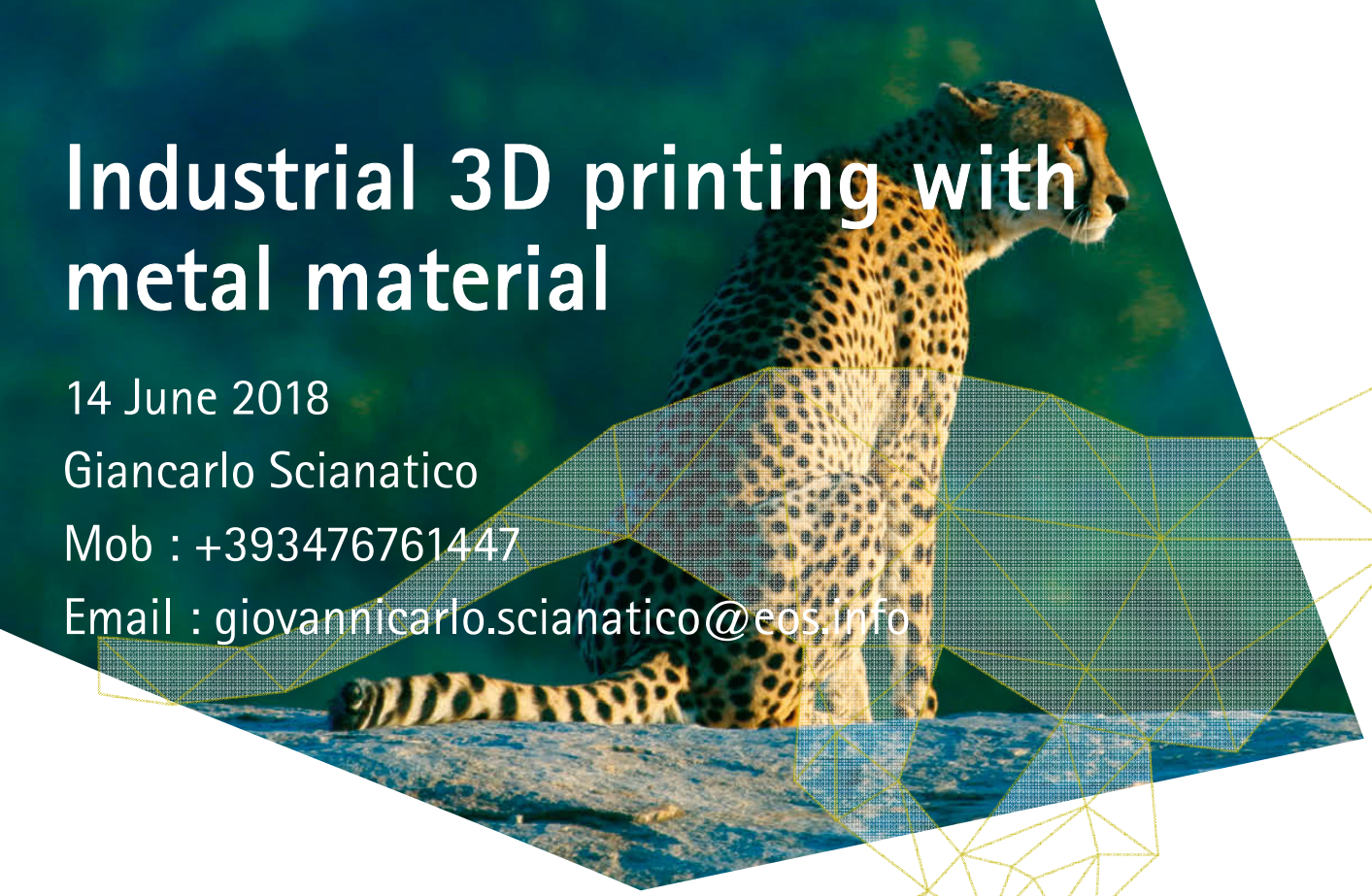

Industrial 3D printing with metal material

14 June 2018

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Email : giovannicarlo.scianatico@eos.info

EOS

Electro Optical Systems

EOS – More than 25 Years of Experience in Additive Manufacturing

EOS – Technology and Market Leader for 3D Printing Solutions

- **EOS** is the **world's leading technology** supplier in the field of **industrial 3D printing** of metals and polymers
- **Family-owned**, founded in 1989
- Headquartered in Krailling near **Munich,** Germany
- **Solution portfolio:** Additive Manufacturing (AM) systems, materials (plastics and metals), software, services and consulting
- Complete **end-to-end solutions:** from part design and data generation to part building and post-processing
- **EOS helps companies leverage competitive advantages in a variety of industries**, such as medical, aerospace, tooling, industry, lifestyle products and automotive

(f.l.t.r.): CEO and Chairman of EOS Group: Dr. Hans J. Langer and the Corporate Management of EOS GmbH : Dr. Adrian Keppler, Dr. Tobias Abeln, Eric Paffrath

EOS is committed to:
Innovation – Quality – Sustainability

EOS: A Growing Company

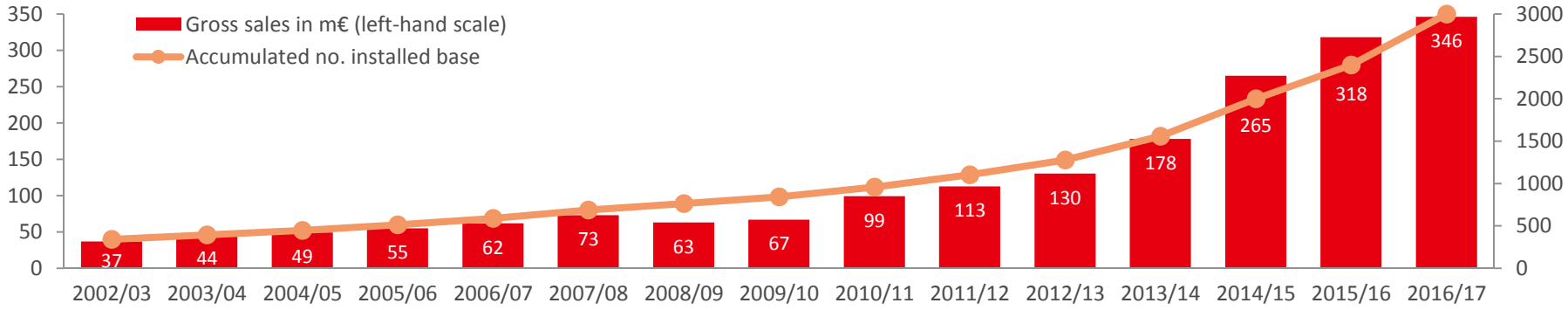
EOS worldwide installed base

3,000 systems

- 49% metal systems
- 51% polymer systems

EOS global footprint

- Customers in 65 countries
- EOS Sales & Service offices in 13 countries, distribution partners in 41 countries
- Some 1,200 employees worldwide (70% Germany, 30% International)
- Strong patent portfolio: more than 750 active and pending patents in more than 175 patent families



Social Impact of Our Business

Contribution to sustainability

- Recycling of residual powder materials → less waste
- Lightweight construction → reduced fuel consumption
- Local "on-demand" production → Less CO_2 emissions

High cost-effectiveness

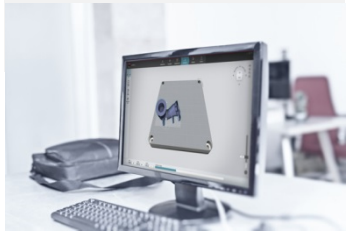
- More efficient production thanks to:
- ✓ Reduced use of resources
- ✓ Fewer subcomponents
- ✓ Lower installation costs
- ✓ Lower stock requirements
- ✓ Faster development times

Advances in medicine

- Individual, customized prostheses / implants → accelerated healing processes
- Faster delivery times of medical aids

Easier market entry

- Economic viability of smaller quantities → Fewer barriers to market entry
- New opportunities and flexibility for entrepreneurs through internet-based technology



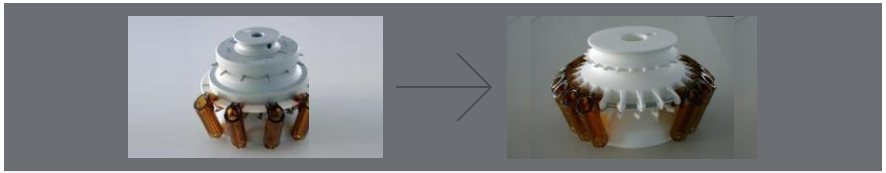
Greater economic growth

- Promotion of economic growth by creation of new jobs
- Transformation of the startup landscape, less initial funding required

Additive Manufacturing Opens Two Roads to Success

1 Eliminating the constraints of conventional manufacturing

- AM eliminates the design constraints of traditional manufacturing by:
  - Reducing part complexity
  - Reducing costs by reducing no. of manufacturing operations, such as post-production tooling

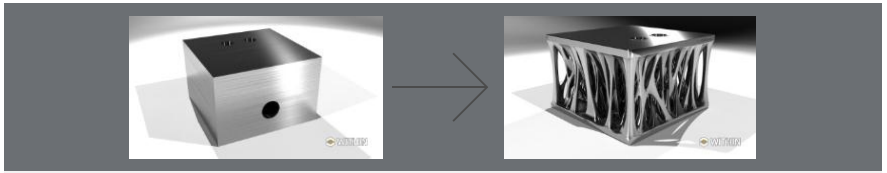


Example: Washing rotor (Hettich)

- From 32 components to 2 laser sintered parts + 1 steel ring
- No tooling necessary
- Functional integration, product customization, production on demand

2 Enabling a completely new design approach

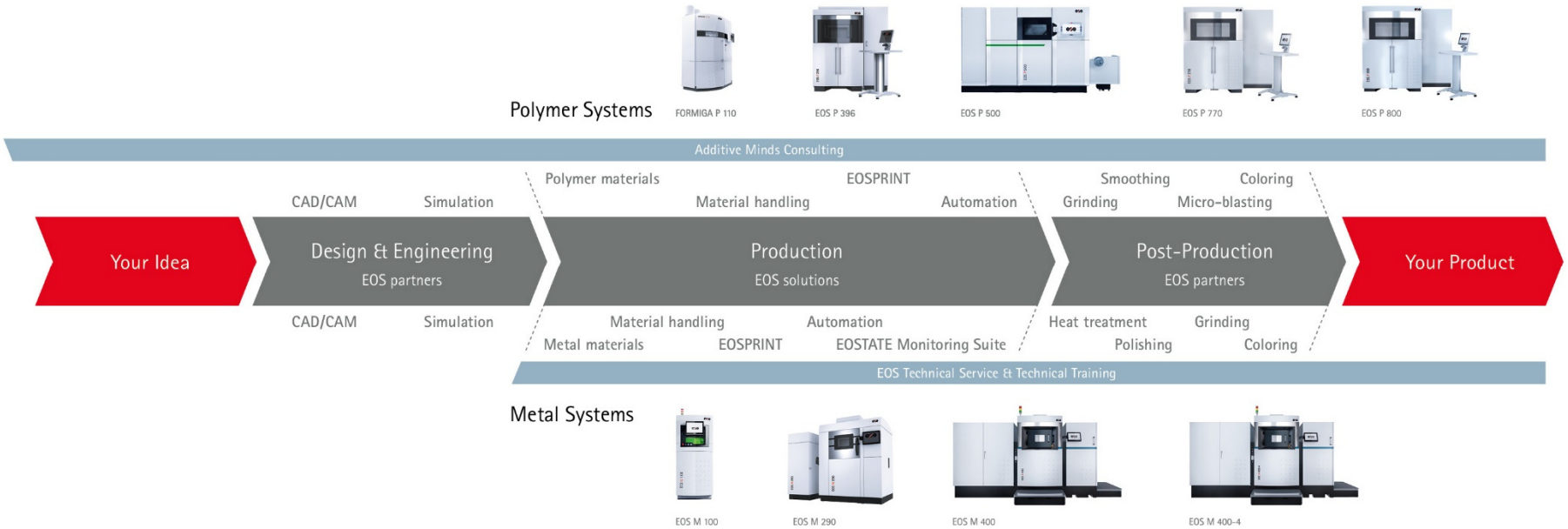
- AM allows designs not previously possible in conventional manufacturing environments
- Enabling completely new solutions, such as
  - Transition from metal to plastic
  - Production of parts that are lightweight, yet functional



Example: Load-bearing engine block (WITHIN Labs)

- New design not possible with conventional methods
- Integrated conformal cooling channels, lightweight design
- Reduced weight and cycle times, increased part quality

From Idea to Product. With EOS.



Industrial Companies Face Similar Challenges – Additive Manufacturing Offers Unique Solutions

Challenges of industrial companies

- Faster **time-to-market** combined with **shorter lifecycle**
- **Productivity increase:** need for cost reduction
- **Flexible production** ("factory around the corner")
- **Innovation** → Increase of customer value-add
- **Customization** of products
- Focus on **sustainability**

Additive manufacturing advantages

Freedom of design
- Lightweight
- Enables highly complex structures

Functional integration
- Embedded functionality without assembly

Customization
- Customer-specific adaptations
- Cost-efficient small series

Increased productivity
- Rapid prototyping and serial applications

Advantages of Additive Manufacturing

Laser sintering offers various advantages over traditional manufacturing processes

Freedom of design

Lightweight

- Static: weight of parts
- Dynamic: moving, accelerated parts

Complex components

- E.g. alternative structures of heat exchangers

Functional integration

Total cost optimization

- Embedded functionality without assembly
- Material efficiency
- No tooling costs

Customization

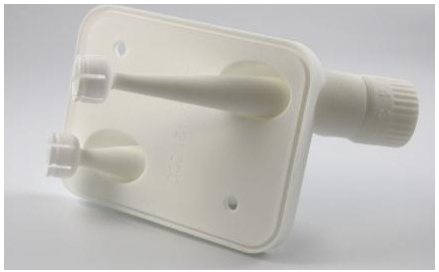
Individualized parts

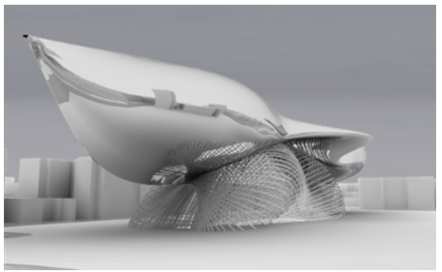
- Customer-specific adaptations
- Cost-efficient small series up to 'lot size one'

Time to market

Rapid prototyping

- Fast feasibility feedback of virtual models
- Haptic feedback





Evolution of Additive Manufacturing

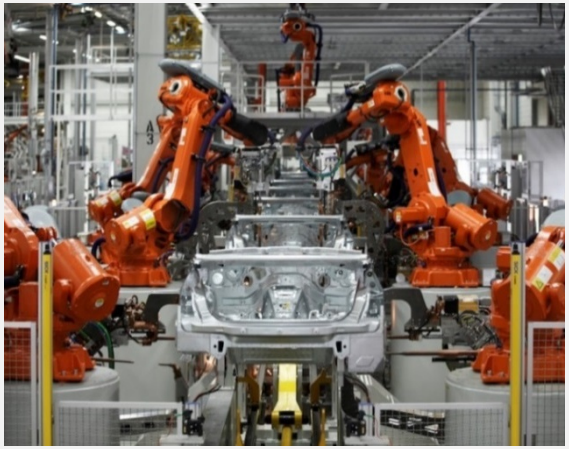
Yesterday:
Prototyping

Technological capabilities

Today:
Pre-production

- Part quality
- Process robustness
- Cost per part

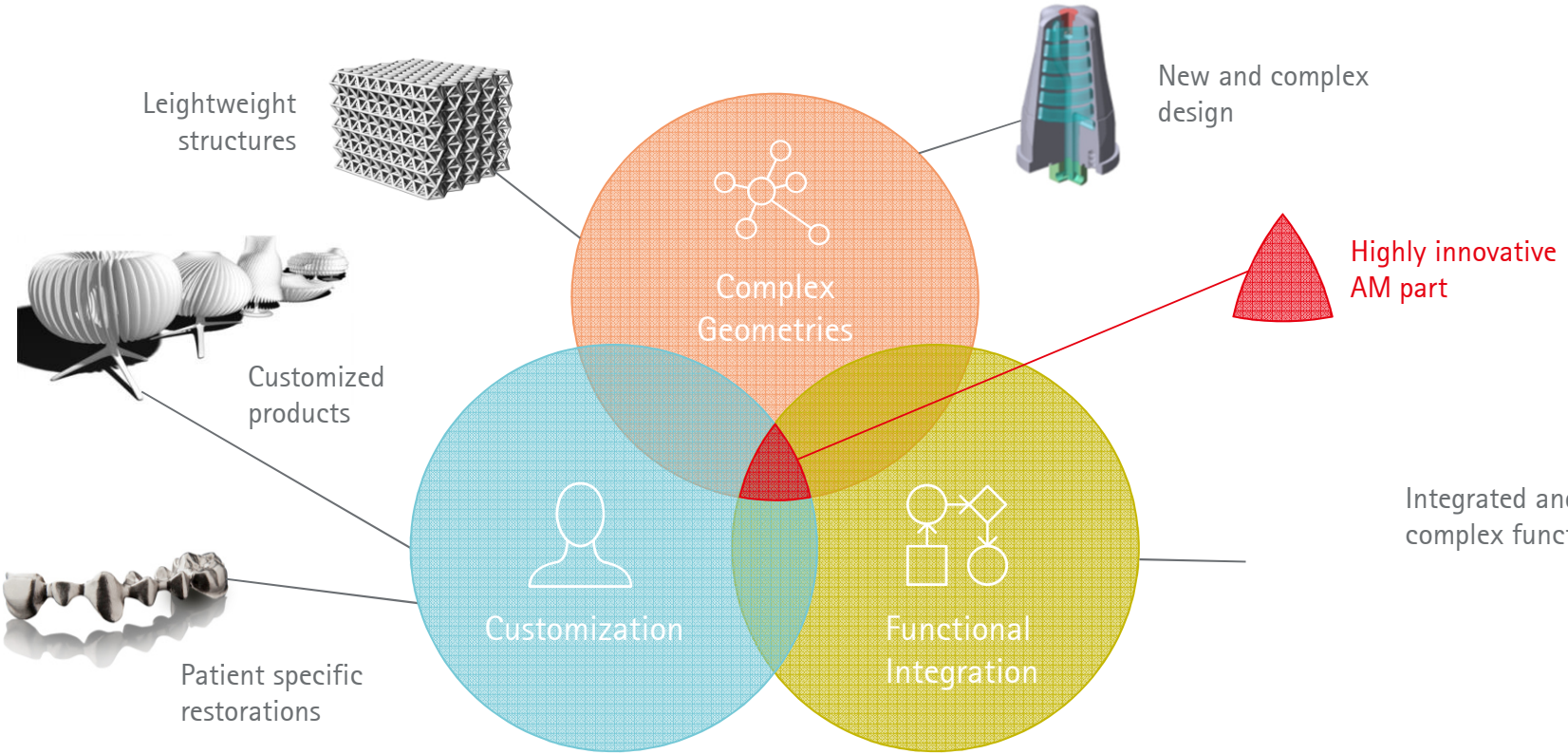
By 2020:
Production ramp-up



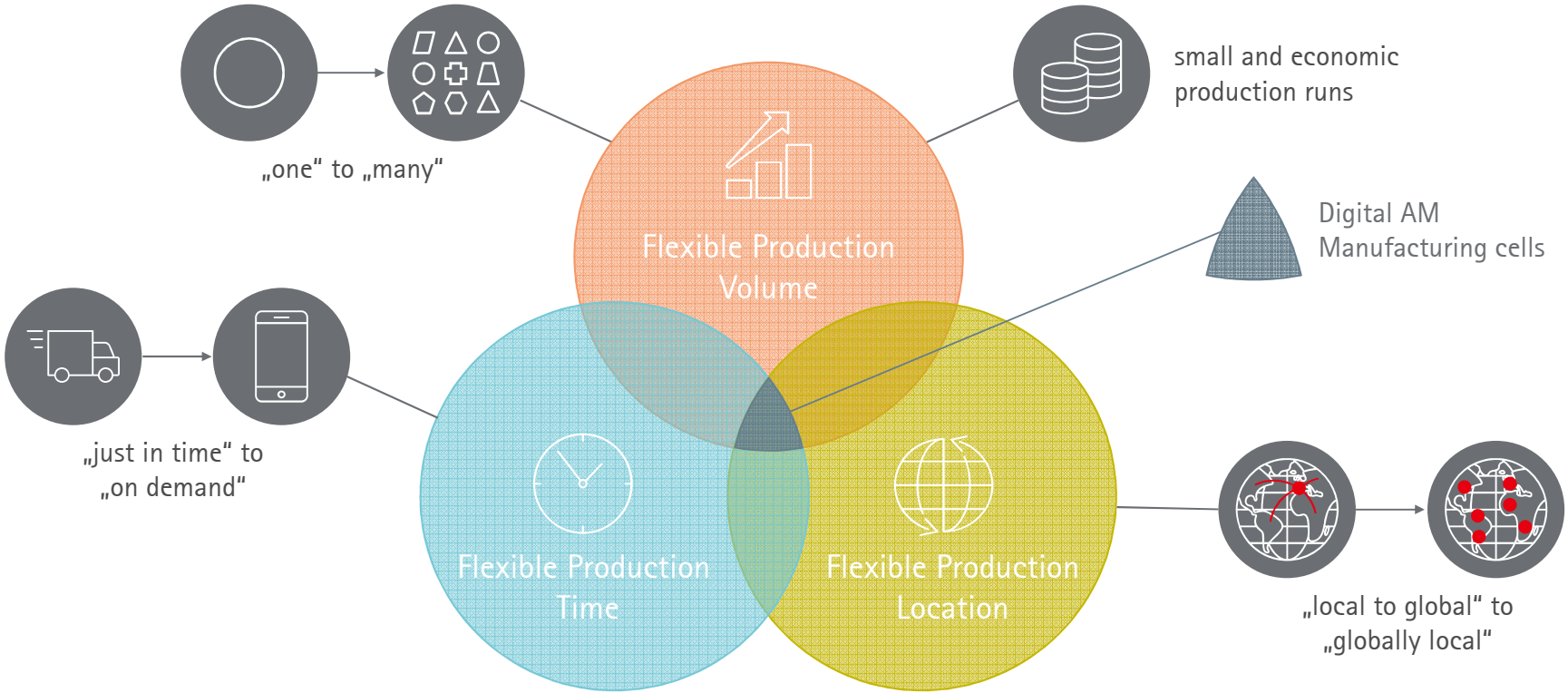
- Quality control
- Differentiation
- Total cost (TCO)
- Automation
- Technology integration

Applications

Characteristics of the Innovative AM part



Characteristics of a highly efficient AM Production Chain

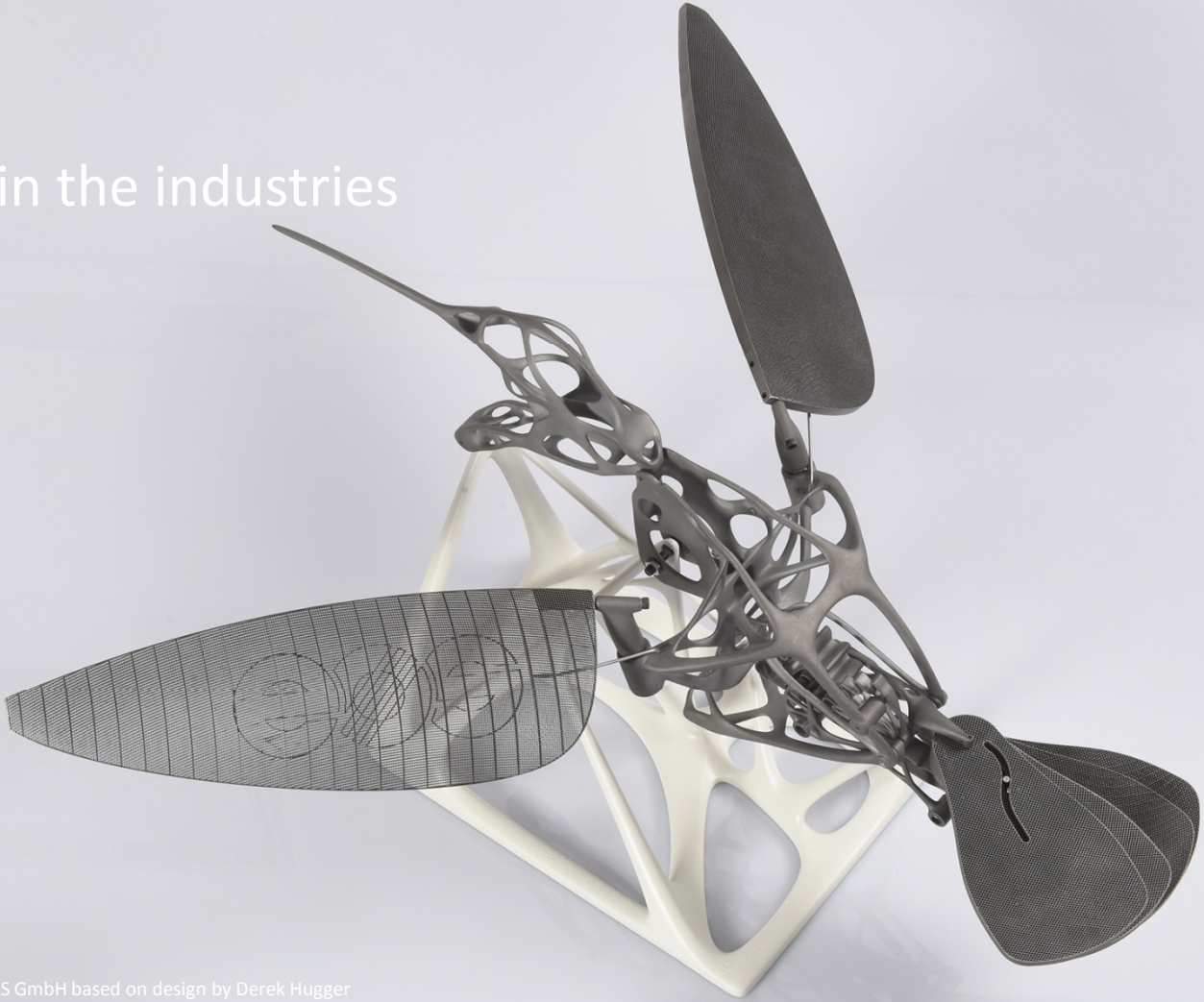


We have the solutions on your key challenges!

Your key benefits:

- → Enable your people faster and better to become the next industry champions
- → Face lack of competence in Additive Manufacturing in your existing organization
- → Gain competitive advantage through Additive Manufacturing
- → Accept economical pressure as a challenge for faster innovation

AM in the industries



Made by EOS GmbH based on design by Derek Hugger

Medical application examples

Dental Applications

Bridge made from EOS CobaltChrome SP2

- **Challenge:** Economic production of patient-specific restorations made of high-performance alloy
- **Solution:** Manufacture of fully dense restorations w/o porosity using EOS M 100

- Fast and cost-efficient manufacturing
- Accuracy of units is +/- 20 microns
- Restorations are durable, high-performing and consistently high quality

Orthopedic Devices

Orthoses, PlusMedica OT

- **Challenge:** Design, CAD engineering and production of orthoses that combine several functions
- **Solution:** Construction of customized orthoses, using PA 11 with EOS P 396

- Complete freedom of design for structures and material thicknesses
- High-quality and precision, inde-pendent of level of craftsmanship
- Each orthoses is bespoke

Implants

Acetabular Cups, WITHIN Labs

- **Challenge:** Production of acetabular cups that pro-motes osseointegration
- **Solution:** EOS DMLS using EOS Titanium Ti64. Design using WITHIN software

- Fully dense sections for stability, lattice structures for better osseointegration
- Both sections produced in a single production step
- Sections merge seamlessly for optimum load absorption

Medical Devices

Hettich wash rotor Rotolavit

- **Challenge:** Simplify production of ROTOLAVIT washing rotor
- **Solution:** Laser sintering on EOSINT P 395 with PA 2200 as series material

- High functional integration
- 3 parts (laser sintered parts plus 1 steel ring) vs. 32 parts
- Significant reduction in finish and assembly requirements

Aerospace application examples

Jet engines

Swirler, Morris Technologies

- **Challenge:** Build a highly complex design (fuel injection systems, vane segments) as “one piece”
- **Solution:** Manufacturing with DMLS using EOS technology and EOS CobaltChrome MP1

- **Optimized:** Improved design, no brazed joins, increased robustness
- **Quick:** Delivery time less than 2 weeks (vs. 6 weeks)
- **Economic:** Significant cost reduction – typically 50% less

Injector heads

Injector head, ArianeGroup

- **Challenge:** Produce an injector head for rocket engines with as few components as possible and lower unit costs
- **Solution:** Additive manufacturing with EOS M 400-4 and functional integration

- **Simplified:** 1 component vs. 248
- **Speedy:** Significant reduction in production time
- **Economic:** 50% lower costs

Hydraulic components

Source: Liebherr

- **Challenge:** Substitute a conventional primary flight control hydraulic component with an additively manufactured part – fulfilling all certification requirements for flight test
- **Solution:** Manufacture of a lightweight 3D-printed component with fewer parts using an EOS M 290 and an efficient process chain

- **Optimized:** 35% less weight
- **Simplified:** 10 parts eliminated
- **Safe:** Meets all certification requirements for flight
- **Efficient:** Identical functionality to conventional part

Industry application examples

Gripper: lightweight and complex components

Festo gripper
Bionic Assistance System

- **Challenge:** Produce a bionic gripper able to reliably pick up and safely put down objects gently and flexibly
- **Solution:** Small batch production using EOS FORMIGA P 100

- **Optimized**: Functional integration reduces number of single parts and cuts assembly costs
- **Economic:** Lightweight and long-lasting due to innovative manufacturing method
- **Efficient:** Tool-free production saves time and money

Special purpose machinery: integrated functionality

EOS FORMIGA P 1
Laser adjustment unit

- **Challenge:** Produce a device to adjust laser mirror in Y and Z direction for EOS FORMIGA
- **Solution:** Production with EOS plastic laser sintering technology using EOS material PA2200

- **Optimized**: Functional integration:
  - Integrated cam levers to fix regulating screws
  - Integrated control angle markings (no stickers required)
- **Economic:** Manufacturing on Demand possible, enabling adjustments and production of spare parts

HYDROPOX® burner: complex and scalable components

HYDROPOX® burner, Linde

- **Challenge:** Produce a HYDROPOX® burner for flame-based glass surface treatment with as few components as possible, lower unit costs and improved functionality
- **Solution:** Additive manufacturing enables functional integration

- **Simplified:** 1 part vs. 15
- **Efficient:** Homogeneous flame front
- **Speedy:** 5h per part (18 parts/build job), functional design optimized for serial production

Tooling application examples

Smarter design of conformal cooling channels: Reduced costs, cycle times and scrap rates, increased performance

Injection Molding

Salcomp tool insert and injection-molding part

- **Challenge:** Enable precision cooling for production of plastic parts for cell phones
- **Solution:** Improved cooling design. Manufacture of core inserts using EOS technology

- Production increased by 56,000 units/month
- Rejection rate reduced from 2% to 1.4%
- Annual cost savings of approx. 20,000 euros

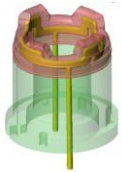
Repairing

Ecoparts tool insert

- **Challenge:** Repair a partially damaged tool insert
- **Solution:** Generation of a new reference surface; positioning of part in EOS machine. On-top construct-ion of missing parts

- Reduced construction costs for a complete new insert
- Reduction of lead time: partial construction instead of complete construction

Die Casting



Innomia tool insert for die casting

- **Challenge:** Build a tool insert for a die-casting application
- **Solution:** Cooling system optimization; insert built via DMLS on EOSINT M 270 in EOS MaragingSteel MS1

- Significant reduction of cycle time
- Improved lifetime of inserts

Rapid Tooling

PEP (Pôle Europeen de Plasturgie) tool insert

- **Challenge:** Injection molding tooling for 50,000 electrical component parts
- **Solution:** Redesign of inserts with conformal cooling channels; inserts built in EOS MaragingSteel MS1

- Reduced lead time and costs
- Increased mold productivity
- Better thermal management

Develop Your Application – Linde

Source: Linde Logo: http://www.the-linde-group.com/de/news_and_media/image_library/index.html

Linde is confronted with several challenges

Strong competitive environment

Both increasing productivity and comply environmental regulations

Call for innovation

Existing production technologies are exhausted

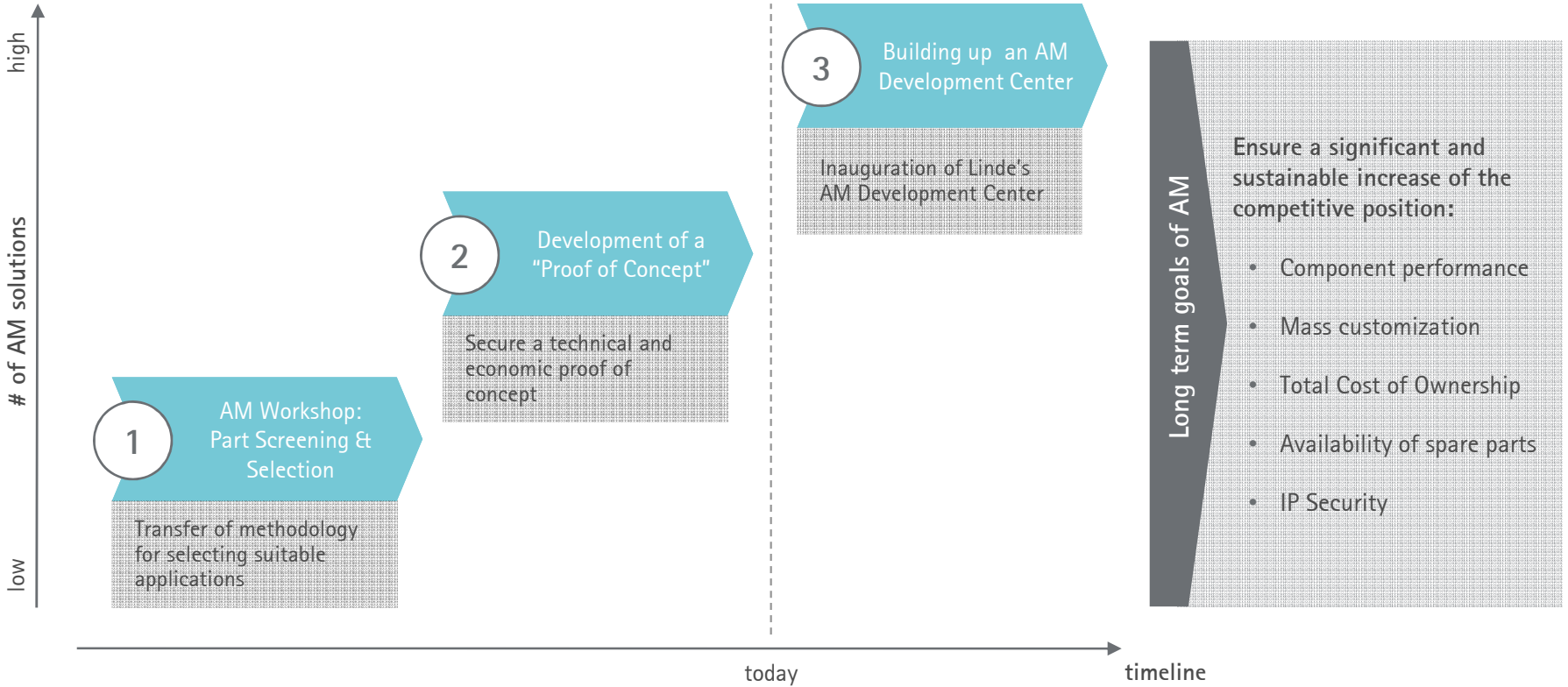
Skills shortage

Lack of knowhow in Additive Manufacturing

Goal of Linde

Build up and test new production and design competences in Additive Manufacturing in no time

Solution for the implementation of Additive Manufacturing



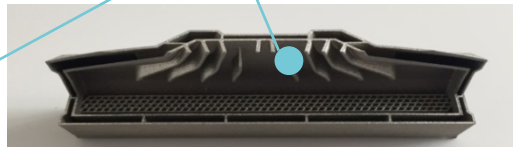
Redesign and Manufacturing of Hydropox burner

Function integration (15 to 1)

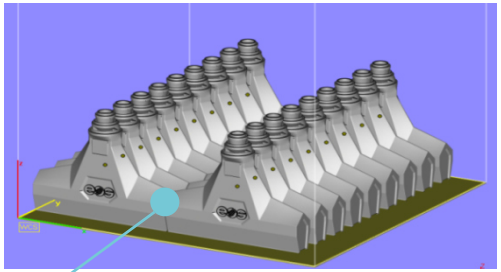
Redesign of burner

Minimization of support structures

complex sandwich construction



Optimized gas flow



production-friendly design

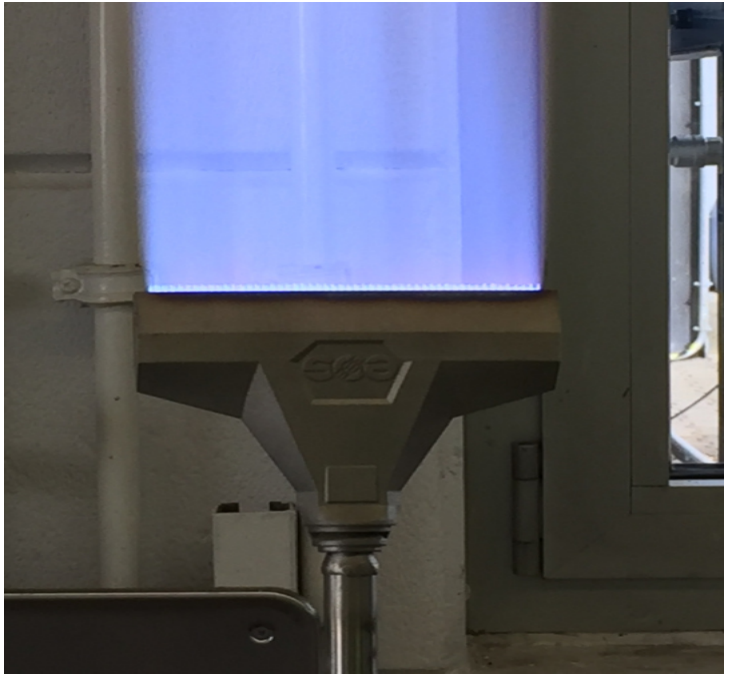
Project results of the cooperation between Linde and Additive Minds

Gas burner

- uniform flame shape
- low construction time: just 5h per part (18 per job)
- compact and responsive design
- low post processing
- components reduction from 15 to 1

Competitive strategy

- Building up extensive knowhow within Linde in the field of Additive Manufacturing
- Expanding internal competences to spread Additive Manufacturing to other departments and products

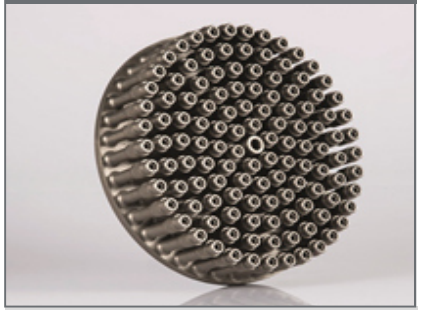


Ramp Up Your Production – Ariane Group

Develop your application

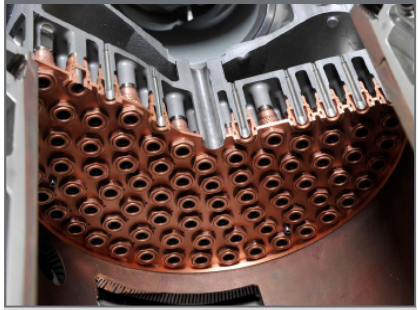
Ariane Group faces several challenges in their injector head development

Reduce part complexity



248 single parts
(> 8,000 drill holes)

High performance



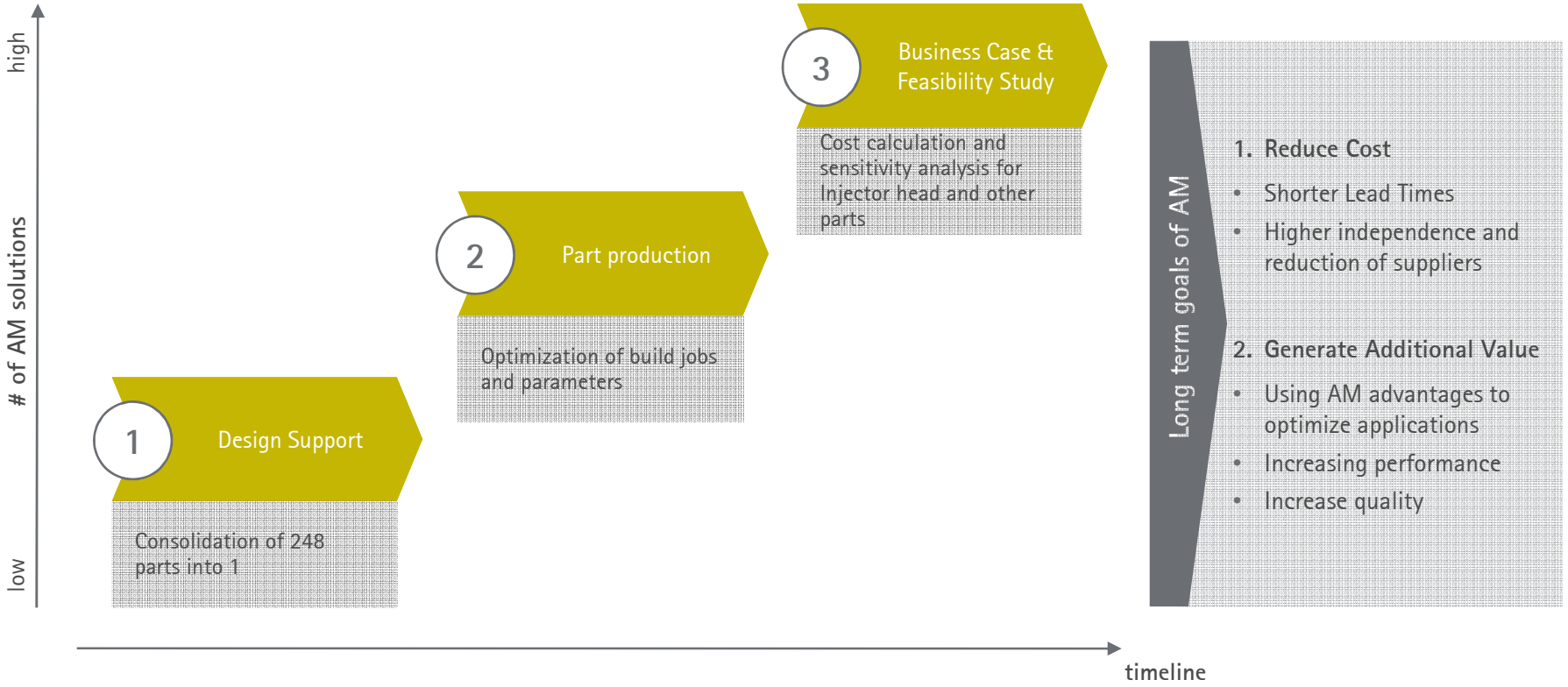
Ensure high performance

Keep quality standards

Class 1 component
(mission critical)

Goal of Ariane Group Production of an injector head for rocket engines with as few components as possible and lower unit costs

The goal of producing the injector head is achieved in 3 steps in collaboration with Additive Minds



Injector head of Ariane 6 upper stage propulsion module VINCI realized as an all-in-one design (AiO)

Injector Head Ariane 6 – Project Overview

Challenge

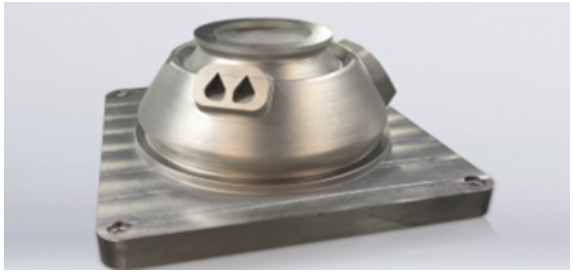
Production of an injector head for rocket engines with as few components as possible and lower unit costs.

Solution

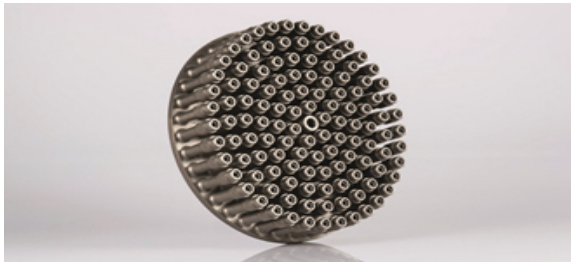
Additive manufacturing with EOS M 400-4 (IN 718) and functional integration.

Results

- Simplified: One component instead of 248
- Cost-efficient: 50 % lower costs
- Fast: Significant reduction in production time (Lead time reduction of 80%)
- Higher quality and better performance
- Insourcing of production



Injector head of Ariane 6 upper stage propulsion module VINCI as an all-in-one design (AiO).



The additively manufactured baseplate of the injector head of a rocket engine with 122 injection elements is made from EOS NickelAlloy IN718.

Customer's Voice

Project Overview

Production process	Construction time for 1 injector head
Casting & machining finishing	3 months
Additive manufacturing with EOS M 290	133 hours
EOS M 400-4 (1 laser for 1 component)	65 hours
EOS M 400-4 (4 lasers for 1 component)	35 hours

Project Results

- Simplified: One component instead of 248
- Cost-efficient: 50 % lower costs
- Fast: Significant reduction in production time (Lead time reduction of 80%)
- Higher quality and better performance
- Insourcing of production

» On Ariane 6, we are combining our innovative strength with the expertise of EOS. Together, we have implemented the additive production of an injector head for a rocket engine. The results are impressive: Significant reduction in production time and 50 % lower costs. «

Dr. Steffen Beyer, Head of Production Technology – Materials & Processes at ArianeGroup.

Certify & Scale Your Production – Permedica

Source: https://www.permedica.it/en/company/

Permedica is confronted with several challenges

Quality assurance

Strict standards for medical devices

Call for innovation

New hip cup system with a highly porous structure

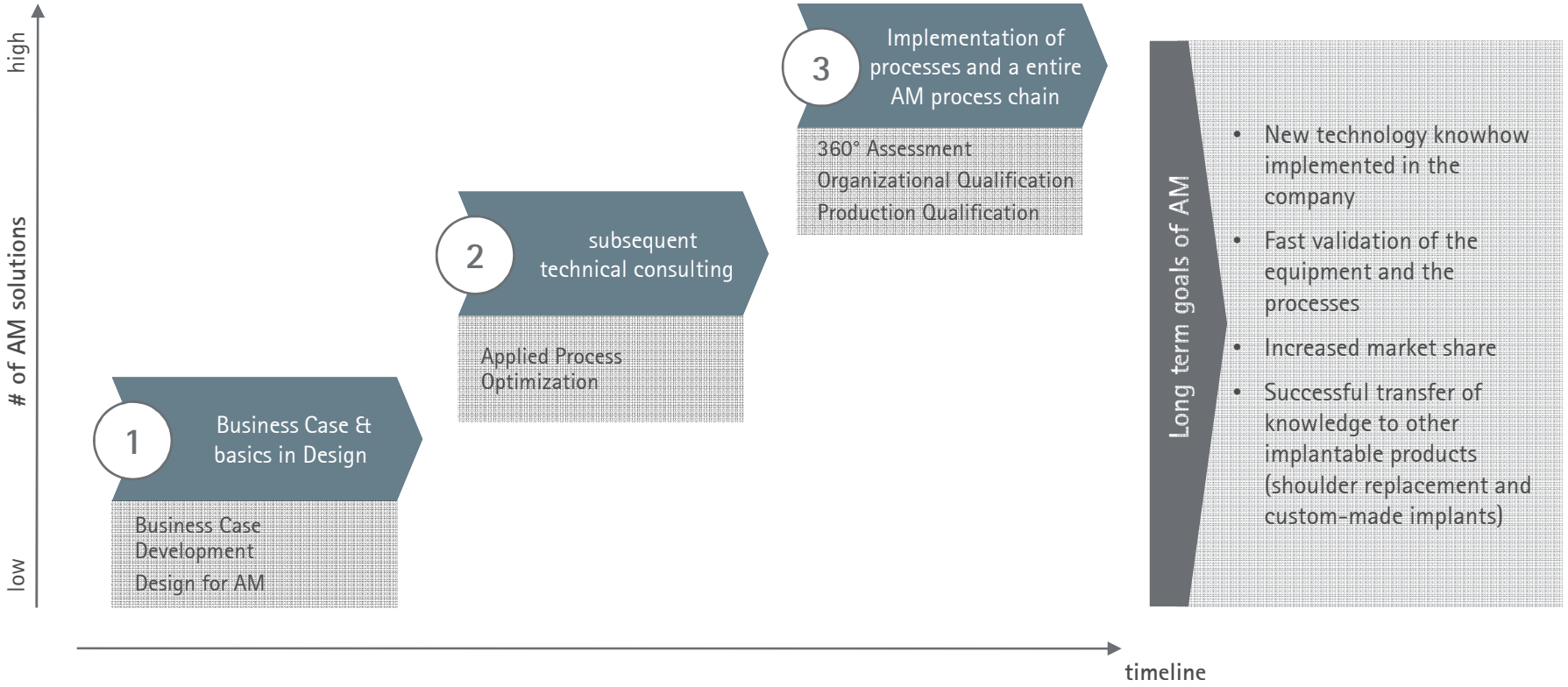
Lack of knowhow

Build up knowhow in the field of Additive Manufacturing

Goal of Permedica

Enter and acquire knowhow in industrial metal 3D printing within the organization

The goal of producing the injector head is achieved in 3 steps in collaboration with Additive Minds



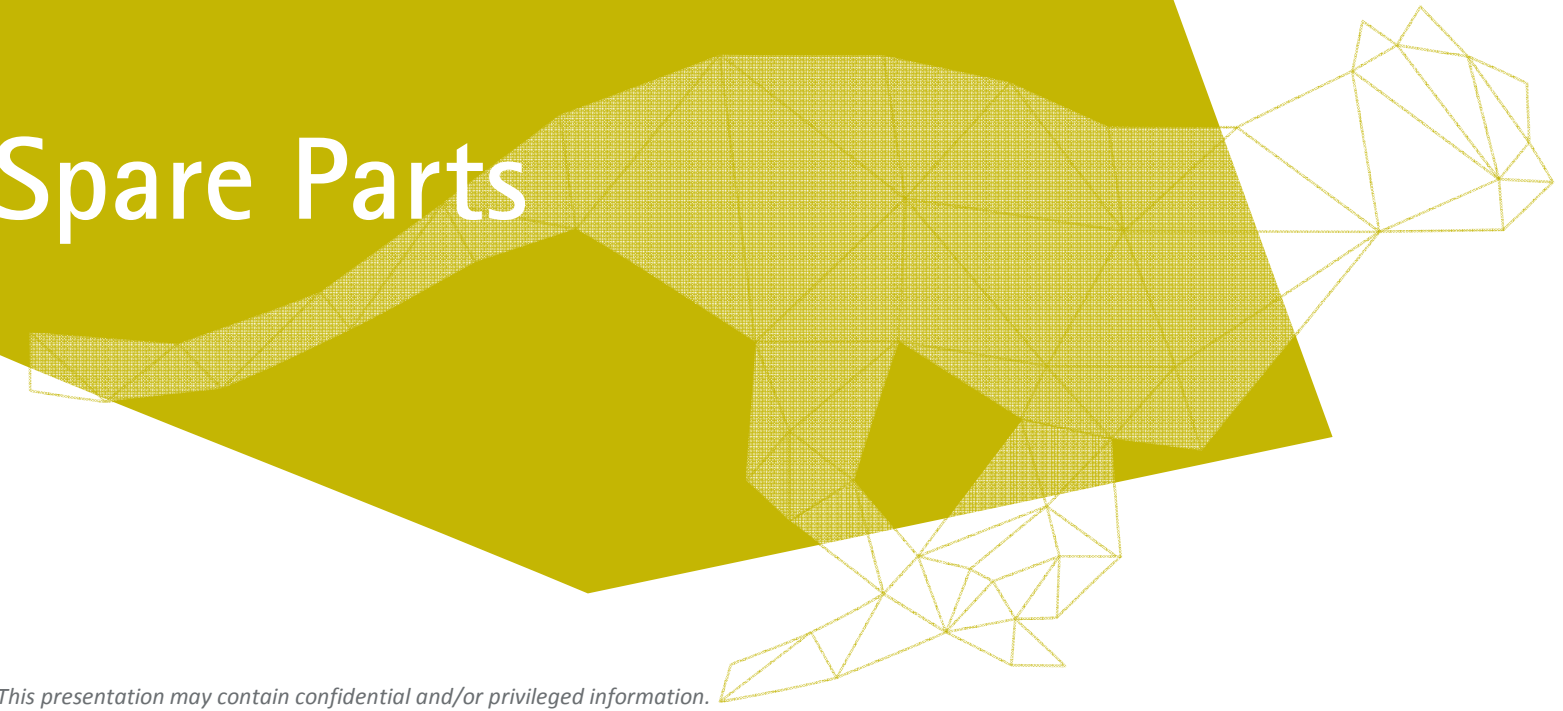
Permedica & Additive Minds

Project review

- Development of a new hip cup system with a highly porous titanium structure to promote new bone formation and fast osseointegration
- Lead by Additive Minds from start to serial production
- Special focus on quality, the production setup and the qualification process

Additive Minds Success Stories

Spare Parts



Summary

e-Manufacturing Solutions

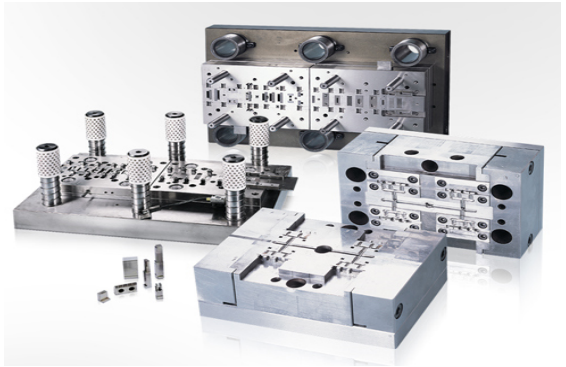
General considerations

- 3D printing spare parts reduces cost, lead time and fixed assets
- Additive Minds is the quickest way to realizing the potential
- Several industries have already started

Conventional on-demand production is too slow, stock keeping is too expensive

Conventional production on-demand

- Long lead times with tooling on demand
- or keep tooling in stock (fixed asset, logistics, aging)
- Labor intensive set-up times (minimum order quantities)



Stock keeping

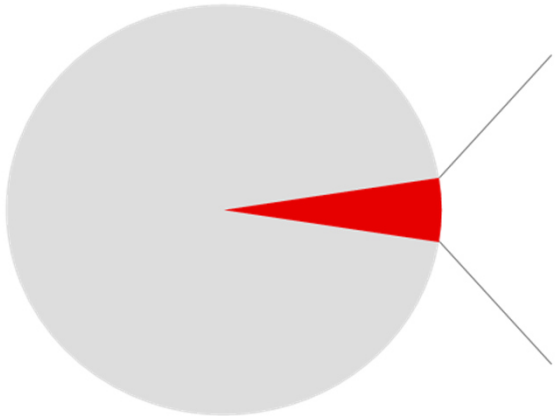
- Planning ahead for 10 years near impossible
- Fixed assets, storage and logistics costs
- Scrap cost and unfavorable ecological footprint
- Aging issues (plastic gets brittle, metal corrodes)

Spare parts obligations are forcing expensive measures

Source: ANT Precision Industry Co., Ltd; REA Group Ltd

Spare parts worth billions of dollars are fixed assets

Global inventory is over 10 Trillion USD



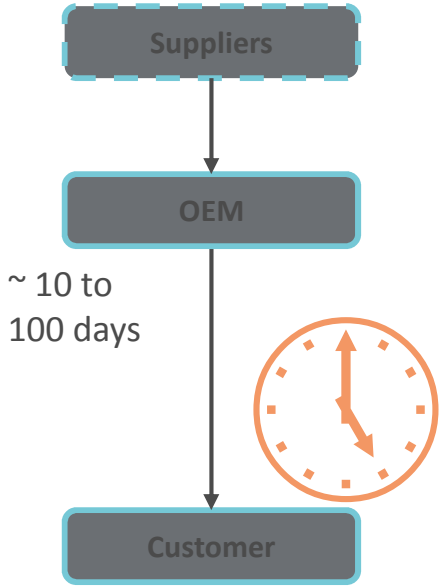
if spare parts
were only 5% of that
inventory,
up to 500 Billion USD
in assets could be freed

Potential of saving billions by reducing stock

Source: SAP Distributed Manufacturing Introduction (Nov. 2016); image don-jai.com

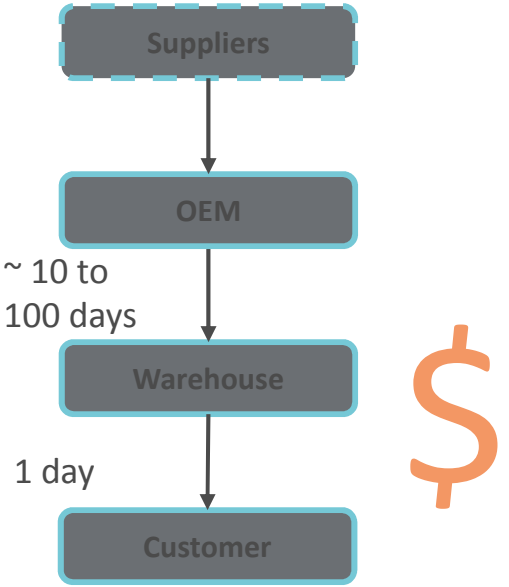
Conventional on-demand production is too slow, stock keeping is too expensive

Conventional production on-demand



slow

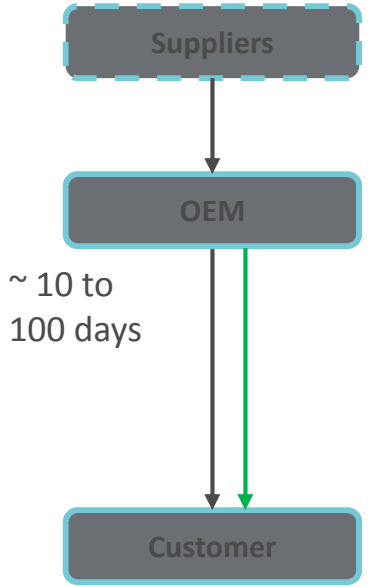
Stock keeping



fixed assets

3D printing can improve lead time and cost of many spare parts significantly

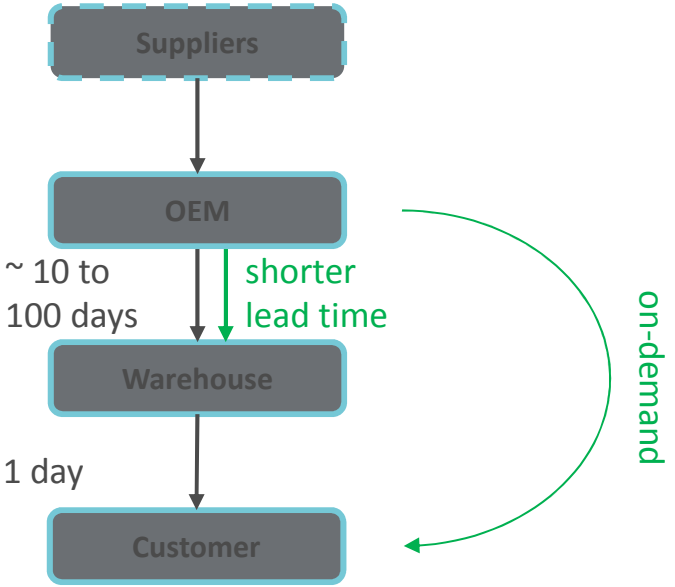
Additive production on-demand



shorter lead time

3D printing feasible for
1% to 10% of all spare parts

Stock keeping



less warehousing

Additive Minds can support along the way

Step 1: part selection

- spare parts suitable for 3D printing

Step 2: qualification

- properties and conformity with regulations
- trial phase

Step 3: roll-out

- make or buy
- quality assurance
- in-house processes

Important first step: part selection

Since 2014 our Global Application Consulting has grown into a powerful Additive Minds team

Güngör Kara
Director of Global Application & Consulting

116

37

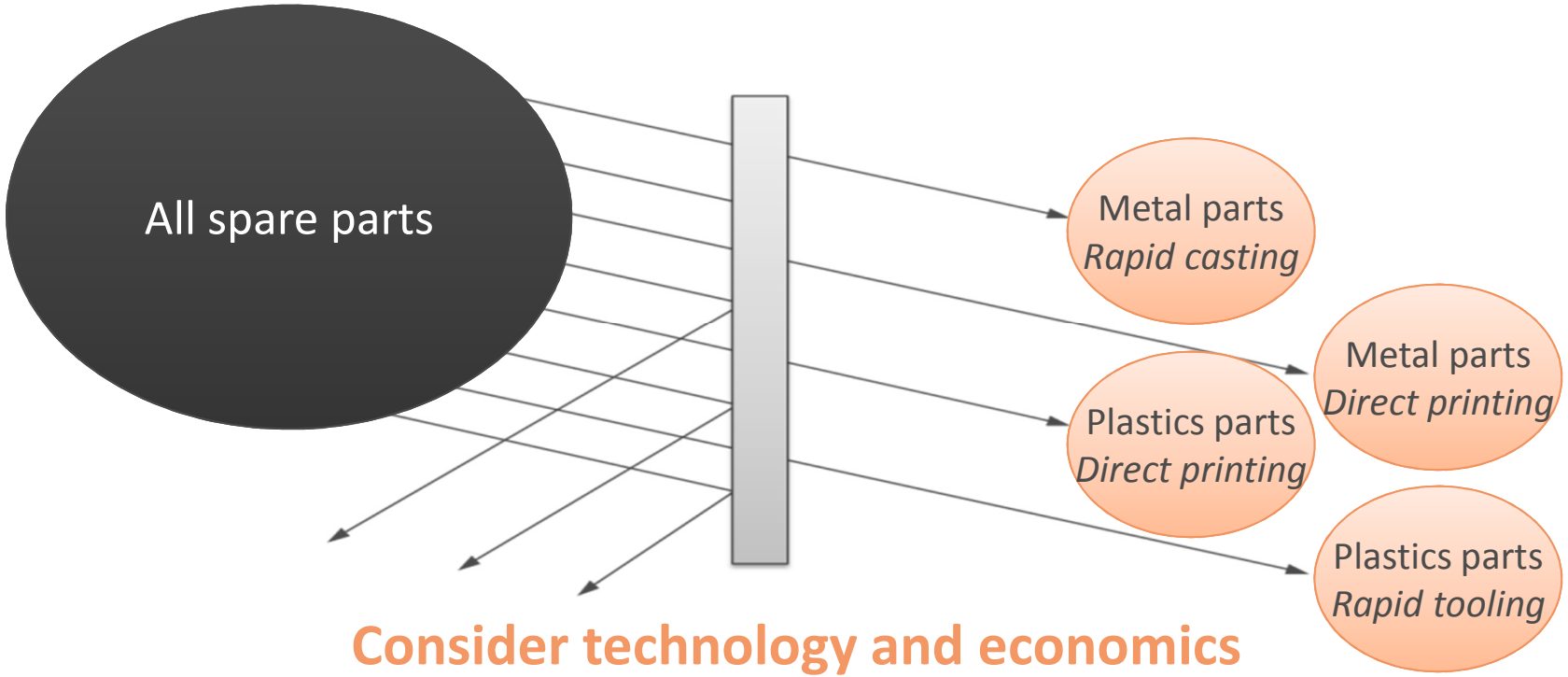
24

Application Eng. HQ	Consulting HQ	North America	Central Europe	Asia/ Pacific	Export
Patrick Schrade *Head of Application Engineering*	**NN** *Head of Global Consulting*	**Greg Hayes** *Director of Application & Consulting NA*	**Bernd Reinarz** *AM Consultant*	**Kei Long Ho** *Director of Application & Consulting APAC*	
Rainer Salzberger *Team Manager Testing & Development*	**Michael Galba** *Team Manager AM Engineering Consulting*	15	3	8	2
Frank Müller *Team Manager Customer Support Polymer*	**Detlef Scholz** *Team Manager AM Technology Consulting*				
Marco Schürg *Team Manager Customer Support Metal*	**NN** *Team Manager Innovation Center*				

116 Engineers & Consultants globally!

Only a percentage of all parts is suitable for 3D printing

Step 1: part selection



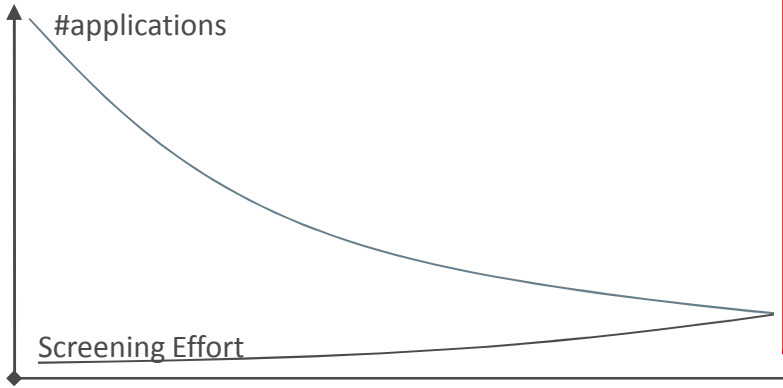
Consider technology and economics

Part Selection Methodology for Spare Parts Mngt

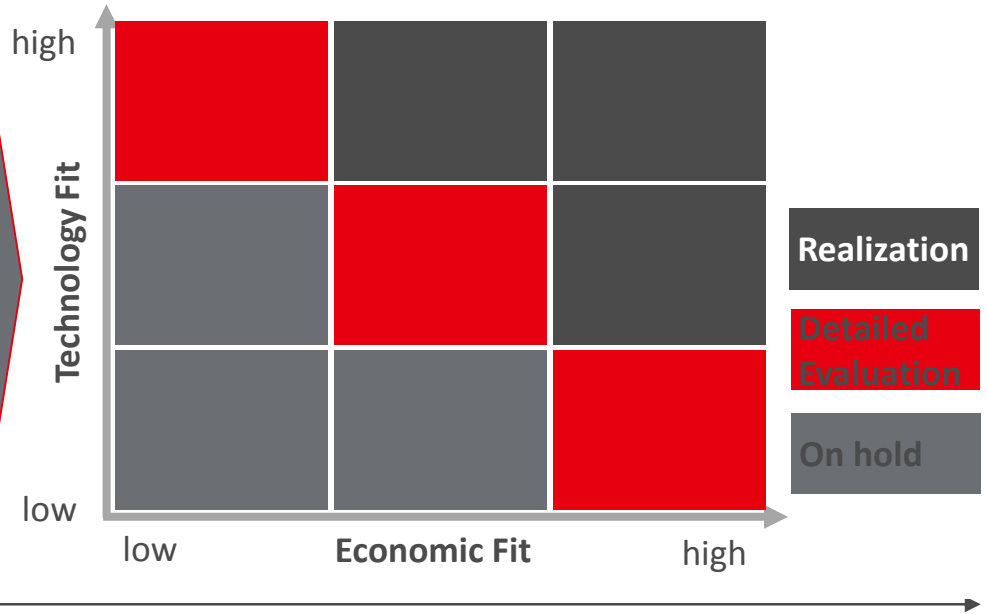
Portfolio Assessment

Portfolio Assessment:
High level part evaluation

Check **Technology Fit** → Evaluate **Economic Fit**



Recommended proceeding



Established methodology for part selection

Major players of mobility and 3D printing founded network for railway spare parts in 2016

Goals of Mobility goes Additive network

- Secure supply chain
- Cost-efficient manufacturing
- Reduced stock
- Fast on-demand production

SIEMENS

eos

KNORR-BREMSE

PAUL SCHOCKEMÖHLE LOGISTICS

SBB CFF FFS

Mobility goes Additive

DB BAHN

Rail industry is realizing the potential

Industrial 3D printing is cost-efficient and fast

Example of head rest for old trains with 20 spare parts annual demand

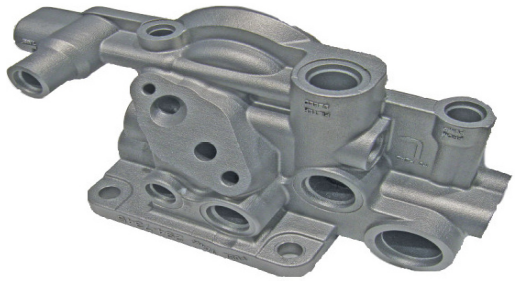
major improvements for rarely required spare parts

Source: Total cost calculation, Deutsche Bahn (injection molding cost, lead time), Hasenauer & Hesser (additive manufacturing cost including margin)

CAT is 3D printing spare parts for their special vehicles

e-Manufacturing Solutions

Focusing on aftermarket parts in preparation for future production parts



Fuel filter base from an engine.
Used in the excavator (left image) and other special vehicles.
Previously a casting part. Now additive manufacturing (80 hours build time).

CAT is introducing 3D printing for special vehicles

Source: Additive Manufacturing Magazine, “Caterpillar lays the groundwork” by Peter Zelinski (May 2016).

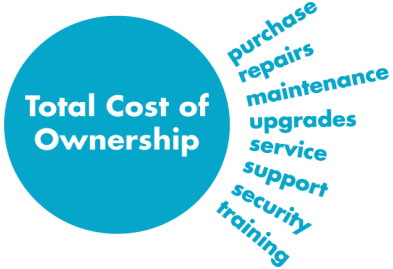
Find Your Application – Evobus

EvoBus faces several challenges in their Spare Parts Business

Huge Product Portfolio

Over 320,000 different spare parts

Total Cost of Ownership



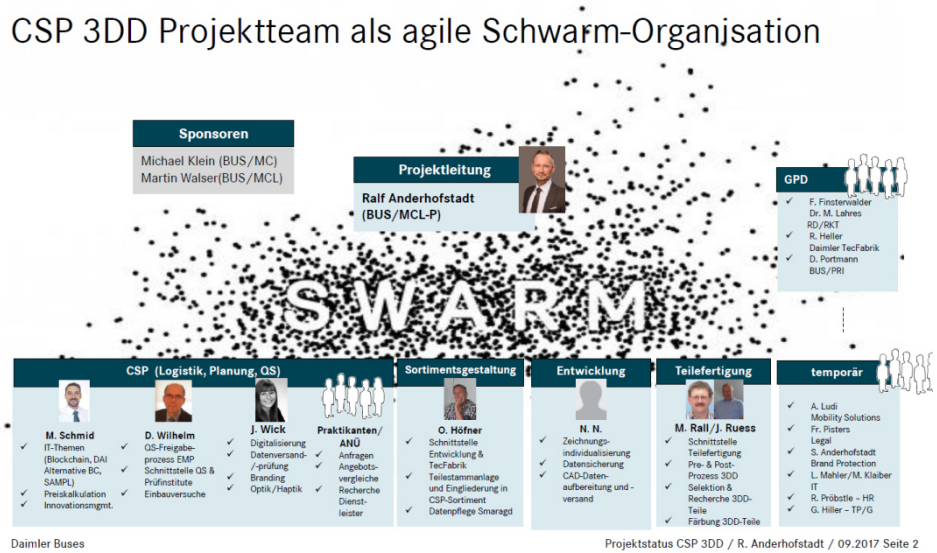
Customer expect short lead times

Long product lifetime

High cost for storage & logistics and a huge number of suppliers

Goal of Evobus Use Additive Manufacturing to develop a sustainable business model in the spare parts management

Organization of project team



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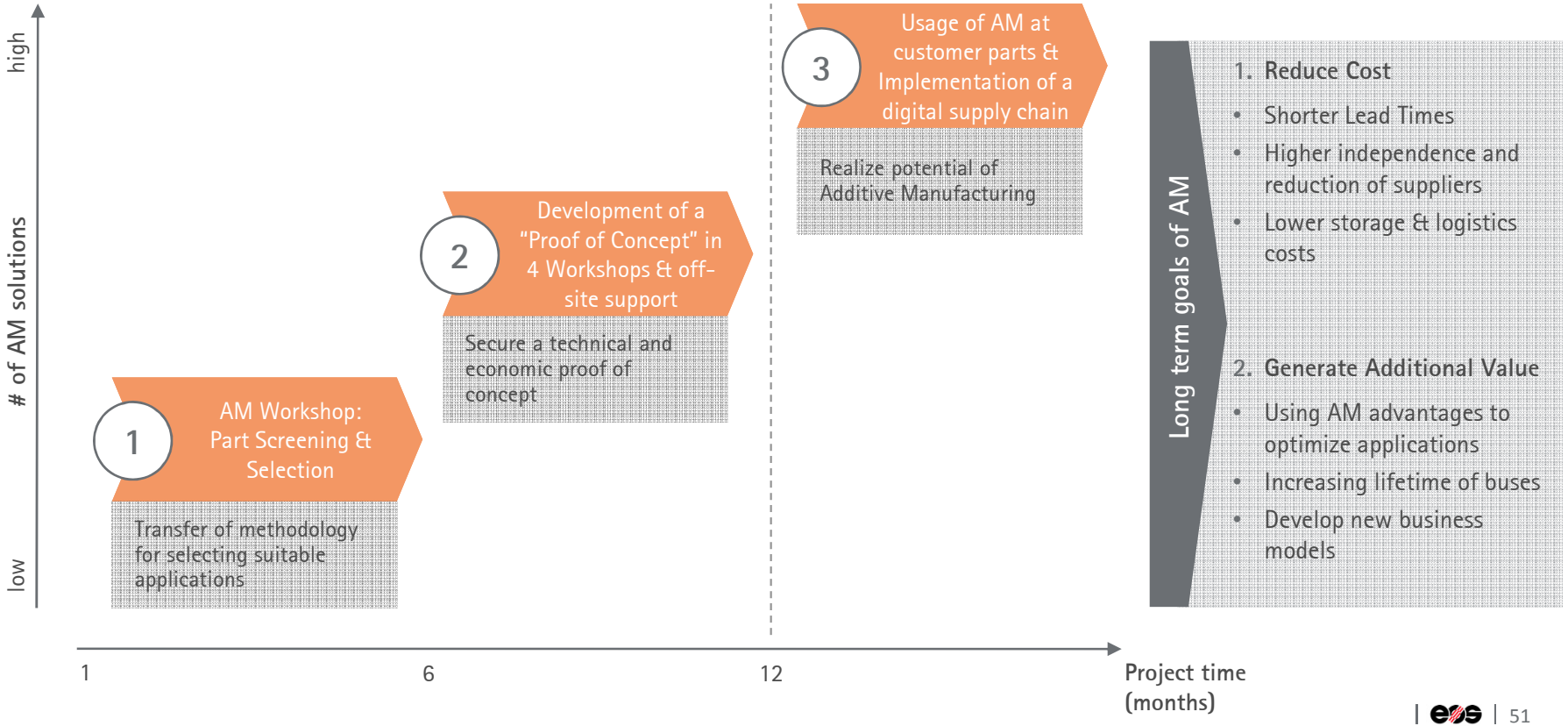
ADDITIVEMINDS
EXCELLENCE IN INDUSTRIAL 3D PRINTING

The goal of using AM for customer parts is achieved in 3 steps – Thanks to Additive Minds



Spare Parts 2.0 – Additive Minds / Daimler Buses

Thank you for your attention!