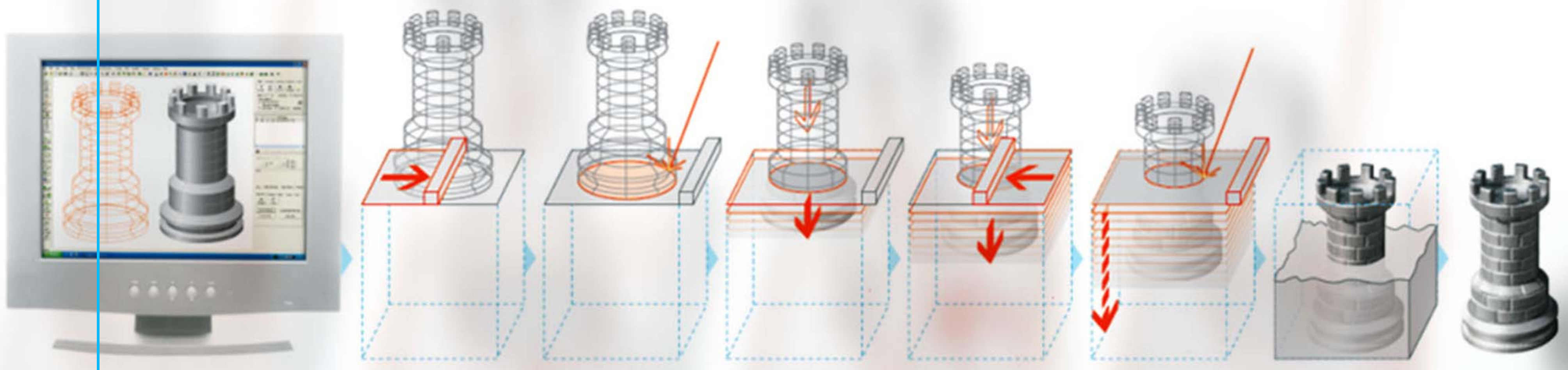


Additive manufacturing

A game changer for the manufacturing industry?

Roland Berger Strategy Consultants

Munich, November 2013

Source: EOS

Roland Berger
Strategy Consultants

Contents

A. Approach and conclusions

Additive manufacturing – A complementary technology on the rise

Roland Berger
Strategy Consultants

Roland Berger
Strategy Consultants

Additive manufacturing (AM) will become a future core technology of the engineered products industry

Rationale, aim and approach of the study

RATIONALE

- AM is on the verge of shifting from a pure rapid prototyping technology to **series production readiness** and is therefore **opening up new market opportunities** for machine suppliers, manufacturing service providers and designers/OEMs
- Manufacturing metal components with virtually no geometric limitations or tools offers **new ways to increase product performance or establish new processes and revenue streams**

AIM

In this study, Roland Berger's Engineered Products and High Tech Competence Center (EPHT) has **summarized the current maturity level** of AM and describes the

- Technological opportunities and limitations
- Market outlook
- Machine supplier and manufacturing service provider landscape
- The future outlook with regard to increased build rates and associated cost reductions

The core focus is on metal components and laser AM for the engineered products industry

APPROACH

- We **interviewed experts** from AM machine suppliers, manufacturing service providers, engineering consultancies, public research institutions, corporate R&D and manufacturing departments and powder suppliers
- We simulated the **cost impact of technological improvements** (basically the build rate) and powder price reduction in a cost model and discussed it with experts in order to provide an outlook for the cost development/ competitiveness of this new manufacturing technology

Roland Berger
Strategy Consultants

Additive manufacturing (AM) will have significant impact on product lifecycle performance – Costs expected to fall in the coming years

Conclusion

The market for systems, service and materials for AM currently totals EUR 1.7 bn (2012) and is expected to quadruple over the next 10 years.

The ability to manufacture metal objects without virtually no limitations on geometry and without tools offers the opportunity to create new products that help boost product performance (e.g. tool inserts with cooling channels or highly efficient injection nozzles) or manufacture batch sizes consisting of just one item (e.g. medical applications, design objects) using special highly resistant alloys.

With about 1% of the machine tools market, the share of AM is relatively small. The supplier base for AM machines is dominated by German suppliers. In addition, an infrastructure of engineering and AM service providers has developed close to technological leaders in aerospace, turbine development and motorsports production.

In certain areas, the technology has already achieved manufacturing readiness (e.g. dental or design objects), whereas in the aerospace and turbine industry, process development and complex field testing are ongoing. The potential of AM in these industries is extremely high, which means that AM is on the agenda of every CTO.

The costs of this technology are significantly higher than for conventional production, so it can be only justified by special benefits in the lifecycle or tooling costs. A detailed analysis of the current manufacturing cost and evaluation of expected improvements reveals a cost reduction potential of about 60% in the next 5 years and another 30% within the next 10 years. These reductions will significantly boost the market for metal AM.

B. Introduction to additive manufacturing

Technology – Applications – Benefits and challenges

Roland Berger
Strategy Consultants

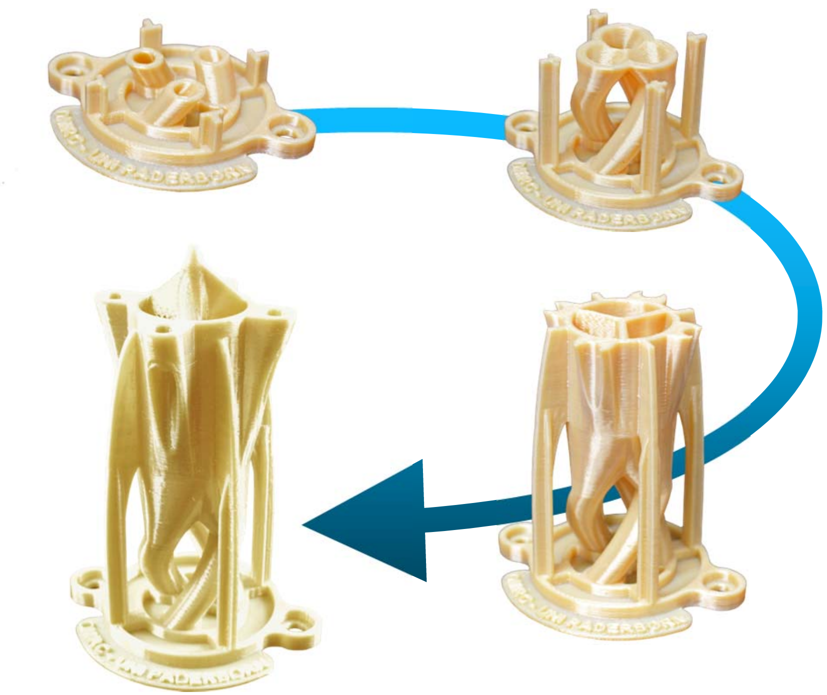
Source: SLM Solutions

Roland Berger Strategy Consultants

Using additive manufacturing technology, three-dimensional solid objects of virtually any shape can be made from a digital model

Definition

- Additive manufacturing (AM) is a **process of making a three-dimensional solid object of** virtually **any shape** from a digital model
- AM uses an **additive process**, where materials are applied in successive layers
- AM **is distinguished from traditional** subtractive **machining techniques** that rely on the removal of material by methods such as cutting or milling
- AM has a 26-year history for plastic objects – **the capacity to make metal objects** relevant to the engineered products and high tech industries **has been around since 1995.** The study therefore focuses on metal AM technologies



Source: Direct Manufacturing Research Center (DMRC)

Additive manufacturing is a step up from rapid prototyping – Manufacturing readiness level differs by application

Origin and manufacturing readiness

ORIGIN

> AM was **invented for creation of prototypes** (rapid prototyping)

> First commercial **plastic AM system dates back to 1987**

> First commercial **metal AM system was introduced in 1995**

> **System users**, not system manufacturers, **started using AM for direct manufacturing of parts**

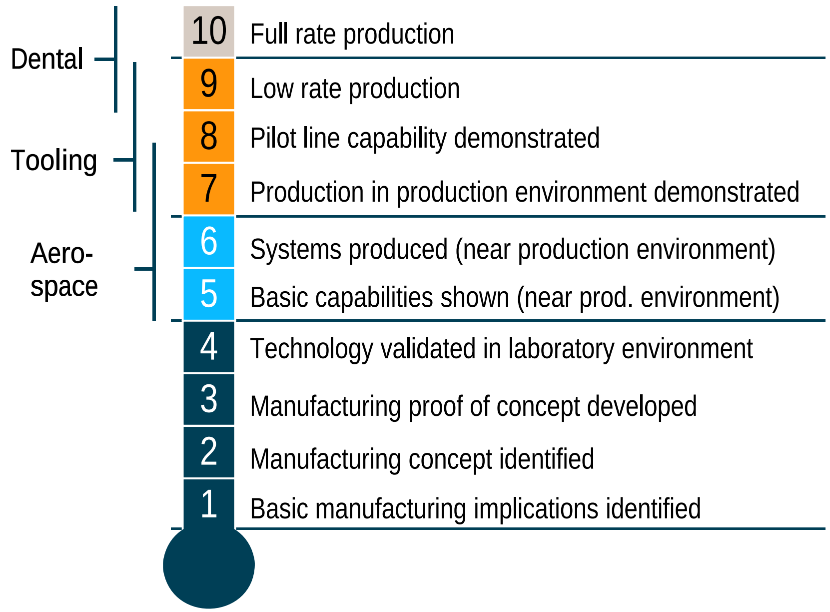
MANUFACTURING READINESS

> Starting from prototypes, today's AM systems are not designed for series production

> Process speed, material costs and process control have not been an issue for prototyping

> AM needs to show that it can manufacture parts economically, in volume and with constant quality for several applications

Manufacturing readiness level



Source: Roland Berger

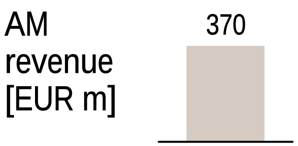
Roland Berger
Strategy Consultants

As of today, AM applications have been developed in various industries – AM usually has only a marginal share of manufacturing

Typical applications per industry segment

CONSUMER PROD./ELECTRONICS

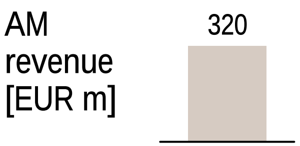
Source: Kuhn-Stoff



> Production of tools and manufacturing equipment such as grippers
> Production of embedded electronics, e.g. RFID devices

AUTOMOTIVE

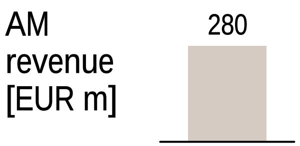
Source: Rennteam Uni Stuttgart



> Primarily used for rapid prototyping esp. for visual aids and presentation models
> Production of special components for motorsports sector, e.g. cooling ducts

MEDICAL/DENTAL

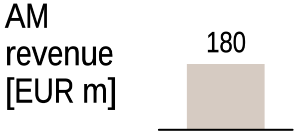
Source: SLM Solutions



> Production of dental bridges, copings, crowns, caps and invisible braces
> Customized prosthetics such as head implants

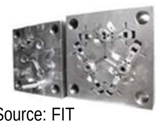
AEROSPACE

Source: Morris Techn. Inc.

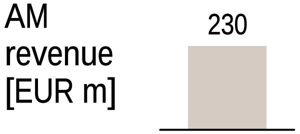


> Production of lightweight parts with complex geometry, e.g. fuel nozzles
> Stationary turbine components
> Reworking of burners (stat. turbine)

TOOLS/MOLDS



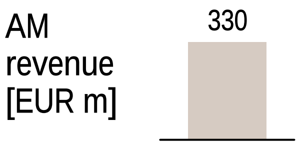
Source: FIT



> High usage for manufacturing inserts and tools/molds with cooling channels
> Direct tooling (tools made via AM) and indirect tooling (patterns made via AM)

OTHER

Source: CPM



> Several other industrial areas such as military, architectural, oil & gas, space
> Consumer markets, e.g. customized design objects, collectibles, jewelry

Source: Wohlers Associates; Expert interviews; Roland Berger

Roland Berger
Strategy Consultants

AM is on the verge of maturity for industrial manufacturing – Huge lifecycle saving potential for aircraft engines

AM in the aircraft engine industry

> Aero engines suppliers have been **exploring metal AM** technology **since 2003**
> For performance testing of AM products, engine suppliers require **high quantities of AM** samples and therefore invest heavily in AM
> Key players have expanded manufacturing capacity recently by procuring new equipment and acquiring suppliers
> For series production, manufacturing capacity needs to be further extended

> Potential volume for new turbine series could be up to several thousand per year
> Key AM components are found multiple times in each engine, e.g. injection nozzles, resulting in a production of tens of thousands of single components per year

> New generation of turbines is expected to be launched within the next 3 years, so the manufacturing infrastructure needs to be established in time
> AM fuel nozzles offer great potential as they are lighter and enable a reduction in fuel consumption and CO_2 emissions

Source: press research; Roland Berger

Roland Berger Strategy Consultants

Additive manufacturing enables weight reduction by optimizing design structure

AM benefits: Weight reduction

TRADITIONAL DESIGN

Source: SAVING project

- A conventional steel buckle weights 155 g[1)]
- Weight should be reduced on a like-for-like basis within the SAVING project
- Project partners are Plunkett Associates, Crucible Industrial Design, EOS, 3T PRD, Simpleware, Delcam, University of Exeter

AM OPTIMIZED DESIGN

Source: SAVING project

- Titanium buckle designed with AM weighs 70 g – reduction of 55%
- For an Airbus 380 with all economy seating (853 seats), this would mean a reduction of 72.5 kg
- Over the airplane's lifetime, 3.3 million liters of fuel or approx. EUR 2 m could be saved, assuming a saving of 45,000 liters per kg and airplane lifetime

1) 120 g when made of aluminum

Source: SAVING project/Crucible Industrial Design Ltd.; Roland Berger

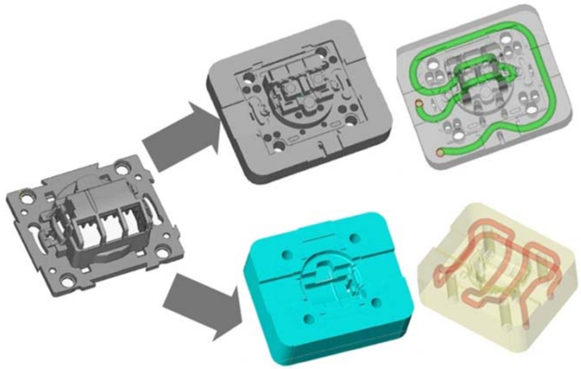
Roland Berger Strategy Consultants

Using AM, geometrically complex shapes with increased functional performance can be manufactured at virtually no additional cost

AM benefits: Complexity for free

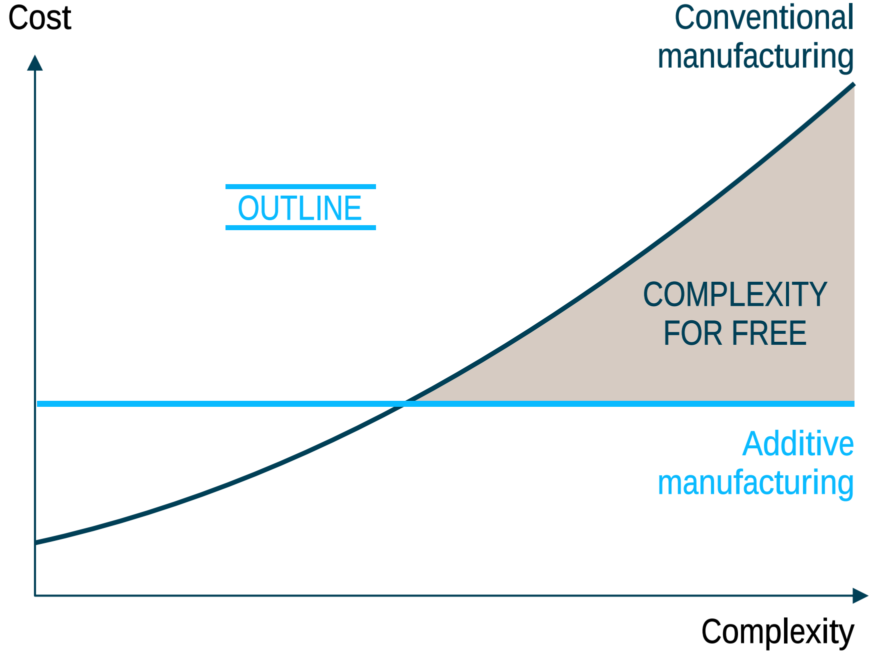
AM ENABLES NEW GEOMETRIC SHAPES ...

Source: PEP



> AM enables the manufacturing of new geometric shapes that are not possible with conventional methods

> Example: AM makes it possible to design advanced cooling channels that cool tools/ components better and therefore reduce cycle time



... AT NO ADDITIONAL COST

Source: Roland Berger

Roland Berger
Strategy Consultants

Additive manufacturing will replace conventional production methods for dental crowns/bridges and customized implants

AM for customized medical products

DENTAL CROWNS/BRIDGES

Source: EOS

- > **AM holds a large share of the dental crowns and bridges market** – Geometry is scanned and processed via CAD/CAM. More than 30 million crowns, copings and bridges have already been made on AM machines over the last 6 years
- > **Increasing market share** – Experts estimate that more than 10,000 copings are produced every day using AM
- > **Faster production** – One AM machine produces up to 450 crowns per day, while a dental technician can make around 40

IMPLANTS

Source: EOS

- > **AM offers advantages with regard to manufacturing time, geometric fit and materials** – Example of a skull implant with modified surface structure
- > **Improved fit via AM** – Based on 3D scans of the skull, the resulting implant fits perfectly into the skull cap, leads to faster recovery and reduces operation time

Additive manufacturing will replace conventional manufacturing methods for customized products

Source: Press research; expert interviews; Oxford Performance Materials, Roland Berger

Several technologies have been developed for additive manufacturing – Powder bed fusion is the leading technology for metal objects

Additive manufacturing technologies

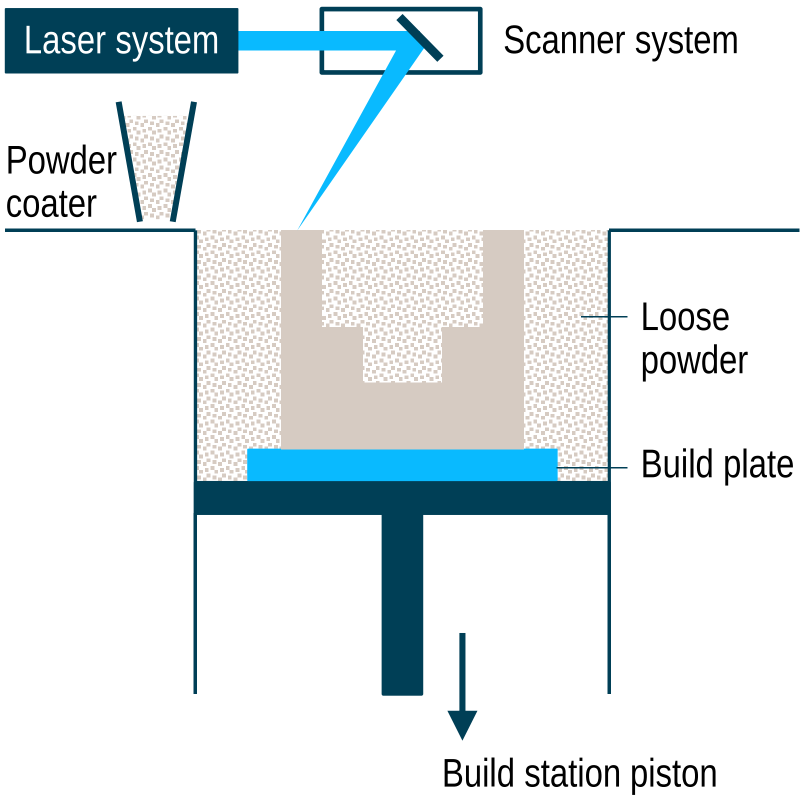
TECHNOLOGY	MATERIALS	TYPICAL MARKETS	RELEVANCE FOR METAL
Powder bed fusion – Thermal energy selectively fuses regions of a powder bed	Metals, polymers	Prototyping, direct part	●
Directed energy deposition – Focused thermal energy is used to fuse materials by melting as the material is deposited	Metals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

Powder bed fusion is the most frequently used technique for printing metal objects

Powder bed fusion (PBF)



PROCESS STEPS AND COMMENTS

> **Powder bed fusion (PBF) is the accepted ASTM**[1] **term** for an additive manufacturing process where a point heat source selectively fuses or melts a region of a powder bed. The process is also known as direct metal laser sintering (DMLS) or selective laser melting (SLM)

> PBF **is the most frequently used technique:**
  - Powder is dispensed
  - Parts are selectively melted via laser
  - Build station is lowered and new powder is dispensed

> **PBF systems use** either **a laser beam** (very often) or an electron beam (rarely) **to melt regions of a powder bed**

> Electron beam PBF enables higher build rates, but surface quality and choice of materials are more limited

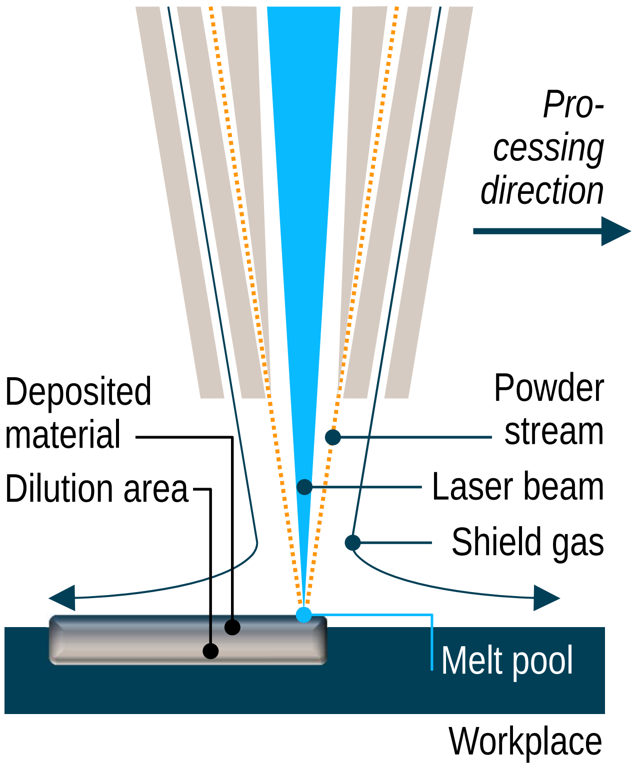
1) American Society for Testing and Materials (ASTM), www.astm.org

Source: Roland Berger

Roland Berger Strategy Consultants

Directed energy deposition for metal AM is less widespread, primarily due to lower accuracy and required post-processing

Directed energy deposition (DED)



PROCESS STEPS AND COMMENTS

> **Directed energy deposition (DED) processes are used primarily to add features to an existing structure** (such as adding strengthening ribs to a plate) **or to repair damaged or worn parts**

> DED production process
  – Melt pool is formed on a metallic substrate with a laser beam
  – Powder is fed into melt pool
  – Powder melts to form a deposit that is fusion-bonded to the substrate

> **Most systems use a 4- or 5-axis motor system** or a robotic arm to position the deposition head, so the process is not limited to successive horizontal layers

> **Less freedom of design** compared to PBF process

> **Post-deposition heat treatment may be required**

> **Final machining is required to achieve the right geometric tolerance**

Source: Roland Berger

Roland Berger Strategy Consultants

Laser powder bed fusion is the dominant technology for metal AM due to higher accuracy, surface quality and freedom of design

Comparison of powder bed fusion and directed energy deposition

CRITERIA	LASER POWDER BED FUSION	DIRECTED ENERGY DEPOSITION
Build speed	5-20 cm^3/h (~40-160 g/h)	Up to 0.5 kg/h (~70 cm^3/h)
Accuracy	+/- 0.02-0.05 mm/25 mm	+/- 0.125-0.25 mm/25 mm
Detail capability	0.04-0.2 mm	0.5-1.0 mm
Surface quality	Ra 4-10 µm	Ra 7-20 µm
Max. part size	500 mm x 280 mm x 325 mm	2,000 mm x 1,500 mm x 750 mm
Avg. system price	EUR 450,000-600,000	EUR 500,000-800,000
FOCUS AREA	> Rapid prototyping > Direct manufacturing of parts	> Repair of worn components > Modification of tooling for re-use
INSTALLED SYSTEMS	~990	~90
	FOCUS OF STUDY	

Source: AM system manufacturers; expert interviews; press research; Roland Berger

AM has several advantages, with freedom of shape being the most important one, but also several drawbacks, esp. slow build rates

Advantages and disadvantages

ADVANTAGES

> **Freedom of design** – AM can produce an object of virtually any shape, even those not producible today

> **Complexity for free** – Increasing object complexity will increase production costs only marginally

> **Potential elimination of tooling** – Direct production possible without costly and time-consuming tooling

> **Lightweight design** – AM enables weight reduction via topological optimization (e.g. with FEA[1)])

> **Part consolidation** – Reducing assembly requirements by consolidating parts into a single component; even complete assemblies with moving parts possible

> **Elimination of production steps** – Even complex objects will be manufactured in one process step

DISADVANTAGES

> **Slow build rates** – Various inefficiencies in the process resulting from prototyping heritage

> **High production costs** – Resulting from slow build rate and high cost of metal powder

> **Considerable effort required for application design and for setting process parameters** – Complex set of around 180 material, process and other parameters

> **Manufacturing process** – Component anisotropy, surface finish and dimensional accuracy may be inferior, which requires post-processing

> **Discontinuous production process** – Use of non-integrated systems prevents economies of scale

> **Limited component size** – Size of producible component is limited by chamber size

1) Finite Elements Analysis

Source: Roland Berger

C. Additive manufacturing market outlook
Value chain – Market size – Key players – Business models

Roland Berger
Strategy Consultants

Roland Berger
Strategy Consultants

The AM value chain consists of five steps – AM system providers are active in most areas of the value chain

AM value chain

Material	System	Software	Application design	Production
> Mainly: Creation of metal powder > Powder with high purity and a very narrow distribution of the granular size (usually 30µm) > Hard to get from large providers due to small orders > Usually sold by AM system providers	> Usually stand-alone powder bed fusion systems > System providers with low levels of vertical integration, standard components usually made by contract manufacturers > Providers integrate components, opt. system & software	> Differentiation between process control and enhancement software > Process control from system prov. > Add-on software such as automatic support generation, design optimization by specialized companies	> Support for end customers > Can be complex and demanding > Done by system providers, software developers and/or service providers > Not every service provider is able to design applications	> Different production scenarios: – Large OEM – Contract manufacturer/service provider – Specialized part manufacturer > Production is normally not done by AM system providers
Players: > Höganäs > TLS Technik > Sandvik > etc.	Players: > EOS > SLM Solutions > Concept Laser > etc.	Players: > Materialise > netfabb > Within > etc.	Players: > 3T PRD > Material Solutions > EOS > etc.	Players: > 3T PRD > Bego > LayerWise > etc.

COMMENTS

> Fragmented market with several small players in all areas

> Players' sizes limit investment in R&D – No player can be active in all fields

> AM system providers have the greatest range of activities

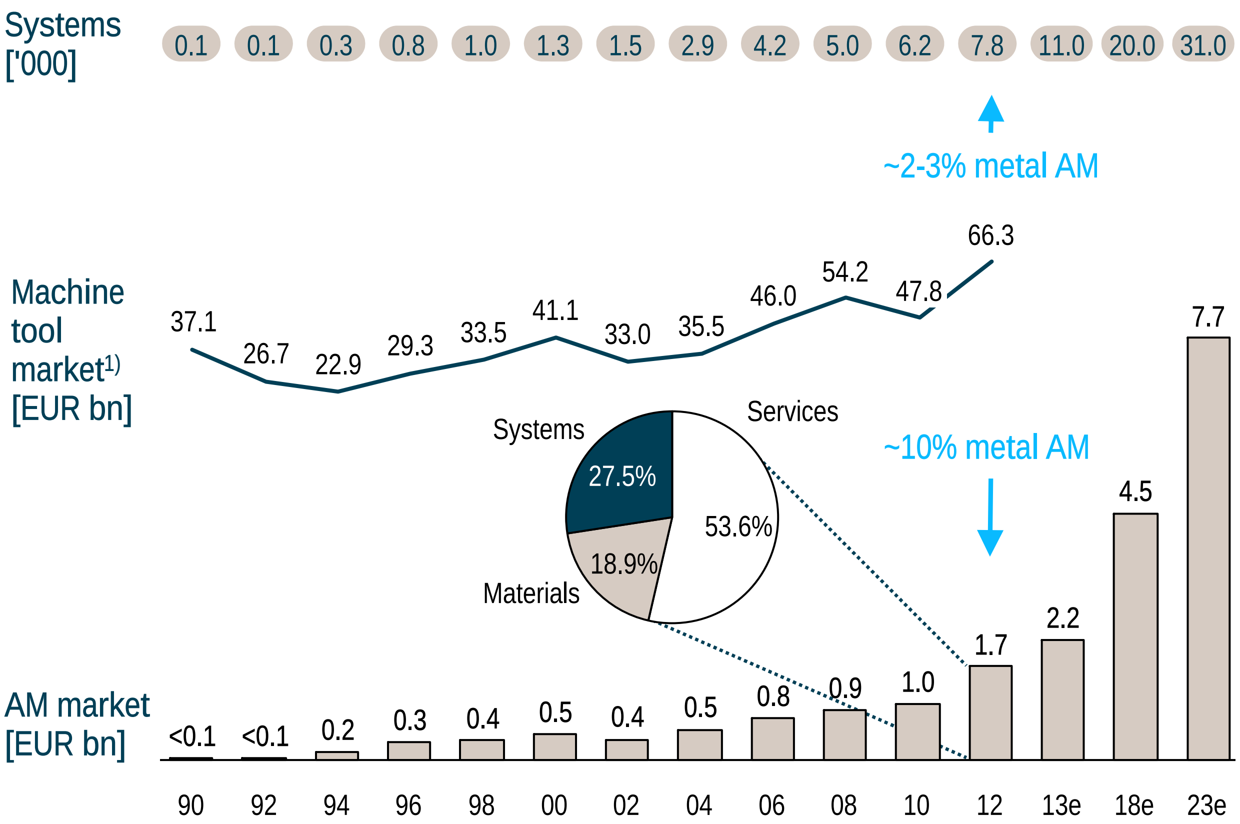
> With growing production volumes, the AM market will become more attractive for large powder producers. This will lower powder prices within the next few years

Source: Expert interviews; Roland Berger

Roland Berger
Strategy Consultants

Despite its strong growth, the AM market remains small compared to the machine tool industry – Metal AM share approximately 10%

Global AM market



1) World machine tool production excl. parts and accessories

COMMENTS

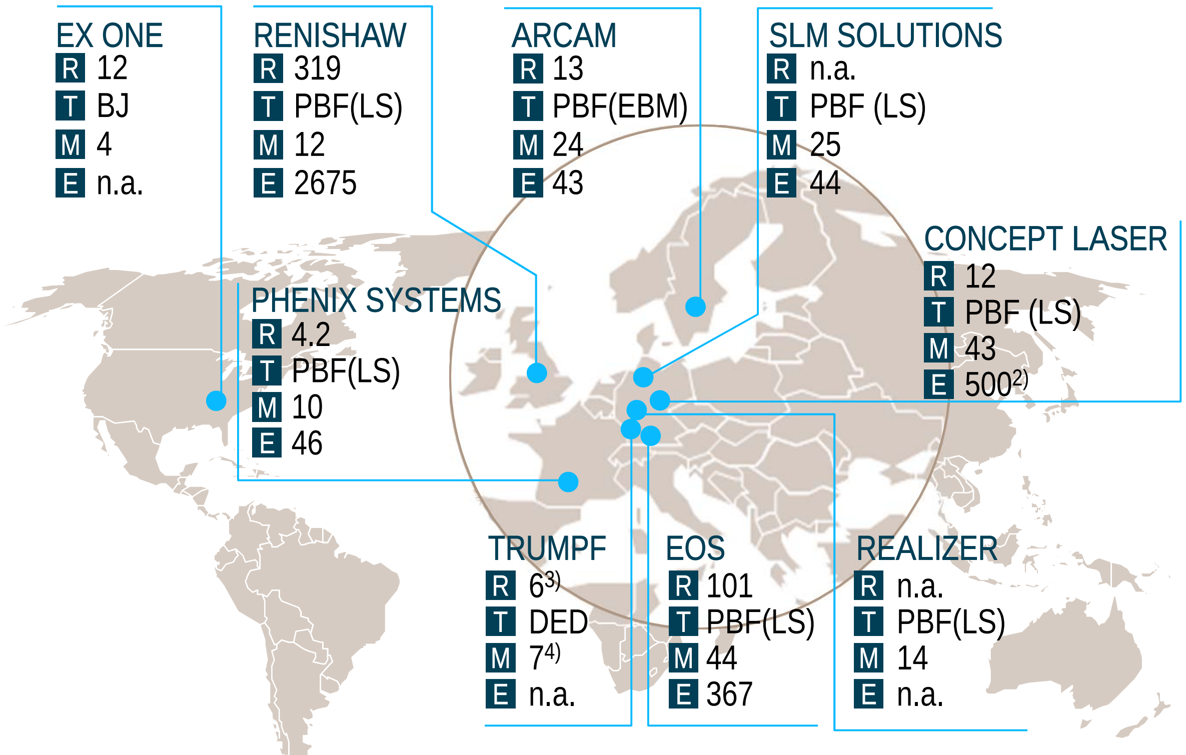
- > Primary **AM market** includes AM systems, materials, services as well as service provider revenues
- > **Commercialization of AM started in 1987** with the SLA-1 stereo-lithography system from 3D Systems
- > Since then, the AM industry has **reached a volume of EUR 1 bn**
- > EOS introduced the **first metal AM system** (EOSINT M250) **in 1995**
- > **AM market will see double-digit growth in the next few years** and volume will double by 2015
- > **Metal AM has higher growth rates than plastic AM**

Source: Wohlers Associates; VDW; expert interviews; Roland Berger

Roland Berger
Strategy Consultants

In 2012, around 190 metal AM systems were sold worldwide, of which 69% were made by the five German manufacturers

Metal AM system manufacturers



1) 2012 2) Hofmann Group incl. Concept Laser in 2012 3) Revenue 2012 for laser deposition segment 4) AM upgrade kits

R Revenue [EUR m] 2011 T Technology M Metal AM systems sold in 2012 E Employees 2011

DED = Directed energy deposition PBF = Powder bed fusion LS = Laser sintering EBM = Electron beam melting BJ = Binder jetting

AM SYSTEM MARKET

- Around 190 metal AM systems were been sold in 2012
- Leading metal AM system manufacturers are located in Germany with a combined market share of 69%
- Recent consolidation (e.g. 3D Systems acquired Phenix Systems, DM3D acquired POM)
- Other small companies include Beijing Longyuan (CHN), DM3D (USA), Fabrisonic (USA), Irepa Laser/BeAM (FRA), Insstek (KOR), Matsuura (JPN), Sciaky (USA), Optomec (USA), Wuhan Binhu Mech. & Elect. (CHN), which sold 2 systems or fewer in 2012

Source: Companies; press research; Bloomberg; Wohlers Associates; Roland Berger

Roland Berger
Strategy Consultants

Today, AM system manufacturers receive recurring and non-recurring revenues from different sources – Mainly system and powder sales

Revenue streams of AM system manufacturers

AM SYSTEM MANU-FACTURERS

SYSTEM

> Standard AM systems
> Customized systems developed for specific needs

SERVICES

> Maintenance contracts
> Spare parts/consumables (e.g. gas, filters, wipers)

LICENSES

> Granting of licenses to competitors

TRAINING AND SEMINARS

> Extended introduction to AM and AM systems
> Seminars/training on AM design, AM production, etc.

POWDER

> Sales of metal powder with high markup
> Readying powders for specific needs

APPLICATION DESIGN

> Consulting on AM readiness
> Support in developing applications

SOFTWARE

> Access to restricted parameter settings
> Add-on software like QM modules, process software

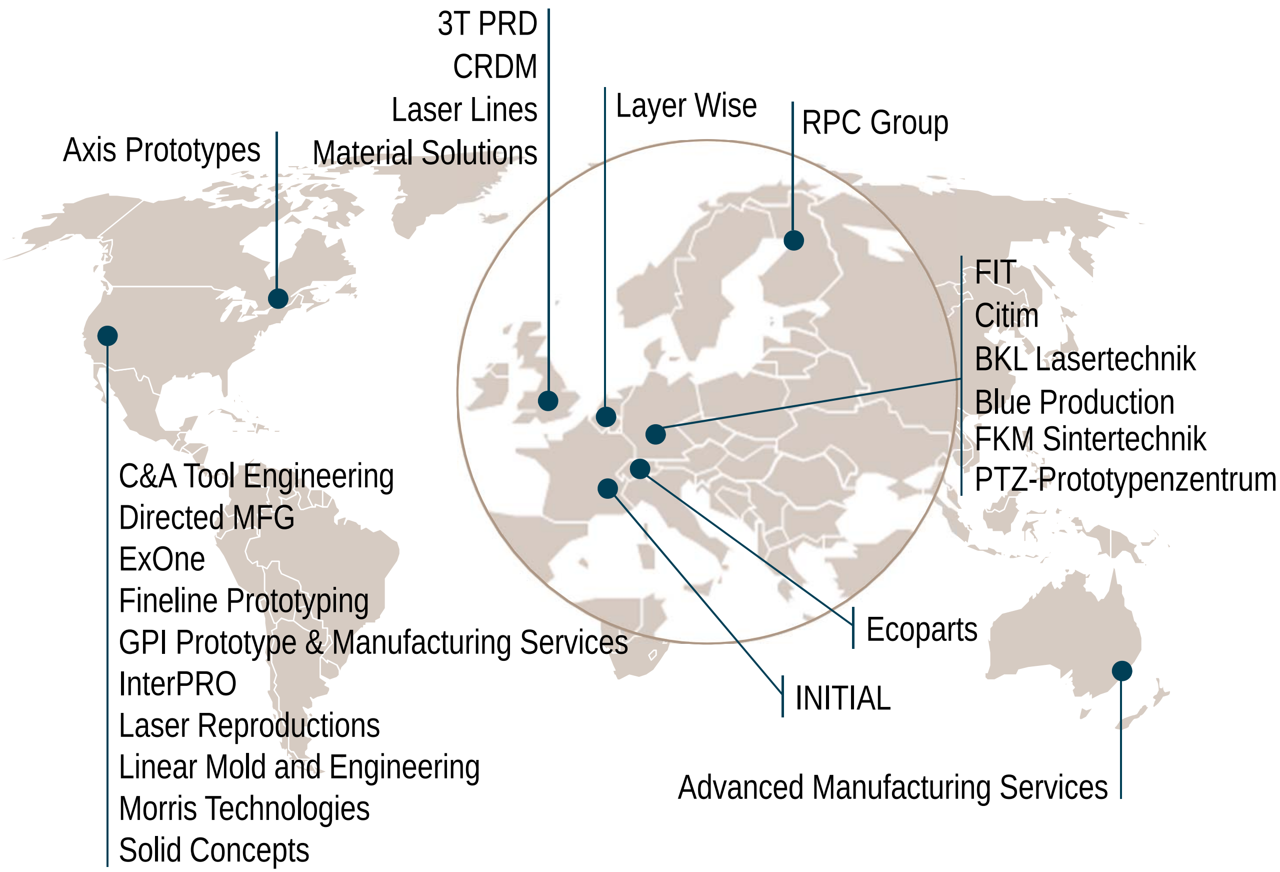
Major revenue stream   Minor revenue stream

Source: Roland Berger

Roland Berger
Strategy Consultants

Many service providers for metal AM contract manufacturing exist worldwide – Most providers are small and have 2-4 metal AM systems

Service providers for metal AM contract manufacturing (selection)



ADDITIONAL INFORMATION

> Worldwide, **more than 90 companies** provide metal AM manufacturing services

> **Most companies are small** (<100 employees) **and independent**

> **A typical service provider has 2-4 metal AM systems**

> Approx. **10% of service providers have advanced capabilities** for designing difficult applications like aerospace components

> Companies have **different backgrounds** and **different business models**

Source: Roland Berger

D. Future potential of additive manufacturing
Series production – Cost competitiveness – New opportunities

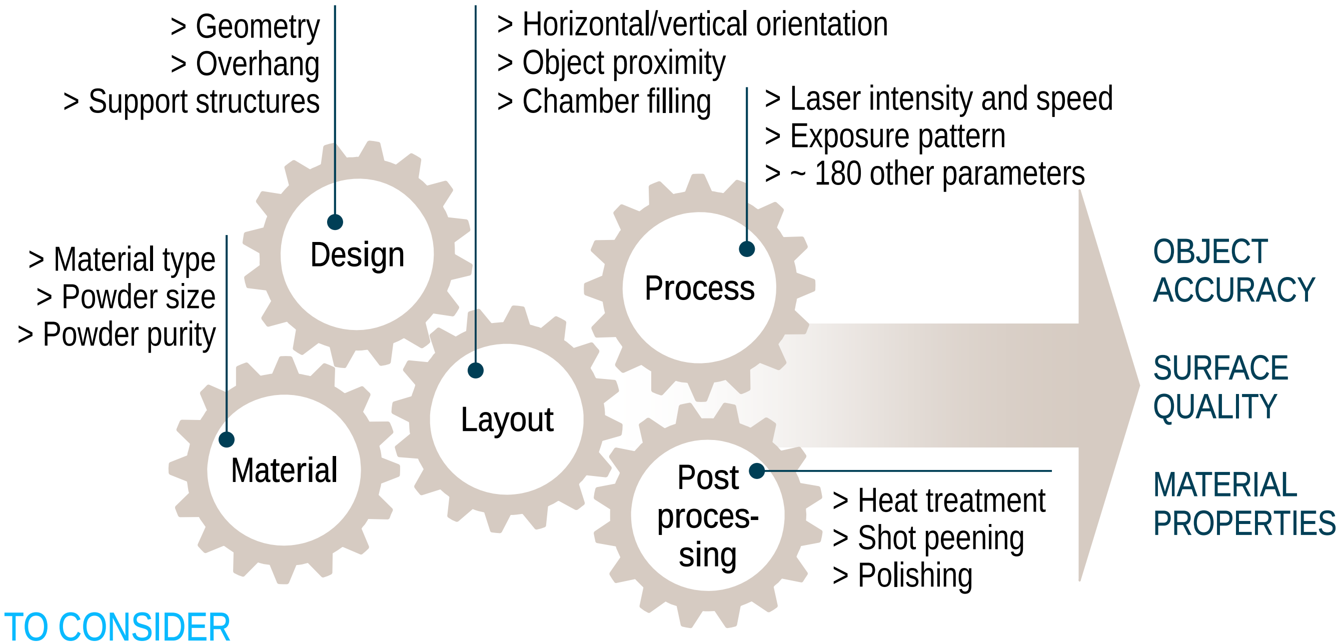
Roland Berger
Strategy Consultants

Roland Berger Strategy Consultants

Currently, the AM process needs to be tailored to specific product requirements in a lengthy development process

Complexity of AM production process

PRODUCTION PARAMETERS AND CHALLENGES (example)



TO CONSIDER

- Tension and curling
- Heat dissipation
- Stair-stepping effect
- Anisotropy in z-axis
- Volume contraction
- Micro melting[1]

IMPLICATIONS

- As of today, there is no complete set of design, layout, material, machine and process rules
- Practitioners need to tailor the production process to each specific object
- Adaptations, such as the use of new material, require up to one year of development time
- More experience needed in the next 5-10 years before new objects can be made with less effort
- Simulation models will shorten development times in the future

1) Change in material properties

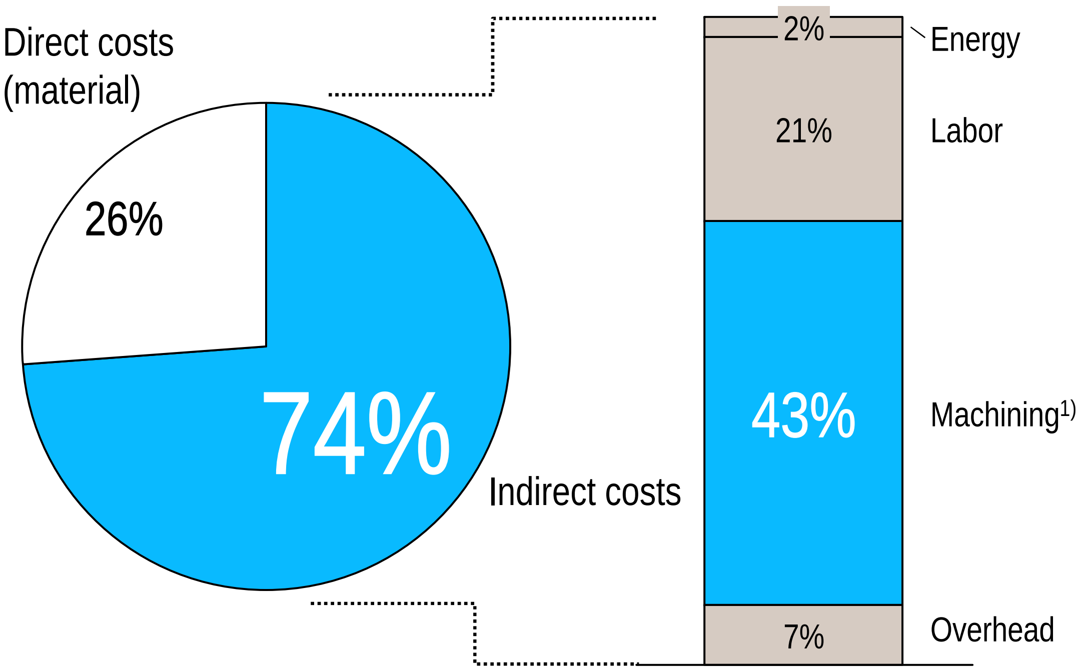
Source: Expert interviews; Roland Berger

Roland Berger
Strategy Consultants

The cost of additive manufacturing is quite high at EUR 3.14/cm³ – Machine accounts for >50% of costs due to low build rates

Current metal AM costs under series production conditions

AM costs of EUR 3.14/cm³



COMMENTS

- Cost estimation assumes **maximum utilization of capacity**
- **Actual costs may differ** – Costs are highly dependent on selected material, object geometry and chamber utilization
- **Only production costs considered** – Product design and CAD file creation plus finishing steps such as heat treatment, shot peening and polishing are not considered

KEY ASSUMPTIONS

> Machine cost:	EUR 500,000
> Operating time:	8 years
> Machine utilization:	83%
> Build rate:	10 cm^3/h
> Material:	Stainless steel
> Powder price[2]:	EUR 89/kg

1) AM system and wire eroding machine incl. depreciation, maintenance, consumables 2) For stainless steel powder

Source: EPSRC; DMRC; expert interviews; Roland Berger

Roland Berger Strategy Consultants

Model parameters are based on published results from research institutes and validated via interviews with market experts

Model parameters for cost estimation

DIRECT COSTS

Cost of 316L stainless steel powder	EUR/kg	89
Cost of energy	ct/kWh	11.70

MACHINE COSTS

AM machine purchase[1)]	EUR '000	500
Maintenance cost p.a.	EUR '000	24
Operating time	years	8
Machine consumables p.a.	EUR '000	3
Wire erosion machine purchase	EUR '000	64

LABOR COSTS

Technician hourly rate	EUR	25
Set-up time per build	h	0.50
Share of monitoring	%	5
Troubleshooting p.a.	h	440
Post-processing per build[2)]	h/kg	1.52

MACHINE PARAMETERS

Machine utilization	%	83
Chamber volume (25.0 x 25.0 x 32.5)	cm^3	20,310
Net utilization of cubic volume[2)]	%	20
Build rates (400W laser)	cm^3/h	10
Energy consumption	MJ/kg	251

ADDITIONAL PARAMETERS

Metal density for 316L	g/cm^3	7.95
Support structure[2)]	%	10

PRODUCTION OVERHEAD

Yearly rent for 28 m^2	EUR	3,640
Administration overhead	%	25

1) Incl. additional AM system-related equipment 2) Depends on application/product

Source: EPSRC; DMRC; expert interviews; Roland Berger

Roland Berger
Strategy Consultants

We expect to see a large increase in build rates and decline in powder prices in the next few years

Future trends for key parameters

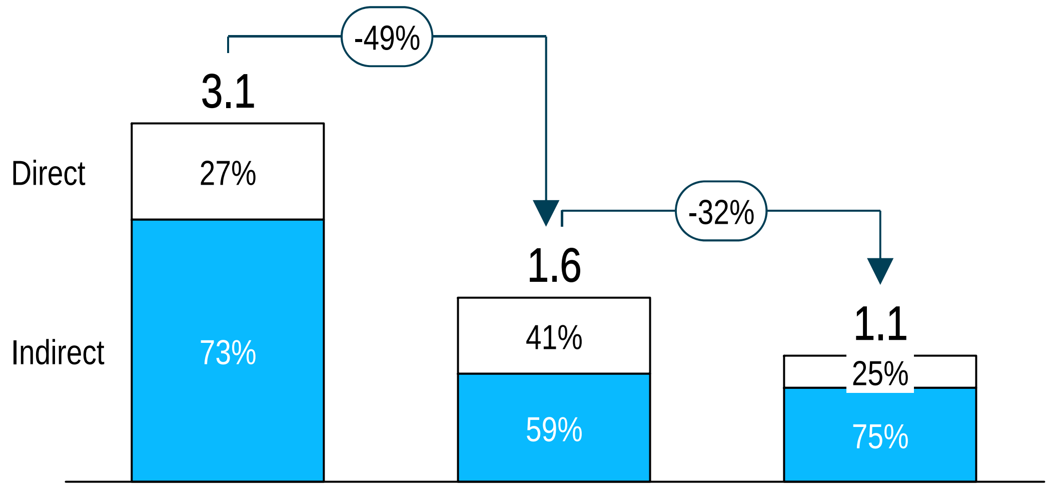
PARAMETERS	TREND	RATIONALES
Build rates	↑	> The application of energy (laser power) per focus point is limited by the process parameters, so the introduction of two and more laser systems (e.g. SLM Solutions) seems the most promising alternative > Optimized layer structure with different layer thicknesses > Process parallelization by simultaneous powder dispensing and laser melting > Optimization of powder dispensing process (e.g. powder dispensing from both directions) > Introduction of two or more chamber systems, continuous production > Increased process stability due to online monitoring systems
Machine prices	→	> Current machine prices seem to be accepted by customers > Increasing addition of process and quality control electronics as well as number of lasers will raise the machine price, partly offset by economies of scales
Powder prices	↘	> Powder prices set by AM system providers do not reflect production costs > With increasing market volume, metal powder producers will sell to end customers directly > Furthermore, production costs for high-quality powder will fall with increasing volume > Total AM material consumption is expected to increase from 900 t to 9,000 t by 2023
Labor costs	↘	> Reliable systems will reduce effort for monitoring and troubleshooting > Introduction of systems with automated removal of excess powder
Chamber volume	↗	> Chamber volumes are currently not perceived as the limiting factor > Problems with process reliability will keep chamber volume increase at a moderate rate

Source: DMRC Think ahead studies; expert interviews; Roland Berger

Roland Berger
Strategy Consultants

Costs can be cut by 50% within the next 5 years if AM system providers can quadruple build rates and improve process stability

Forecast metal AM costs [EUR/cm³]



PREREQUISITES	2013	2018	2023
Build speed	10 cm³/h	40 cm³/h	80 cm³/h
Machine costs	EUR 500,000	EUR 700,000	EUR 800,000
Share of monitoring	5%	2%	0%
Machine utilization	86%	84%	81%
Powder price	EUR 89/kg	EUR 70/kg	EUR 30/kg
Post-processing effort	1.52 h/kg	1.05 h/kg	0.96 h/kg

1) Direct Manufacturing Research Center

COMMENTS

> According to a DMRC survey of 75 AM experts, **build speed will at least quadruple by 2018**

> **Increasing competition for powder supply** will reduce today's markups and **increasing volume will reduce production costs.** Service providers will investigate and develop alternative suppliers to machine OEMs

> Machine utilization is expected to drop slightly due to multiple laser scanners and rising complexity

> **Forecast is based on current market structure** with several small players with low R&D budgets – Entry of larger players with **higher investment budgets may bring down costs even faster**

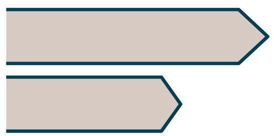
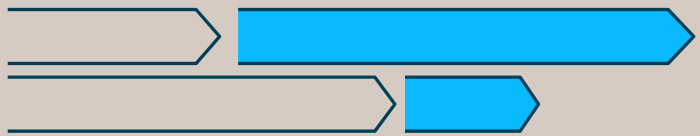
> Increase in build rate is also limited by the part's geometry (e.g. wall thickness)

Source: EPSRC; DMRC; expert interviews; Roland Berger

Roland Berger
Strategy Consultants

Lifecycle cost advantage will be the key benefit of AM for most indus-tries – Only a few will see lower AM production costs

AM cost advantages

	PRODUCTION COST ADVANTAGE	LIFECYCLE COST ADVANTAGE
Cost structure CONV. AM	 Production costs	 Production costs Lifecycle costs
Initial situation	> Complex assembly of several parts > High degree of customization and low volumes > High degree of manual labor or high tooling requirements	> High lifecycle costs compared to production costs > Complex AM manufacturing process > Key components relevant to product performance, e.g. injections systems, burners, etc.
Benefits by AM	> Consistent CAD/CAM process > Elimination of tooling	> New geometrics which enable performance improvement
Examples of industries	> Dental > Prosthetics > Customized design objects	> Molds and dies > Aerospace

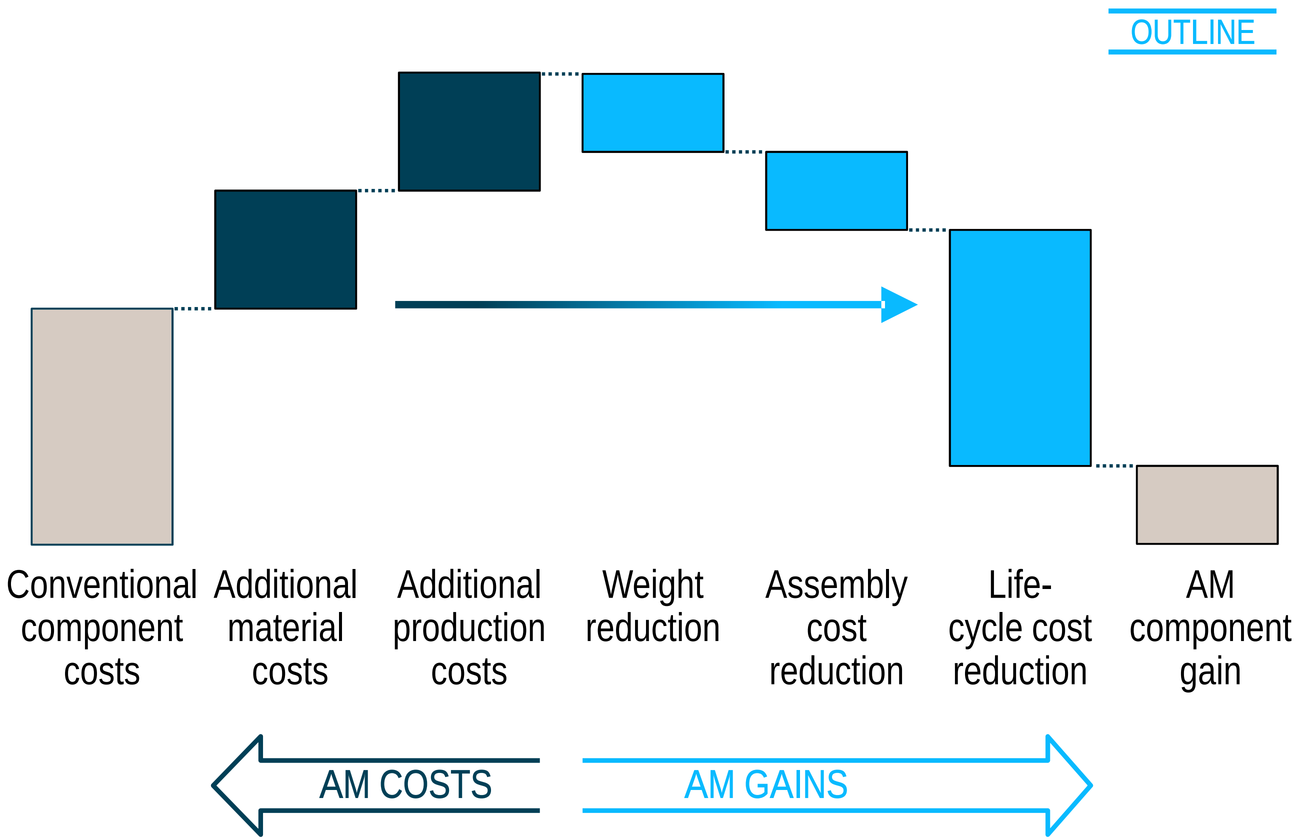
KEY ADVANTAGE FOR MOST INDUSTRIES

Source: Roland Berger

Roland Berger Strategy Consultants

Better product performance is crucial to making AM-manufactured components superior to conventionally manufactured ones

Sources of AM costs and gains



COMMENTS

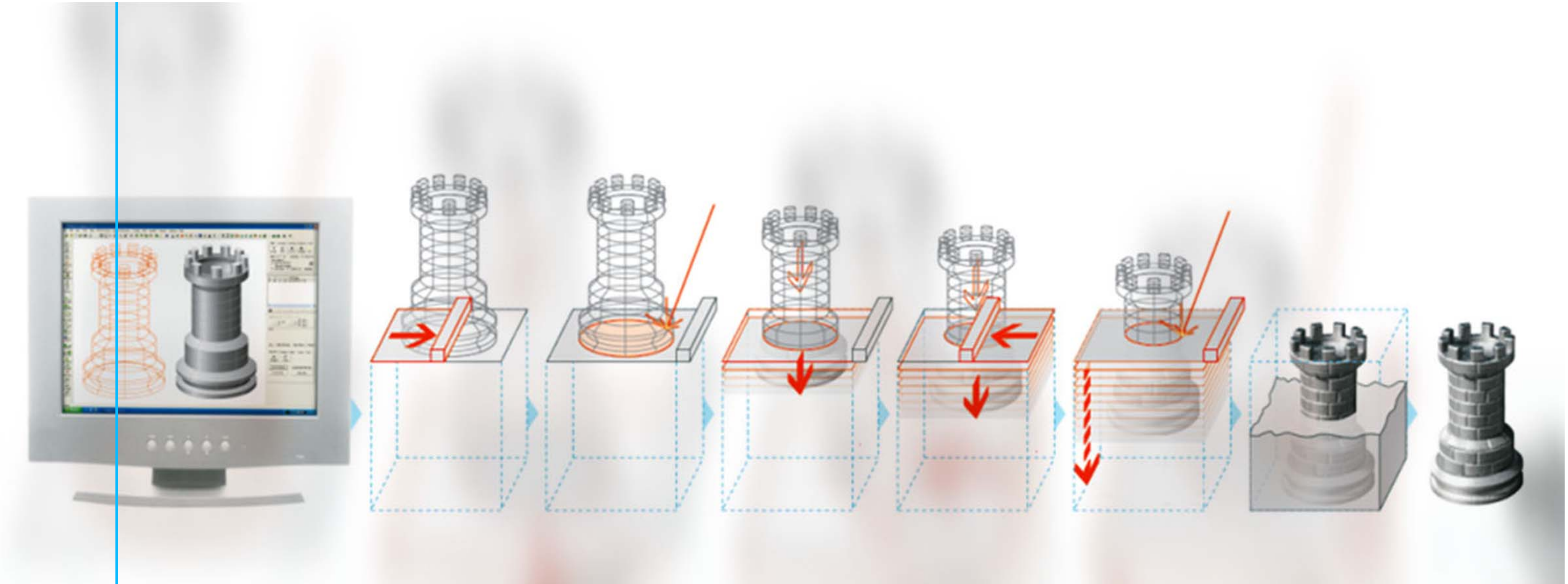
> In most cases, **AM costs will outweigh AM gains from weight reduction and assembly cost reduction**

> Successful AM applications should **aim to improve product performance or product lifecycle cost** by improving key components using AM

> This will usually be done by **applying new geometrics** which are not producible today

> Exceptions are mass customization industries like dental or customized design objects where conventional production is very costly

Source: Roland Berger



Source: EOS

It's character that creates impact

Roland Berger
Strategy Consultants