
LUT
University

Trends and market of AM + costs in metal AM

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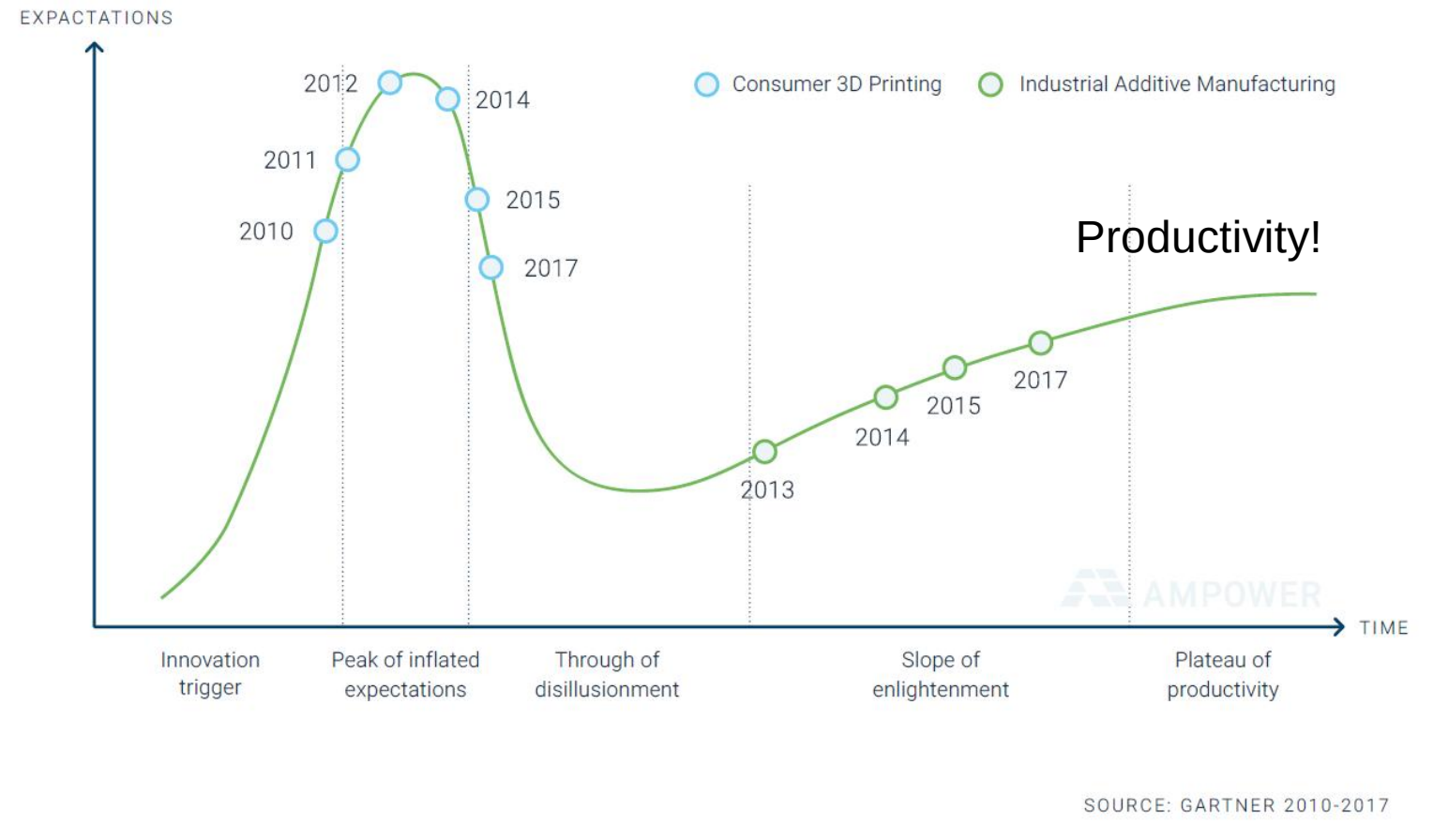
7.6.2019

9 Trends

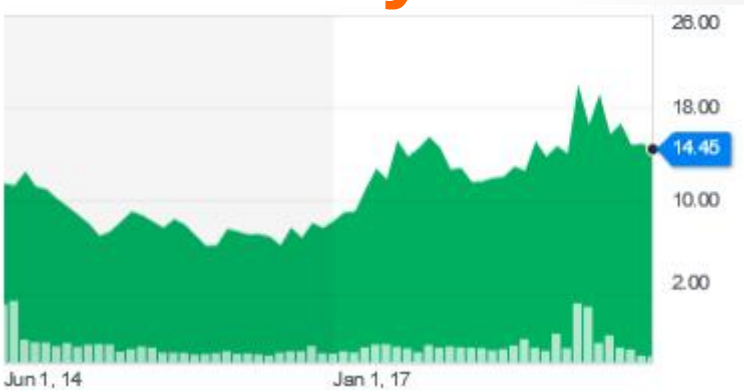
Trend #1 – Hype is decreasing

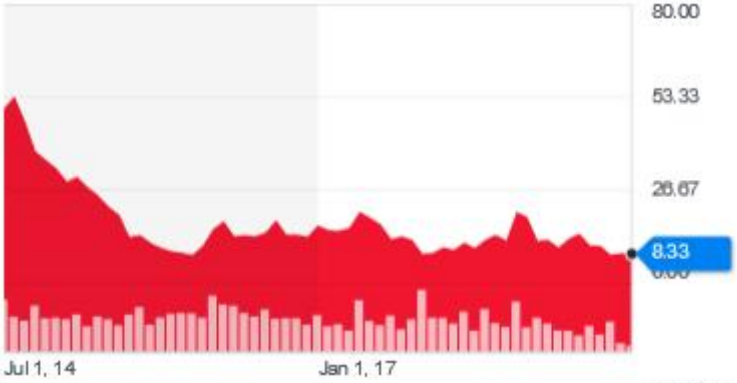


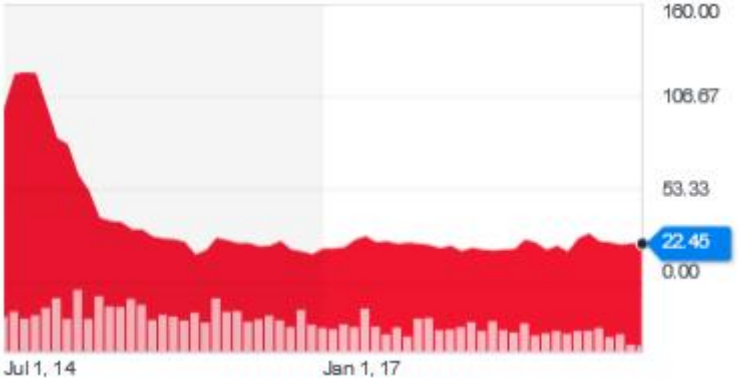
Source or courtesy of: AMPower; Gartner

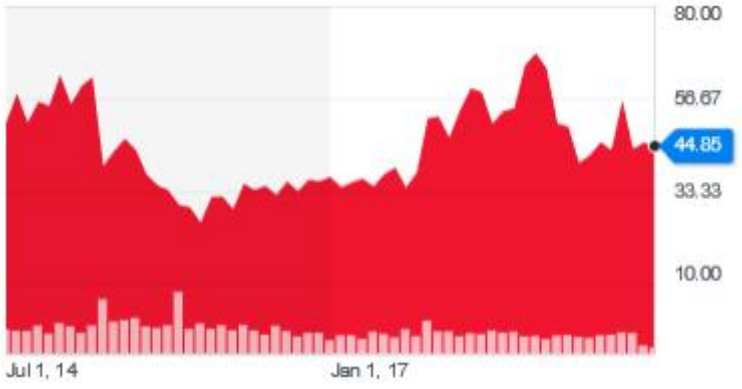
Feeding the hype

Stock prices of six different AM companies from the last 5 years









SITY OF TECHNOLOGY

YAHOO! FINANCE

Trend #2 – High-demand applications

1,35 m and 200 kg ship propeller

Source or courtesy of: DAMEN

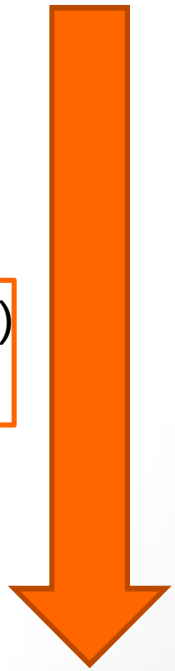
Ternd #2 – High-demand applications

- Brake Caliper (Bugatti Chiron)
- Made of titanium alloy
- 410 x 210 x 136 mm^3

Trend #3 – Technology is close to full rate production in many fields of industries & applications

Technology Readiness Levels (TRL) 1-10

1. Basic manufacturing implications identified
2. Manufacturing concept identified
3. Manufacturing proof of concept developed
4. Technology validated in laboratory environment
5. Basic capabilities shown (near production environment)
6. Systems produced (near production environment)
7. Production in production environment demonstrated
8. Low rate production
9. Pilot line capability demonstrated
10. Full rate production



Single examples of TRLs

Technology readiness level (TRL) – Aerospace industry - METALS

- Aerospace industry TRL metal case examples
  - Airbus, Titanium, *TRL 6*
    - First civil application flight tested. Military applications already flying.
  - GE, Cobalt-Chrome, *TRL 9*
    - Fuel nozzle flight tested, close to mass production
  - MTU, Inconel, *TRL 9*
    - Engines and other parts, close to mass production

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Technology readiness level (TRL) – Aerospace industry - POLYMERS

- Aerospace industry TRL polymer case examples
  - Airbus, Ultem (material extrusion), *TRL 9*
    - Fully certified flying cabin parts in serial production and after sales and in addition:
      - Tools
      - Customized solutions
  - Boeing, polyamide 22FR, *TRL 9*
    - Many parts for venting and air ducts used for years

First part that a passenger is actually going to see was approved in 2018

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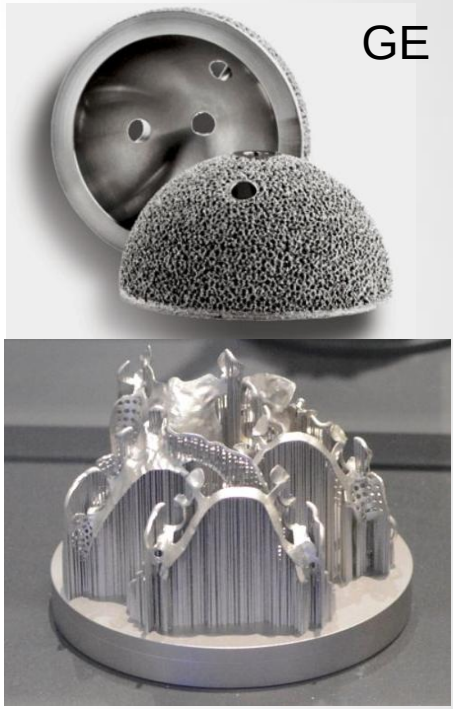
Technology readiness level (TRL) – Medical & Dental industry - METAL

- Medical and Dental industry TRL metal case examples
  - Titanium, *TRL 10*
    - More than 100 000 hip implants additively manufactured
  - Cobalt-Chrome, *TRL 10*
    - Crowns and copings are additively manufactured daily
  - Stainless Steel, *TRL 9*
    - Customized medical instruments



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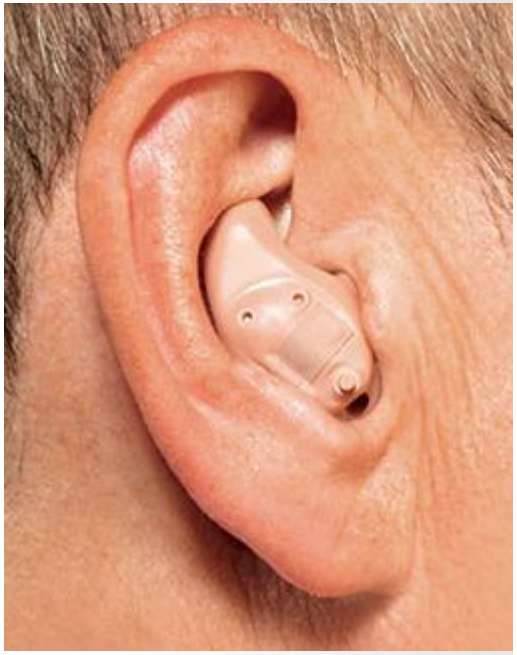
Technology readiness level (TRL) – Medical & Dental industry - POLYMERS

- Polymers, *TRL 10*
  - 50 % of all hearing aids are stereolithographed nowadays
  - Mass production of surgical guides (powder bed fusion)



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Technology readiness level (TRL) – Automotive - METALS

- Automotive industry
  - Metals: *TRL 5-6*
    - Prototypes
    - Tooling
    - “Exotic” small series
    - Motor sports & Formula 1

Technology Readiness Level

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Technology readiness level (TRL) – Automotive - POLYMERS

- Automotive industry
  - Polymers: *TRL 6-9*
    - PA12 & ABS
      - Interior parts
        - Dashboard, doors…
    - Rolls-Royce Phantom
      - 10 000 parts in small series production
    - Daimler
      - Powder bed fusioned parts since 2016

Technology Readiness Level

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Technology readiness level (TRL) – Tooling & Machine Building - METALS

- Tooling & Machine Building (metals)
  - Steel, *TRL 9*
    - Tools
    - Moulds
  - Aluminum, *TRL 9*
    - Final part production

Technology Readiness Level

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Technology readiness level (TRL) – Tooling & Machine Building - POLYMERS

- Tooling & Machine Building (polymers)
  - Polymers *TRL 9*
    - Used for various applications in final part production

Technology Readiness Level

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Trend #4 – Growth
Known Finnish entities with an own industrial metal printer

- LUT-University (2 pcs 2019)
- Aalto-University
- VTT
- Nivalan Teollisuuskylä / Oulu University
- SASKY koulutuskuntayhtymä & TAMK (50/50)
- Oulu PMC Osuuskunta

R&D/education

- Electro Optical Systems Finland Oy (+ 20 pcs)
- Lillbacka Powerco Oy
- V.A.V Group Oy
- Wärtsilä
- Vossi Group
- HT Laser Oy

"Own production"

5 new entities 2019!

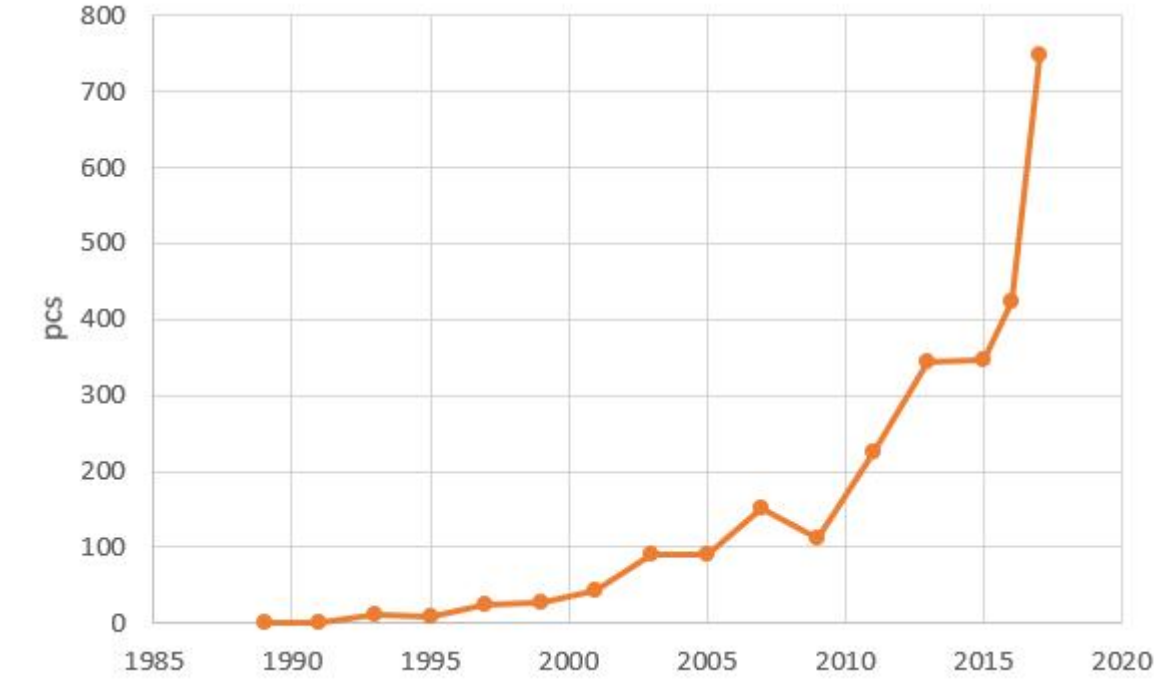
- Materflow Oy
- 3DStep Oy
- 3D Formtech Oy
- Delva Oy (2 pcs 2019)

Service providers

Source or courtesy of: Korpela 2019

Trend #4 – Growth
Amount of issued AM–related patents in USA 1989-2017

Total of 3882 AM-related patents were issued 1989-2017



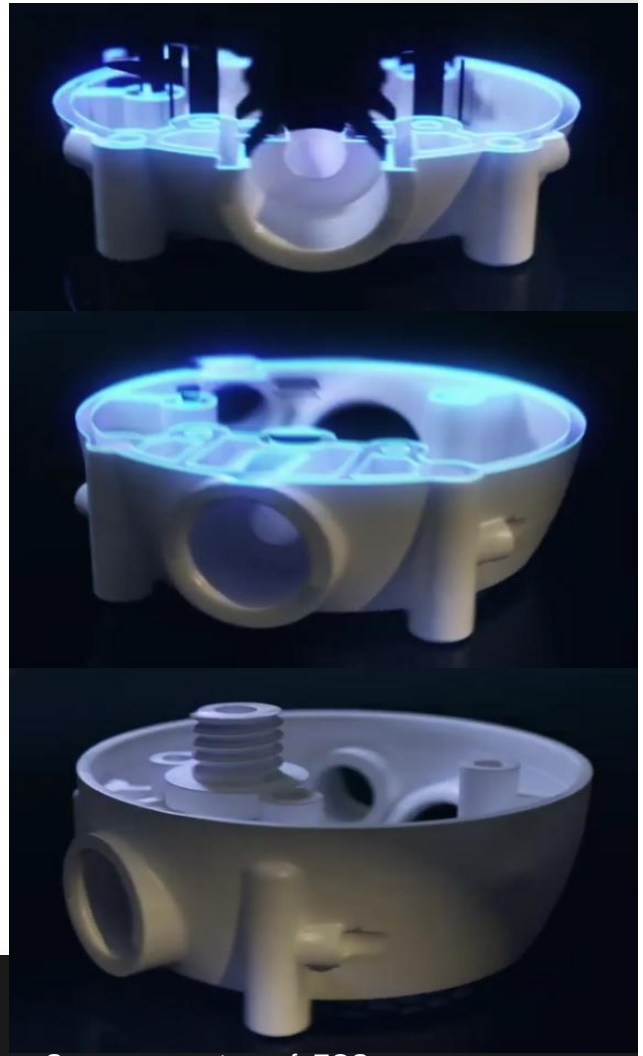
Trend #5 – Increased productivity and quality control possibilities in systems

- The number and power of lasers have increased (metal AM, L-PBF)
- Print area sizes increased
- More automation
- Hybrid systems
- Process monitoring

Trend #6 – New processes/techniques

- EOS Laser Pro Fusion
  - 1 million lasers in one system (polymer)
  - Systems available in 2021

9 seconds/part!



Source or courtesy of: EOS

Trend #6 – New processes/techniques

- Desktop Metal has already been invested more than $ 400 million, by Ford among others
  - Newish semi low cost metal extrusion technique for metals
  - “Same” process than in consumer 3D printing
- New metal system coming soon from HP

Trend #6 – New processes/techniques

- Cold spray AM: **metal** powder is deposited faster than the speed of sound without melting the material with a separate heat source
  - Spee3D: copper and aluminum, 300 x 300 x 300 mm^3 max dimensions. Possibly 100-1000 times faster than traditional AM.
  - Titomic: 9000 x 3000 x 1500 mm^3 max dimensions.

Trend #6 – New processes/techniques

- Traction wheels made by AM Cold Spray (Spee3D)

Left:

- 6061- aluminum
- Production time 15 min
- Weight 0,35 kg

Right:

- 160 mm
- Pure copper
- Production time 30 min
- Weight 1,15 kg

Trend #7 - Standardization

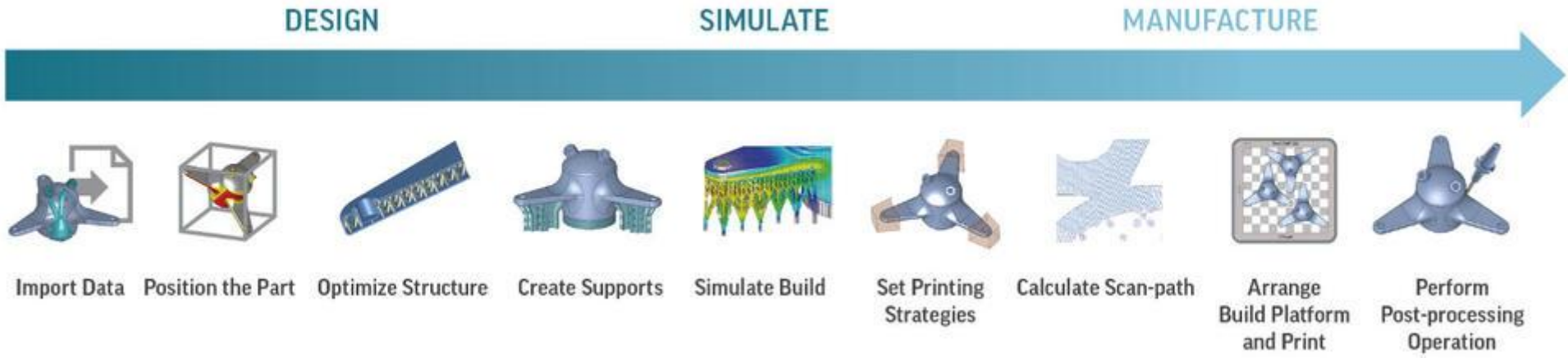
- 24 ASTM, ISO or ISO/ASTM additive manufacturing related standards has been published
  - 8 accepted by EN
    - 2 translated into Finnish by SFS
  - Many new international standards under development (+20 pcs)
  - + National standards: German, French, British…
  - 2011 first non-terminology related standard approved by ASTM

Standardization

Only metal!

- Pure material standards
  - ASTM F2924 – 14 - Ti6Al4V
  - ASTM F3001 - 14 - Ti6Al4V ELI (extra low interstitial)
  - ASTM F3055 - 14a - Inconel 718
  - ASTM F3056 – 14e1 – Inconel 625
  - ASTM F3184 – 16 – 316L
  - ASTM F3318 – 18 – AlSi10Mg
  - ASTM F3213 – 17 – Co28Cr6Mo

Trend #8 – One software for everything

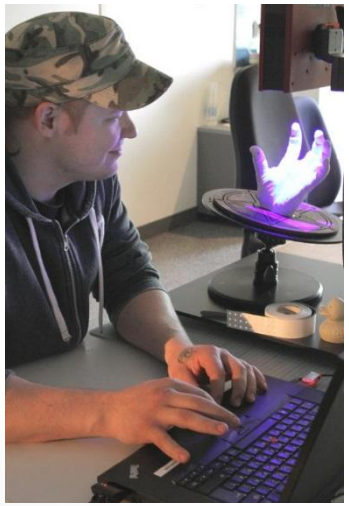


Source or courtesy of: 3D SYSTEMS

Trend 9 - Education

Education of AM in Finland – Second degree

- Artesan, 3D-printing and modeling
  - Ikaalinen School of Arts and Crafts
  - 2-3 year line according to your personal plan
  - *”3D printing and modeling artisan makes product design and products utilizing various printing technologies such as FDM, SLA, SLS, SLM and material injection.”*



SASKY
koulutus-
kuntayhtymä

Courses of 3D printing in Finnish Universities of Applied Sciences (2018)

Ammattikorkeakoulu	3D-tulostuskurssin nimi	Opintopisteet
Satakunnan ammattikorkeakoulu	Tulevaisuuden tuotannon suunnittelu	5
Satakunnan ammattikorkeakoulu	3D-mallinnuksen perusteet	3
Tampereen ammattikorkeakoulu	Basics of Rapid Prototyping	3
Turun ammattikorkeakoulu	Ainetta lisäävä valmistus	2
Yrkeshögskolan Arcada	Additive Manufacturing	5
Metropolia Ammattikorkeakoulu	Hybridimedia ja lisäävä valmistus	10
Oulun ammattikorkeakoulu	Prototyyppitekniikka	3
Haaga-Helia ammattikorkeakoulu	3D Printing using Blender and FDM Printers	3
Haaga-Helia ammattikorkeakoulu	Basic 3D Design with Blender	3
Jyväskylän ammattikorkeakoulu	Kehity 3D-tulostusosaajaksi	5
Karelia-ammattikorkeakoulu	Ultraprecision Manufacturing and Advanced Metrology	4
Lahden ammattikorkeakoulu	3D-tulostus	3

Courses of 3D printing in Finnish Universities of Applied Sciences (2018)

Ammattikorkeakoulu	3D-tulostuskurssin nimi	Opintopisteet
Kaakkois-Suomen ammattikorkeakoulu	3D-tulostus	5
Lapin ammattikorkeakoulu	3D printing	3
Lapin ammattikorkeakoulu	3D tulostus ja sovellukset (HUOM! Konetekniikan pakollinen kurssi 2017 aloittaneille, kolmantena vuonna)	5
Lapin ammattikorkeakoulu	CAD työkaluna	5
Saimaan ammattikorkeakoulu	3D Modelling	3
Savonia-ammattikorkeakoulu	Valmistusmenetelmät	5
Savonia-ammattikorkeakoulu	Lisäävä valmistus ja 3D-skannaus	5
Vaasan ammattikorkeakoulu	Kokoonpanoprojekti	2
Vaasan ammattikorkeakoulu	Kehittyvä koneensuunnittelu DFMAA ja DFAM	5

Teaching of 3D printing in Europe(2018)

- 3D printing courses in ”AM important” European universities typically range from 5 to 15 credits
- 7 Universities offer a master’s degree in 3D printing
  - 20-60 credits for 3D printing courses
  - All in UK

University of Strathclyde Glasgow

The University Of Sheffield.

University of Nottingham
UK | CHINA | MALAYSIA

Loughborough University

Anglia Ruskin University

uclan UNIVERSITY OF CENTRAL LANCASHIRE

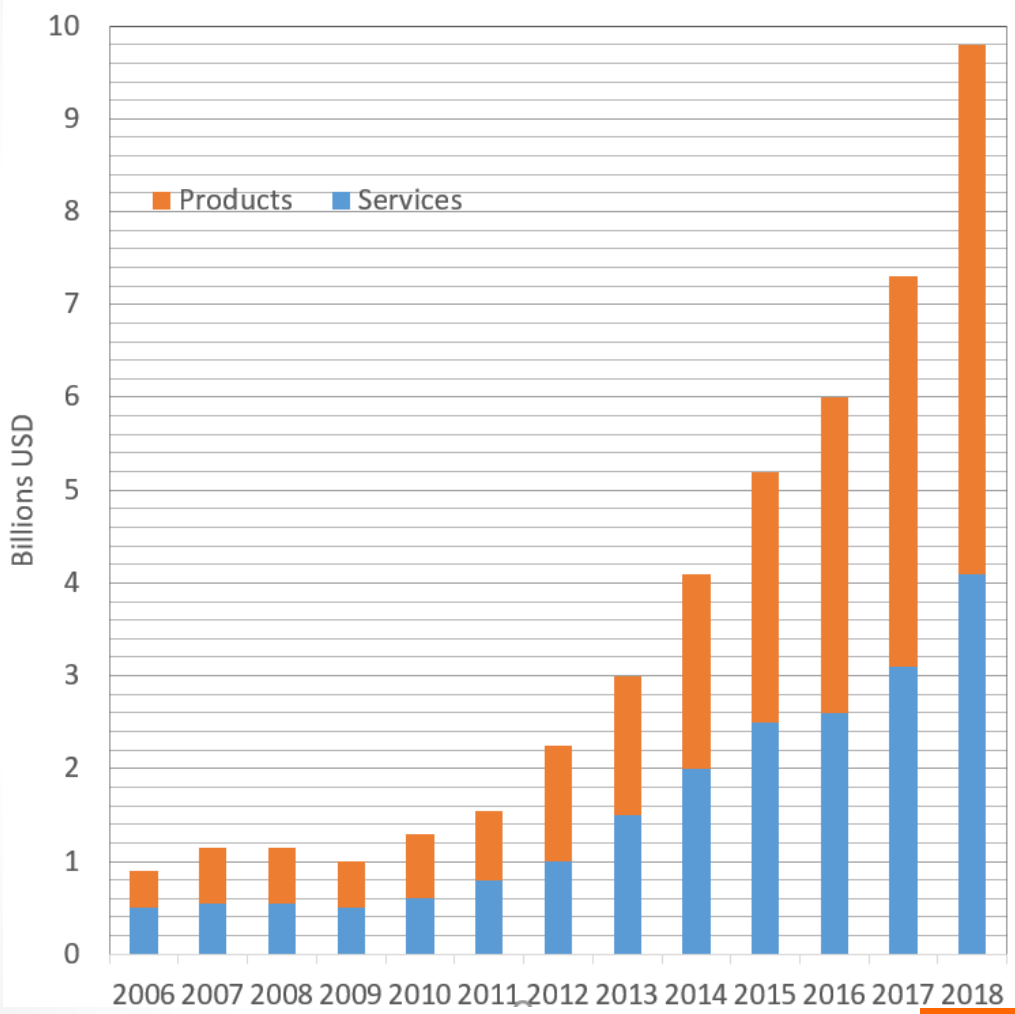
UNIVERSITY of DERBY

Market

Market

- Average annual growth rate of worldwide revenues produced by all products and services over the past 30 years is estimated to be ~27 %
  - Over the past 4 years = ~24 %

Growth of additive manufacturing 2006-2018



10 billion USD business

How much is 10 billion USD?

Bitcoin = USD ~130 B

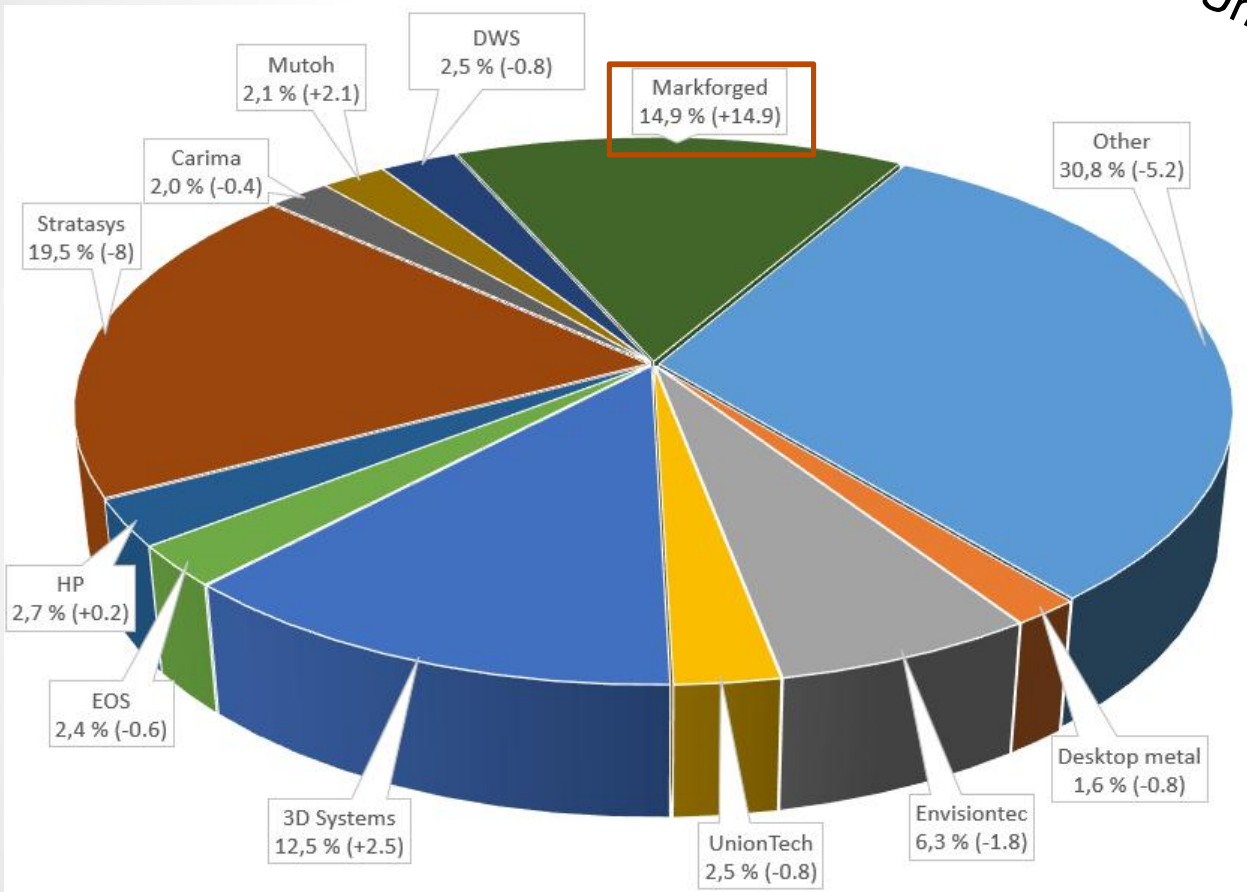
Forbes

Industrial system unit sales

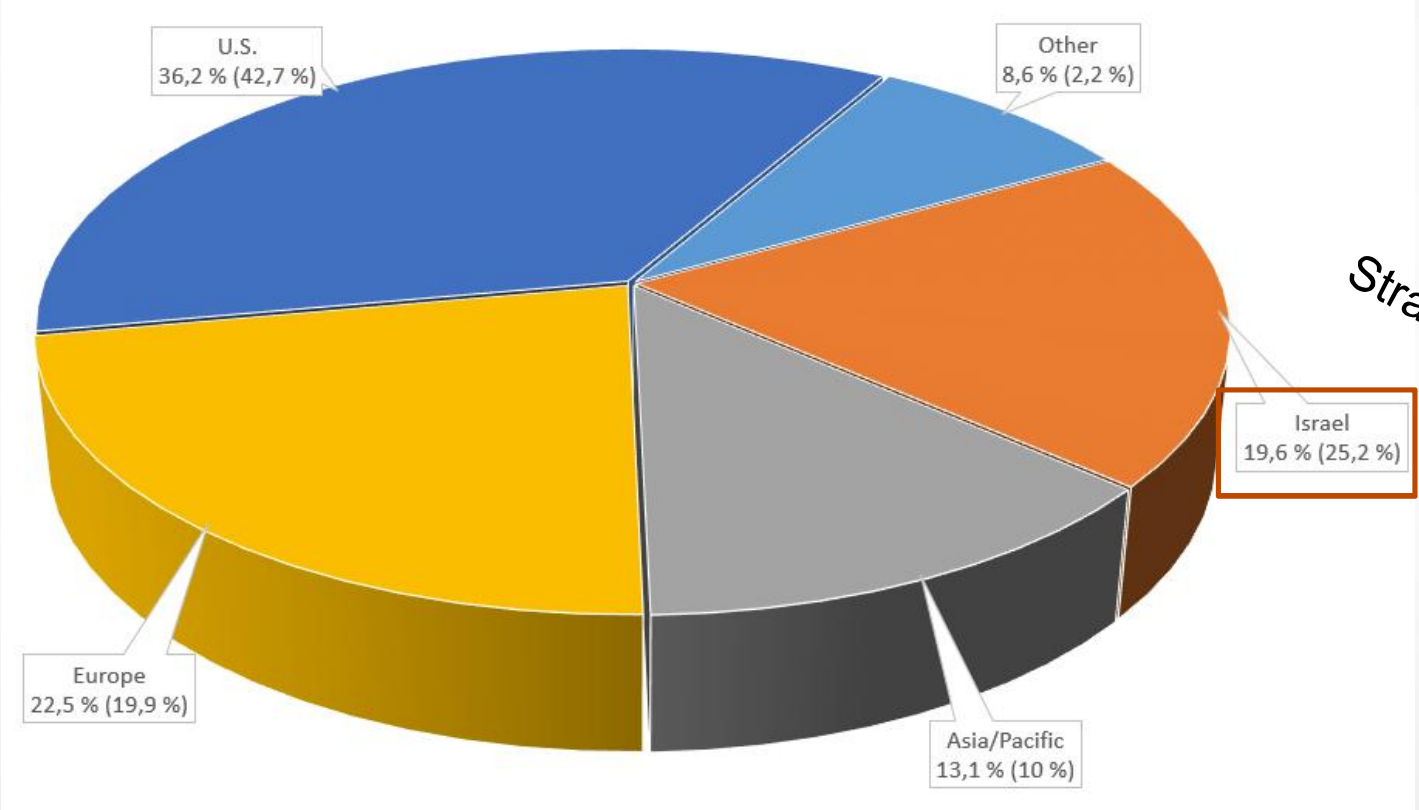
- Industrial system = >5000 USD
  - 2018, ~20 000 systems were sold
    - Growth ~18 % from 2017

Unit sales market share (2018 & differences from 2017)

Unit sales!



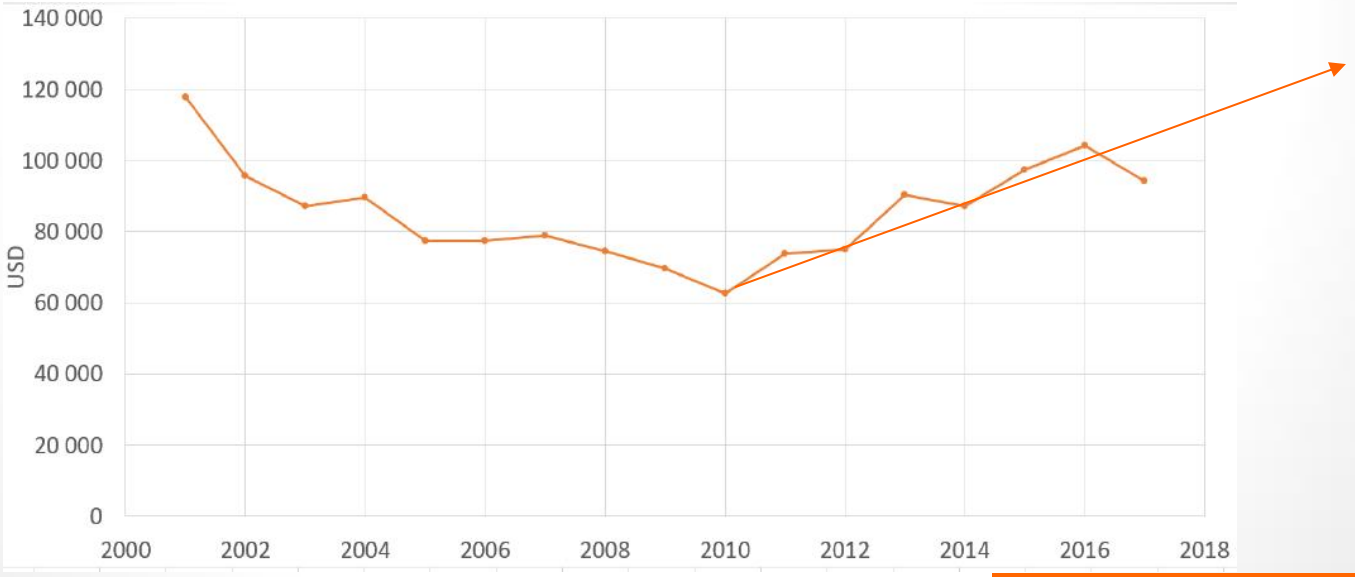
Industrial systems sold by region (2018 & cumulative total number of 1988-2018)



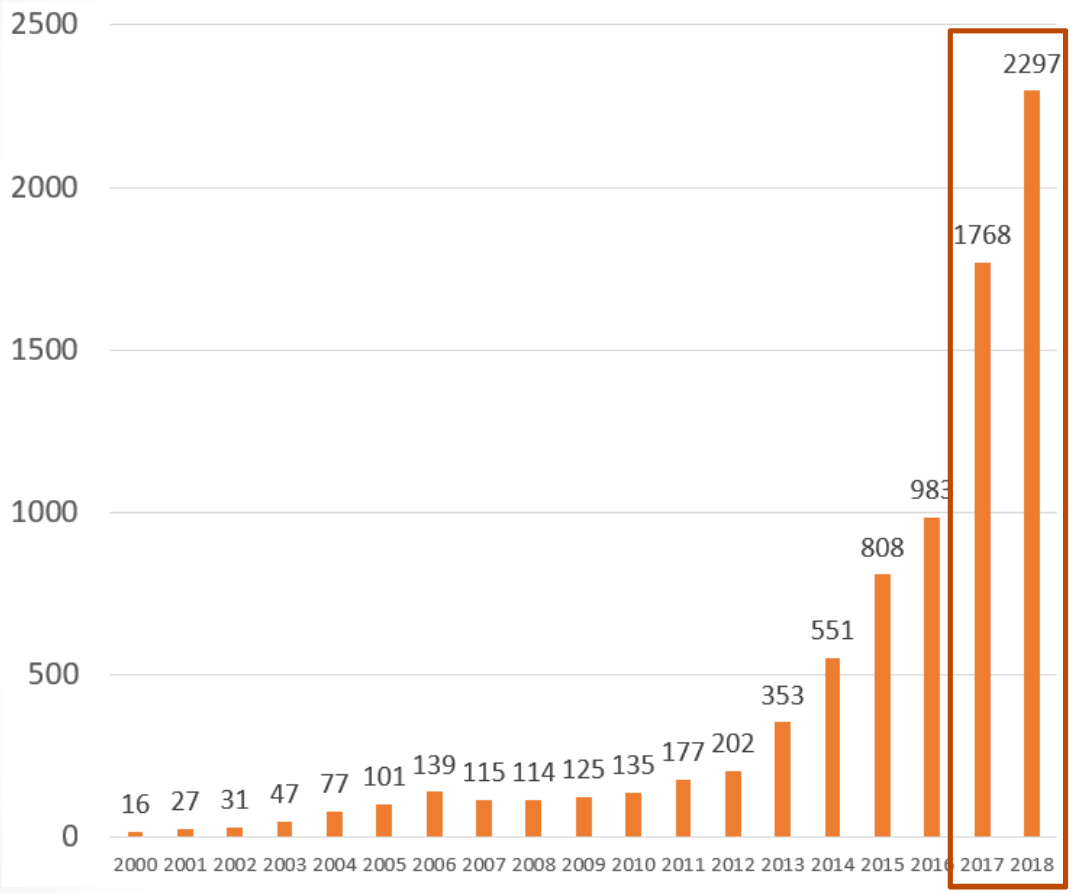
Average price of an industrial system

- ~ 60 000 USD in 2010
- ~ 100 000 USD in 2018
  - Increasing

- Machines have more properties
- Quality control
  - Process monitoring systems
- More lasers in metal AM systems
- Etc.

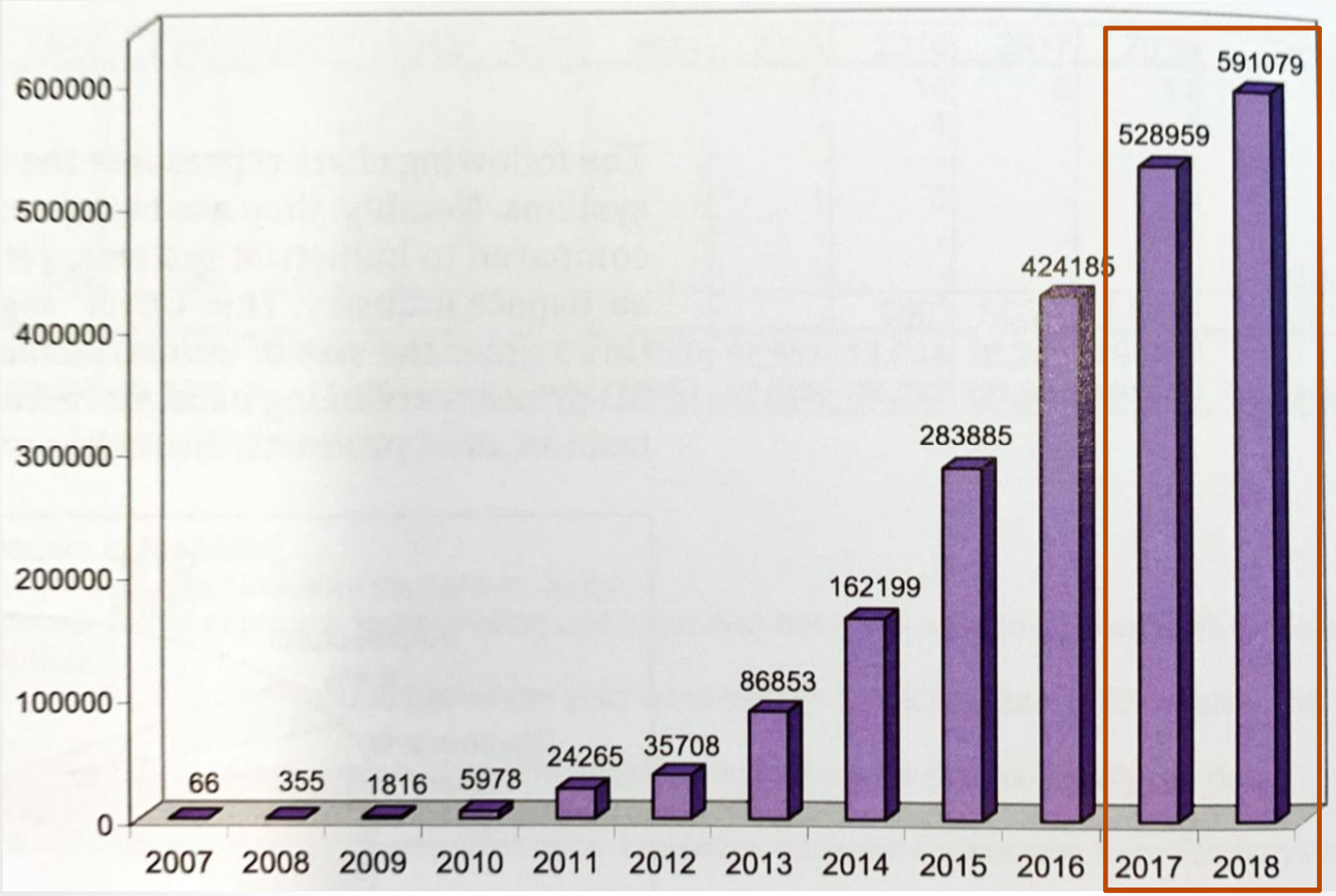


Sold metal AM systems (units)



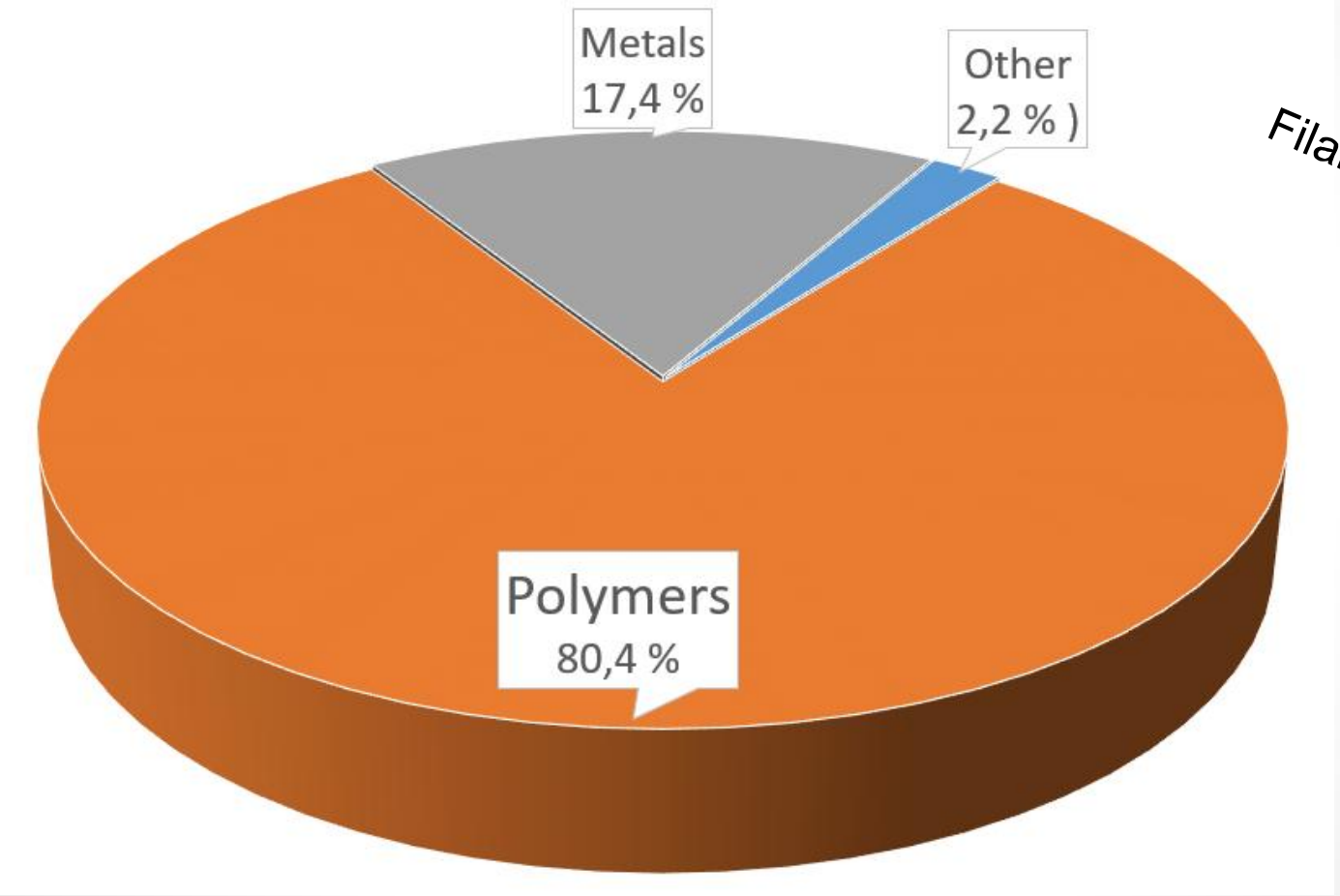
Growth ~50 % per year since 2013

Sales of deskop 3D printers (units)



Growth %

Sales of AM materials



Filaments ~20 %

More about the market

Costs in metal additive manufacturing

Powder Bed Fusion

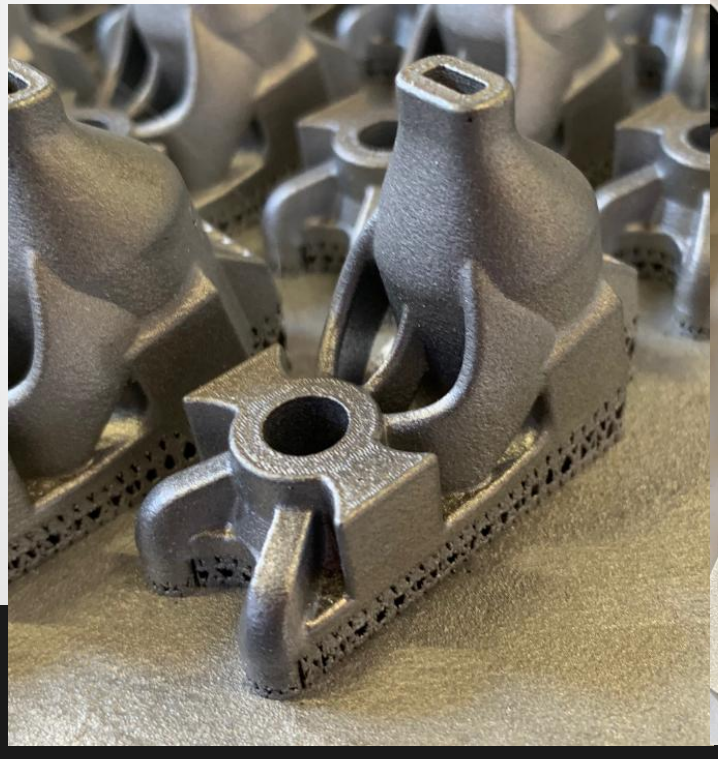
- ~90 % of metal AM systems base on laser-based Powder Bed Fusion technology
  - Today's situation might change in the future due to new techniques

Powder Bed Fusion of metals

- Slow and expensive process
  - Building speeds 5-30 cm^3/h
  - Hourly machine cost 50-100 € at lowest with a mid-size machine
    - 1 litre of solid steel = 30 - 200 hours = 1500 - 20 000 €
      - + material costs & pre- and post-processing

However

- Can still be the most cost-effective option for some applications
  - Complex geometries
  - Part reduction
  - Light-weight structures
  - Customization



Systems - Building volumes

- Three different size classes
  - Small
  - Mid-size
  - Large

Powder Bed Fusion - small systems

- Small systems
  - Building volume less than 10 litres
    - Average volume 1.5 litres
  - Average base price 200 000 €
  - Typically 1 x 200 W laser

•https://www.eos.info/eos-m-100

Powder Bed Fusion – medium size systems

- Medium size systems
  - Building volume 10-30 litres
    - Average volume c. 20 litres
  - Average base price c. 400 000 €
  - Typically 1-2 pcs of 200-700 W laser(s)

Production environment >1 000 000 €

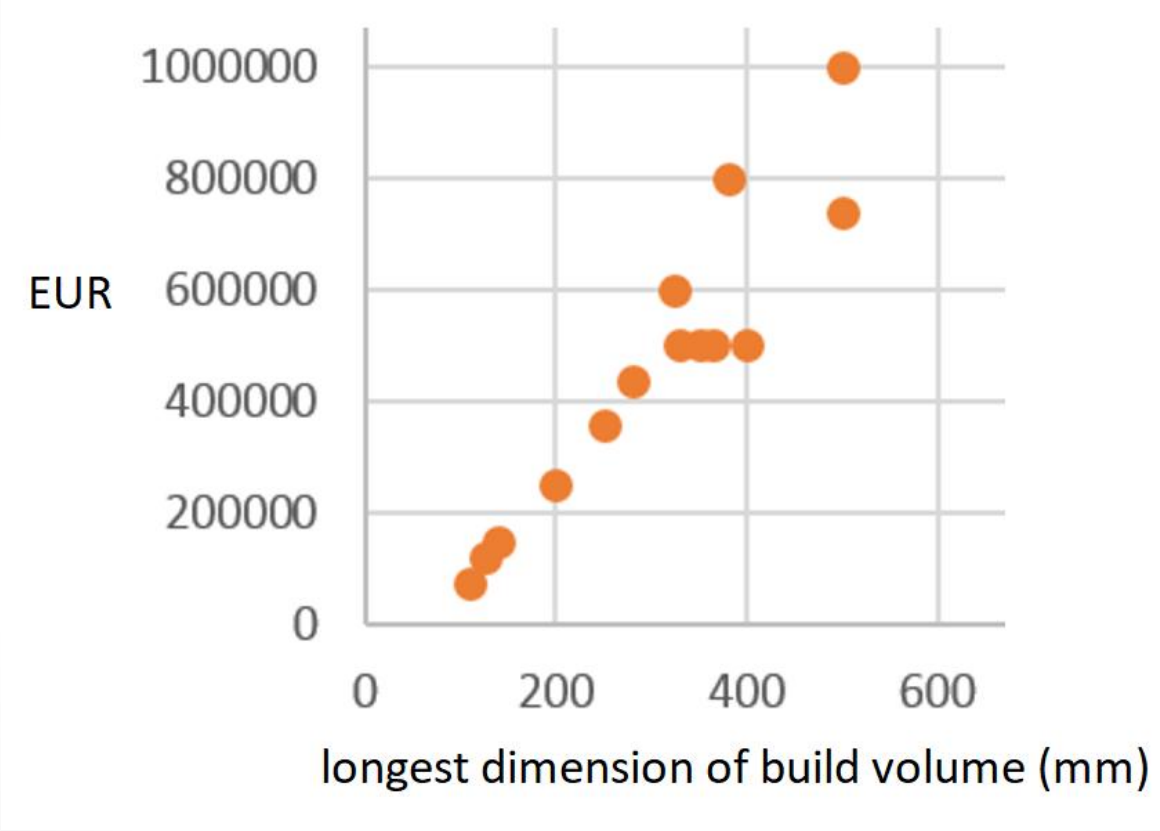
•https://www.renishaw.com/en/am-400--35456

Powder Bed Fusion – Large systems

- Large systems
  - Building volume more than 30 litres
    - Average volume c. 70 litres
  - Average base price c. 1 000 000 €
  - Typically 1-4 pcs of 400-1000 W laser(s)

•https://slm-solutions.com/en/products/machines/slmr800/

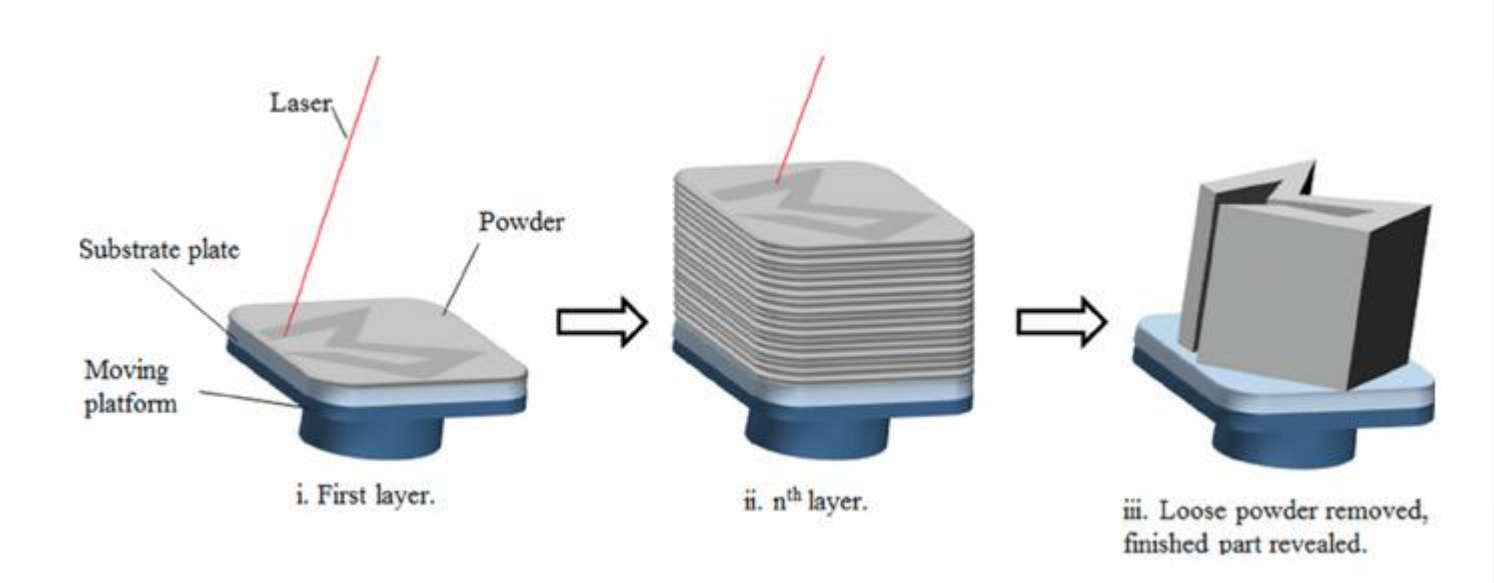
Base prices


1000000
800000
EUR
600000
400000
200000
0
0
200
400
600
longest dimension of build volume (mm)

Material base prices

- **Base** prices
  - Stainless steels ~100 €/kg
  - AlSi10Mg ~80 €/kg
  - Ti6Al4V ~300-500 €/kg
  - Maraging steel 1.2709 ~100-200 €/kg
  - Inconel 718 ~100-250 €/kg

Powder amount



Required equipment - Gas

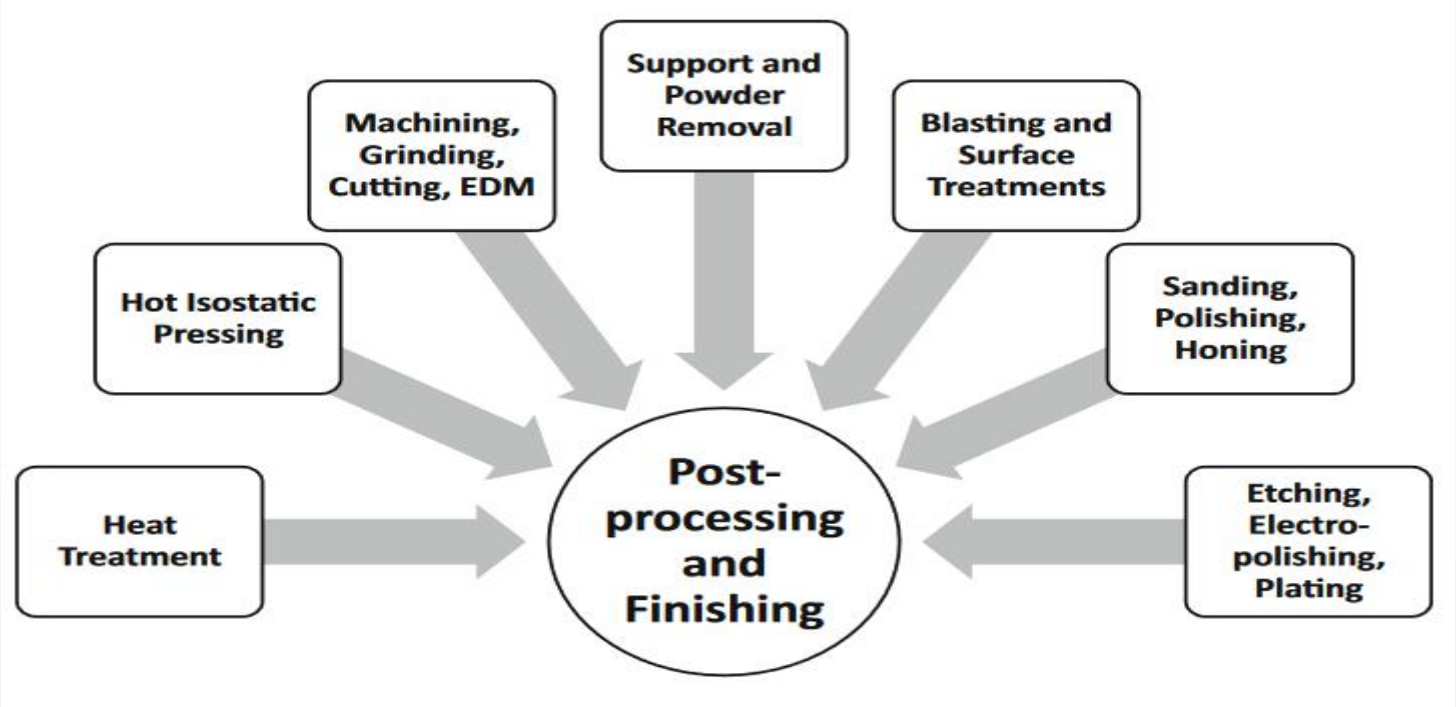
- Gas
  - Ar or N

Required equipment - Powder handling

- Powder handling
  - Refilling
  - Unpacking
  - Sieving

Post-processing phases

- In worst-case scenario almost all treatments below are needed
- €€€€€



Work flow example

- Case example: Aluminum guitar body
- Process: Laser-based powder bed fusion
  - File preparation 2.5 h
  - Machine preparation 2 h
  - Printing 9 h
  - Machine cleaning 2 h
  - Stress relief 3 h
  - Cooling 30 h
  - Removal from building plate 0.25 h
  - Support removal 4 h
  - Surface treatments 4 h

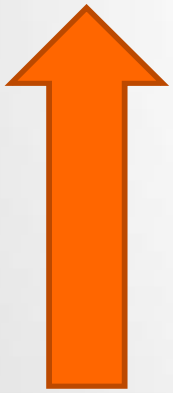
  - -> Printing 9 h, Others ~ 50 h

Property enhancements: Basic heat-treatment

- AlSi10Mg
  - **Casted** part: heat treated to improve mechanical properties
    - T6 cycle of solution annealing
    - Quenching
    - Age hardening
  - In additive manufacturing: as-built condition similar to T6 heat-treated cast parts -> only stress relieving needed
    - 2 hours at 300°C
    - -> tensile strength from 460 MPa to 350 MPa
    - -> yield strength from 240 MPa to 230 MPa

Property enhancements: Basic heat-treatments

- Inconel 718
  - Example heat treatment (AMS 5662)
    1. Solution annealing: at 980°C for 1 hour, air/argon cool
    2. Ageing treatment: at 720°C for 8 hours, furnace cool to 620°C in 2 hours, holding at 620°C for 8 hours, air/argon cool

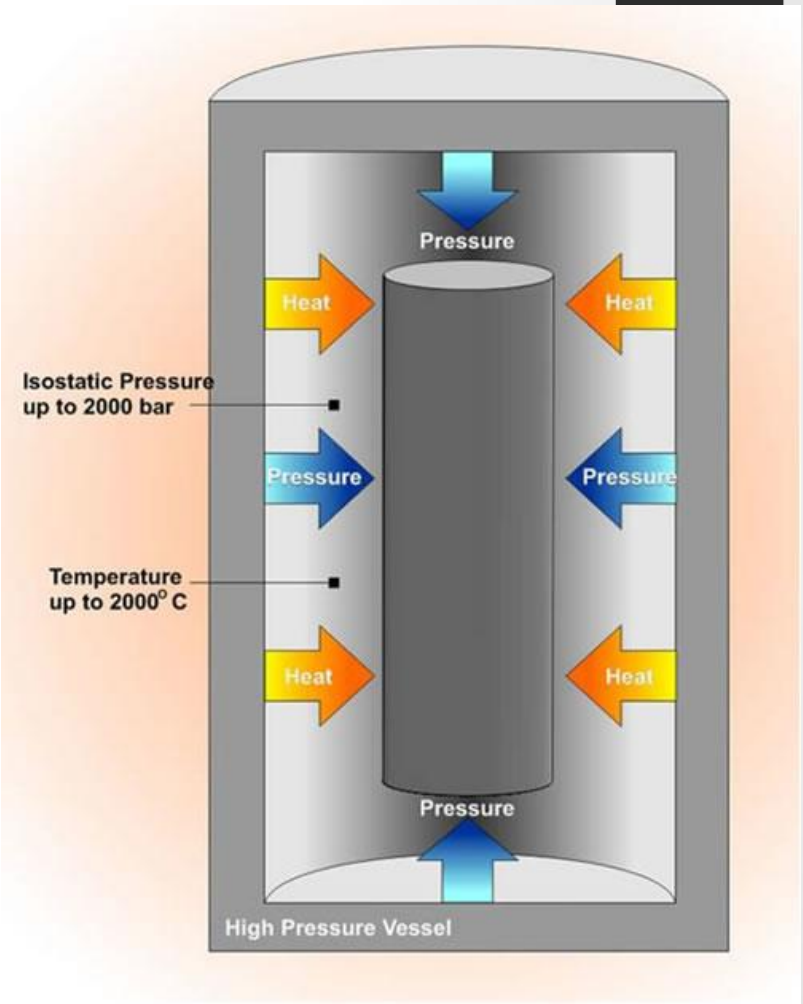


- -> tensile and yield strengths up to 1.5 times higher
- -> hardness from 30 HRC to 47 HRC

ALMOST 20 HOURS + cooling time!

Property enhancements: Hot isostatic pressing (HIP)

- Application of heat and pressure eliminates internal voids
- Reduces porosity
- An inert gas is used as a pressurizing gas, so that the material does not chemically react
  - Ar



Rough costs

- Stress relieving
  - 500 € per batch
- Heat treatments
  - 500-1500 € per batch

Required equipment – Softwares

- Softwares
  - CAD
  - Simulation
  - Build preparing
  - Process monitoring

  - = XXX XXX €

Maintenance/service/consumables

- Filters
- Seals
- Recoater
- Build plate
- ….

www.assemblymag.com & www.3dhubs.com

How much?

- Printing time 45 hours with
- a large system
- Titanium alloy
- 2.9 kg
- Post-processing
- 4 pcs per car

Thank you!

LUT University
Research Group of
Laser Material Processing

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