energy efficiency
- Differential design
- Design improvement:
  - Integration of parts
  - Light weighting
- Cost improvement:
  - Small lots
  - High cost materials

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Value Chain in Additive Manufacturing
Which is the best AM process for my product?

Additive manufacturing technologies

	TECHNOLOGY	MATERIALS	TYPICAL MARKETS	RELEVANCE FOR METAL
Fusion	**Powder bed fusion** – Thermal energy selectively fuses regions of a powder bed	Metals, polymers	Prototyping, direct part	●
Fusion	**Directed energy deposition** – Focused thermal energy is used to fuse materials by melting as the material is deposited	Metals	Direct part, repair	◑
Fusion	**Sheet lamination** – Sheets of material are bonded to form an object	Metals, paper	Prototyping, direct part	◔
Sintering	**Binder jetting** – Liquid bonding agent is selectively deposited to join powder material	Metals, polymers, foundry sand	Prototyping, direct part, casting molds	◔
Sintering	**Material jetting** – Droplets of build material are selectively deposited	Polymers, waxes	Prototyping, casting patterns	○
Sintering	**Material extrusion** – Material are selectively dispensed through a nozzle or orifice	Polymers	Prototyping	○
Sintering	**Vat photopolymerization** – Liquid photopolymer in a vat is selectively cured by light-activated polymerization	Photopolymers	Prototyping	○

AM technologies for metal objects

Source: ASTM International Committee F42 on Additive Manufacturing Technologies; Roland Berger | 14

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Value Chain in Additive Manufacturing
Which is the best AM process for my product?

https://www.rolandberger.com/publications/publication_pdf/Roland_Berger_Additive_Manufacturing.pdf

D: Established and challenger technologies for metal AM

Several new metal AM technologies are emerging alongside powder bed fusion or direct energy deposition – Simplified overview (schematic)

	POWDER BED FUSION – BY LASER	POWDER BED FUSION – BY ELECTRON BEAM	DIRECT ENERGY DEPOSITION – POWDER BY LASER	WIRE BY LASER / PLASMA / EB	MATERIAL JETTING	MATERIAL EXTRUSION	BINDER JETTING
BUILD PRINCIPLE	Thermal energy by laser fuses regions of a powder bed	Thermal energy by electron beam fuses regions of a powder bed	Fusion of powdered material by melting during deposition	Fusion of wire fed material by melting during deposition	Deposition of droplets of molten metal	Dispensing of material through nozzle to form a green part	Joining powder with binding agent to form a green part
MANUFACTURING READINESS FOR AM	Manufacturing readiness reached for selected industries	Manufacturing readiness reached for selected industries	So far mainly used for coating, AM only in niche applications	So far mainly used for coating, AM only in niche applications	Production capabilities shown	Production capabilities shown for prototyping	Manufacturing readiness reached for niche applications
KEY MATERIALS	Al, Ti, Ni-alloys, CoCr, steel	Ti, Ni-alloys, CoCr	Ti, Ni-alloys, steel, Co, Al	Ti, Ni, steel, Co, Al, W, Zr-alloy, CuNi	AL, steel	Cu, Inco, steel, (others incl. Ti in development)	WC, W, CoCr, steel/bronze, steel, Inco, non-metal molds
MECHANICAL PROPERTIES							
POST-PROCESSING REQUIRED	HT[1]/HIP[2], machining, surface treatment	Machining, surface treatment	HT[1], machining, surface treatment	HT[1], machining, surface treatment	HT[1]/HIP[2], machining, surface treatment	HT[1](/HIP[2]), machining, surface treatment	HT[1]/HIP[2], machining, surface treatment
BUILD COSTS							
CORE APPLICATION INDUSTRIES	Aerospace, turbines, med-tech, dental, automotive	Aerospace, turbines, med-tech	Aerospace, general MRO-related business	Aerospace, general MRO-related business	Precision engineering, automotive, prototyping	Precision engineering, automotive, prototyping	Precision engineering, automotive, prototyping, med-tech, arts and design
EQUIPMENT SUPPLIERS (SELECTION)	Concept Laser, Trumpf, EOS, Renishaw, DMG MORI, SLM Solutions, Additive Industries	Arcam	DMG MORI, Mazak, BeAM, PM Innovations, Trumpf, Optomec	Sciaky, OR Laser, Trumpf, Norsk Titanium	Vader Systems, XJet	Desktop Metal, Markforged, BASF	ExOne, Digital Metal, Desktop Metal
	Established technologies			Challenger technologies			

Low degree required · High degree required · Low – High · Proof of concept – Full rate production

1) Heat treatment 2) Hot isostatic pressing
Source: Company information; expert interviews; Roland Berger

AMable

This project has received funding from the European Union's H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775

Thanks for your attention

This project has received funding from the European Union’s H2020 Framework Programme for research, technological development and demonstration under grant agreement no 768775