e-Manufacturing Solutions

Electro Optical Systems: LWC and conformal cooling application

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2013 Molding Innovation Day - POINT Dalmine Bergamo

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Agenda

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Overview

- About EOS and additive manufacturing
- LWC principles and examples
- Conformal cooling applications: principles & argumentation lines
- Inside additive manufacturing technology for tooling
- Examples of conformal cooling applications
- Conclusions

EOS Today: Global Footprint And Significant Worldwide Installed Machine Base

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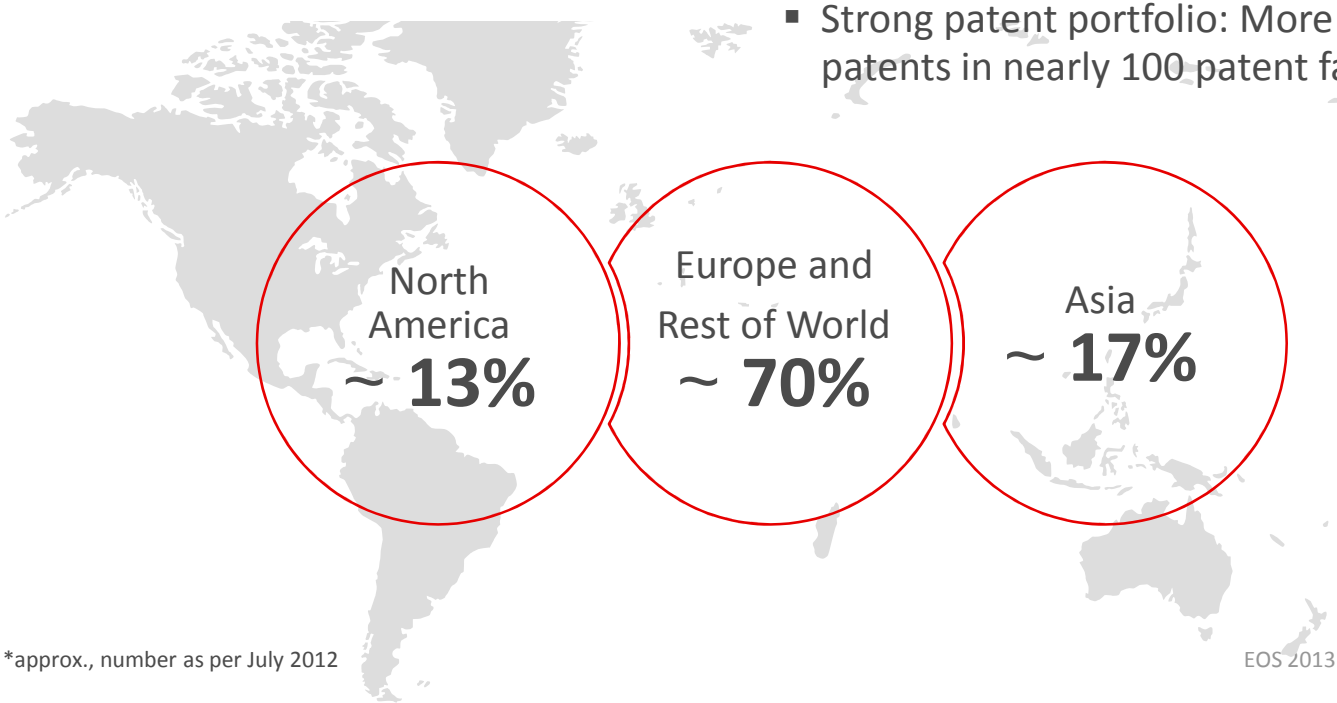
EOS worldwide installed base

~ 1,200 systems*

- 1/3 Metal systems
- 2/3 Plastic systems
- 210 customers with > 1 system

EOS global footprint

- Revenue FY 2011/12: 110 Mio EUR
- Worldwide staff of ~450 (~ 320 in Germany)
- Customers in more than 50 countries
- EOS sales/application/service offices in 11 countries, distribution partners in 22 countries
- Strong patent portfolio: More than 700 active patents in nearly 100 patent families



Source: EOS, *approx., number as per July 2012

Technology and business driven to market leadership

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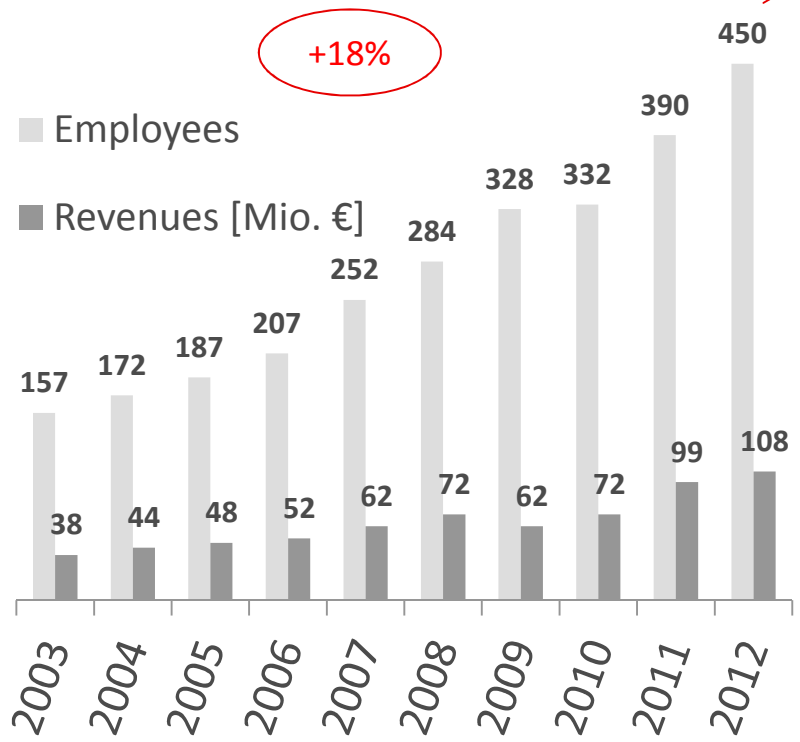
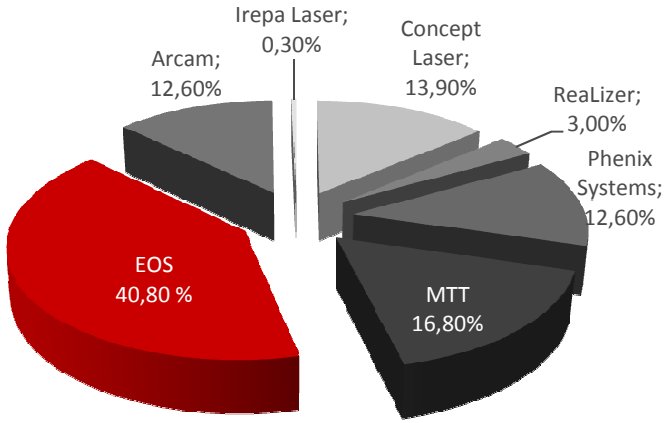
EOS grows its revenue at 18 % p.a. since 2003



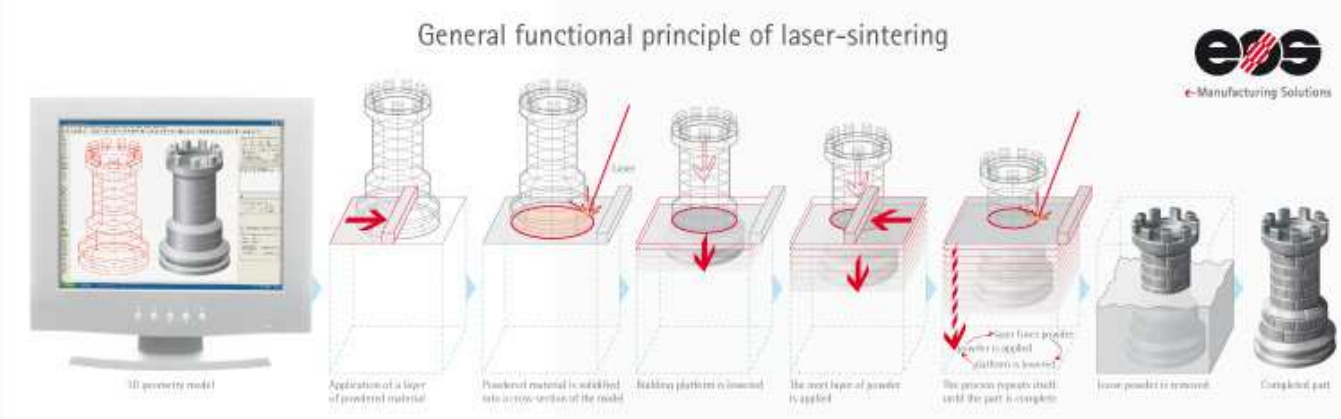
- EOS is reinvesting 15% of revenues in R&D every year
- 65 colleagues working with R&D
- e-Manufacturing major growth driver

EOS has more than 40 % of the metal sold systems



Market shares through the end of 2010 (660 metal-based machine installations). Source: Terry Wholers report

EOSINT Working Principle of Laser-Sintering



1. Exposure

- Laser
- Scanner
- Lenses

2. Lower Platform

- Powder/sand hopper
- Re-coater
- Part
- Container

3. Dispensing

4. Recoating

Source: EOS GmbH

EOS tooling video shows benefit for injection moulding (to be found on EOS@Youtube)

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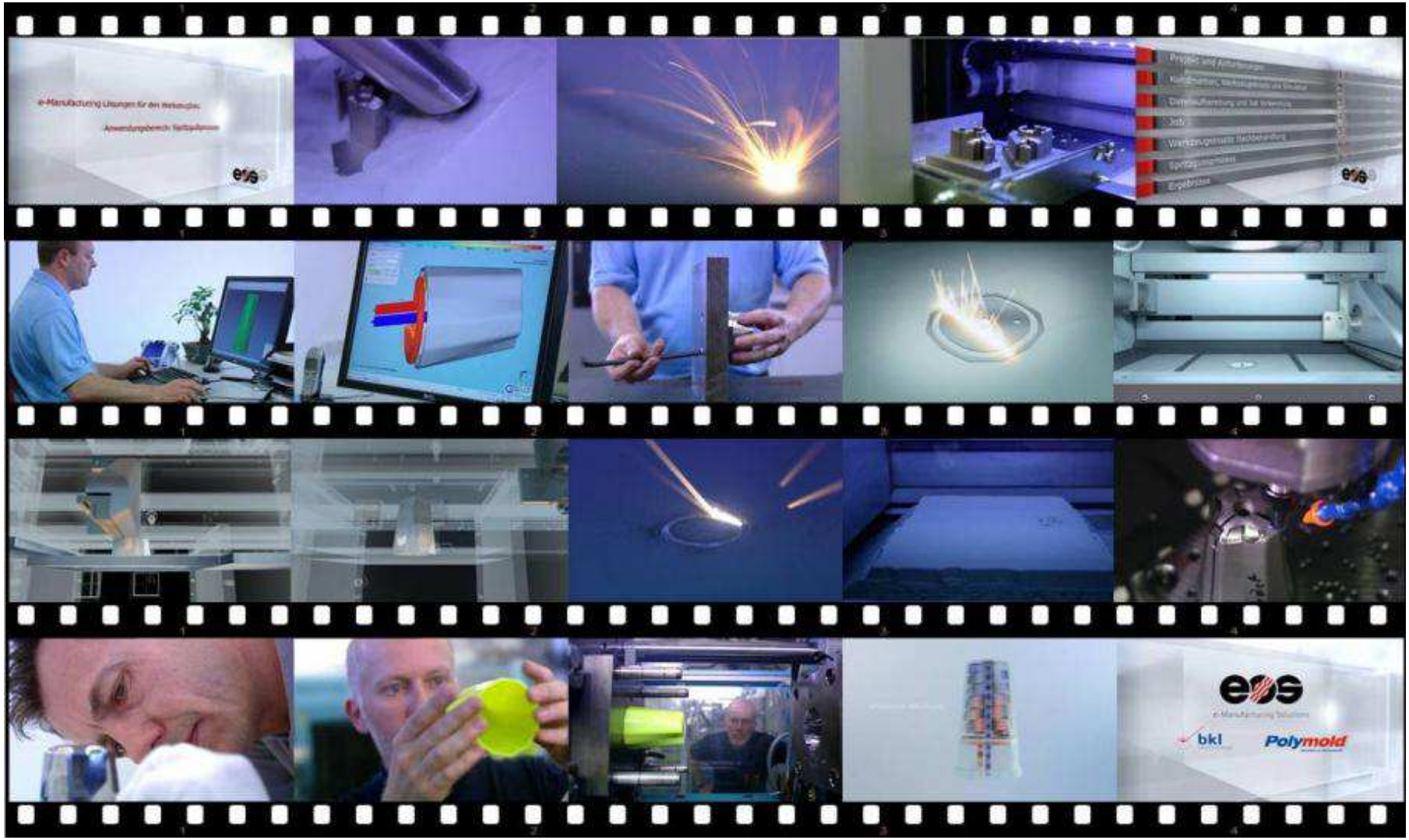

Additive Manufacturing (AM) Offers Various Advantages

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AM technology key differentiators compared to conventional manufacturing processes

Freedom of design

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

Complex components
- E.g. alternative structures of heat exchangers (see below)

Cost advantages

Integrated functionality
- Embedded functionality without assembly

Customization

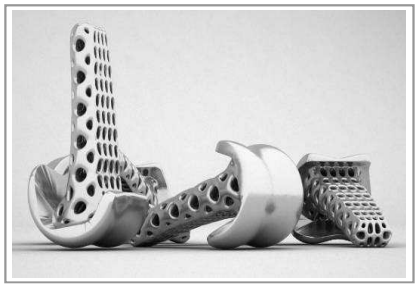
Individualized parts
- Customer specific adaptations
- Cost efficient small series up to "lot size one"

Time to market

Rapid prototyping and serial applications
- Fast feasibility feedback of virtual models
- Haptic feedback

Heat exchanger


Laser adjustment unit


Finger implants

Washing rotor

Image sources: WITHIN Labs, EOS, Hettich

EOS prioritizes Special Industries

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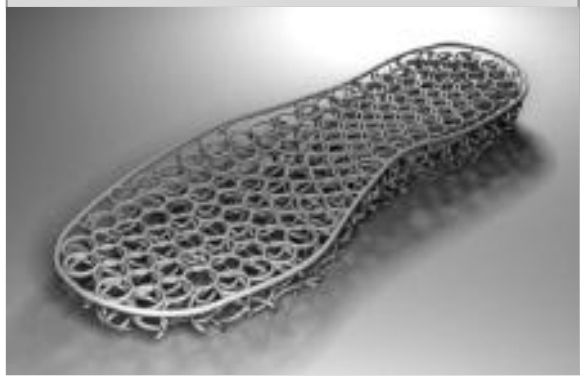
Partnering with lead customers, listening and understanding specific industry requirements, translating customer needs in to adequate offerings

Aerospace

Medical

Industry

Lifestyle



Automotive

Tooling

Sources (upper, left to right): Morris Technologies; M. Kandler, Frauenhofer IPA; Festo; (bottom l. to r.): WITHIN Labs/EOS; EOS; BKL

Additive Manufacturing (AM) enables two roads to success

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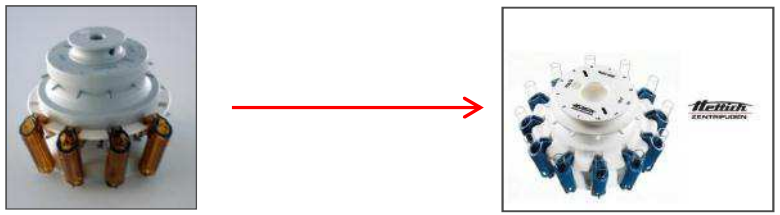
Scenario 1: Resolving constraints of conventional manufacturing

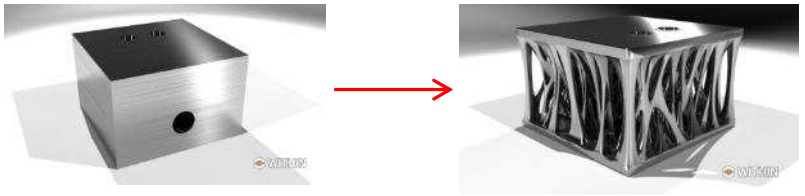
- AM can resolve constraints of conventional design of an existing solution by e.g.
  - Reducing part complexity
  - Reducing costs normally caused by e.g. tooling needed after manufacturing



Washing rotor: from 32 components to 2 laser-sintered parts + 1 steel ring, no tooling necessary, functional integration, product customization, production on demand

Scenario 2: Enabling a completely new design approach

- AM can enable design that in conventional manufacturing environments has not been possible before
- Leading to completely new solutions, e.g
  - Move from metal to plastic
  - Making a part lightweight, yet functional



New design: integrated conformal cooling channels, lightweight design, reduced cycle times, increased part quality, weight reduction = not possible with conventional design

Additive Manufacturing offers two roads to success!

Image sources: Hettich, WithinLabs

For gripper applications, the laser sintering technology is a perfect fit

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Example Unilever / Robomotion

Handling and Robotics

Gripper requirements

- Automated processes widely spread in production environment
- Productivity requirements result in high speed / high acceleration
- Highly fragmented pick geometries

Advantages

- Lightweight design
- Economic individualization up to ‘lot size one’
- Integrated functions (e.g. air channels)

Source: Robomotion, EOS

A conventional handling device was redesigned leveraging the possibilities of laser sintering

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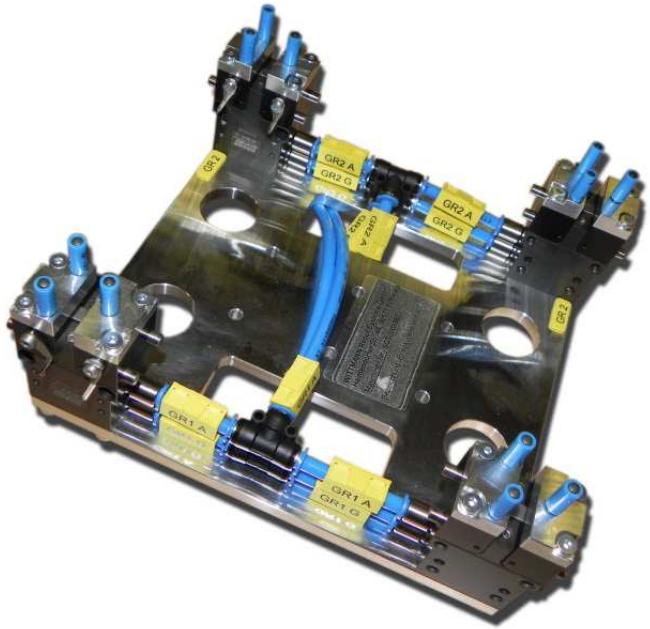
Conventional design



Laser sintered design

- Hole gripper to pick up pieces out of an injection molding machine
- Four grippers mounted on a base plate
- Gripping mechanism operated by distributed compressed air
- Base plate being attached to a three axis robot

Source: Wittmann, Kuhn-Stoff, EOS

For the gripper, weight has been reduced by 80% whilst keeping handling properties

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Example Kuhn-Stoff: new gripper design

KUHNSTOFF Schichtbautechnologien

Lightweight gripper

Application

- Hole gripper for part handling
- **Weight** of gripper: **19g**
- **Handles** up to **12kg parts**
- Integrated pneumatic membrane to apply gripping force

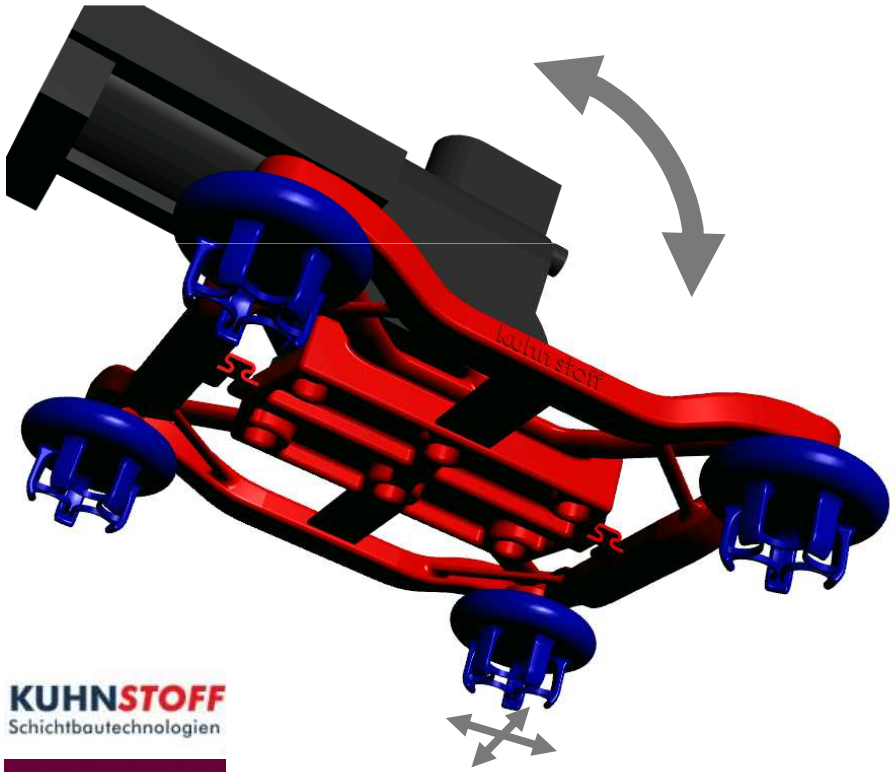
Advantages

- About **80% weight reduction** compared to conventional gripper
- Printed in one shot - no final assembly
- Geometry fully flexible and scalable
- Tested to **>5 mio. cycles**

Source: Kuhn-Stoff, EOS

In a second step, the entire handling device has been redesigned generating significant value

Example Wittmann / Kuhn-Stoff: Redesigned handling device



KUHNSTOFF Schichtbautechnologien

Wittmann Vorsprung durch Innovation

Application details

- Handling device to remove injection molding parts out of the tool during operation
- **Three parts** application:
  - Four laser sintered lightweight **hole grippers**
  - **Base plate** for stability and integrated air distribution
  - **Axis module** for 90° turning operations (embedded mechanics)
- Fully integrated application based on standard PA 2200 plastic material

Source: Wittmann, Kuhn-Stoff, EOS

The application perfectly answers today‘s Handling & Robotics challenges

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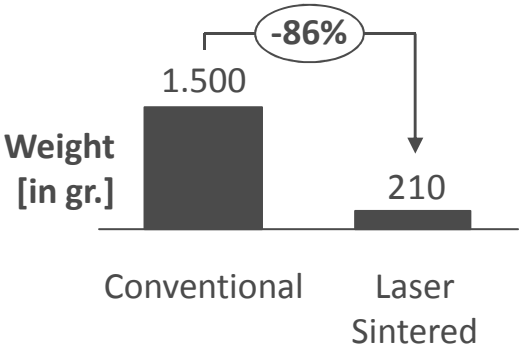
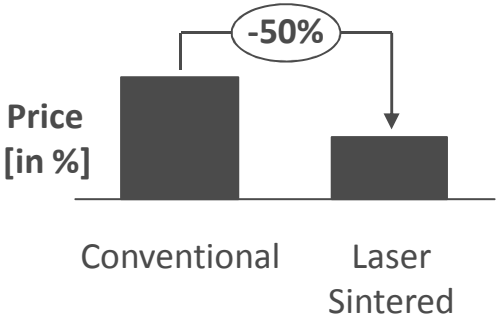
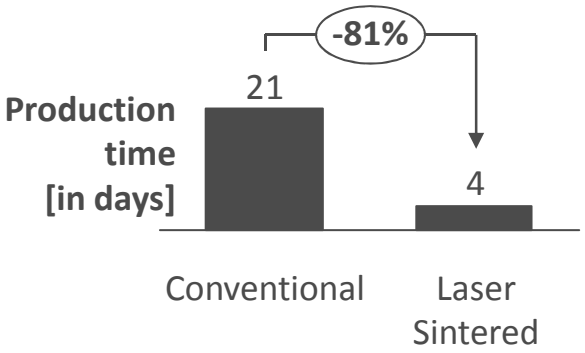
Example Wittmann / Kuhn-Stoff: Advantages compared to conventional solution







Flexibility

- Base plate generates lightweight stiffness and at the same time allows **integrated air channels**
- **Three components vs. 21**, leading to less list positions and logistics effort

Cost per part

CAPEX reduction

- **-50% gripper cost reduction**
- -86% less weight leading to **smaller robot size**

OPEX reduction

- Lightweight and **smaller build height (-60mm)** resulting in shorter cycle times of injection molding machine

Time-to-market

- Laser sintered gripper to be produced “overnight”
- **Reduction** of manufacturing time **by 17 days**
- Fast reaction possible for **spare parts** or product design changes

Source: Wittmann, Kuhn-Stoff, EOS

EOSINT M enables product optimization for aerospace devices with new design concepts

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Overview possible application in the aeronautic industry

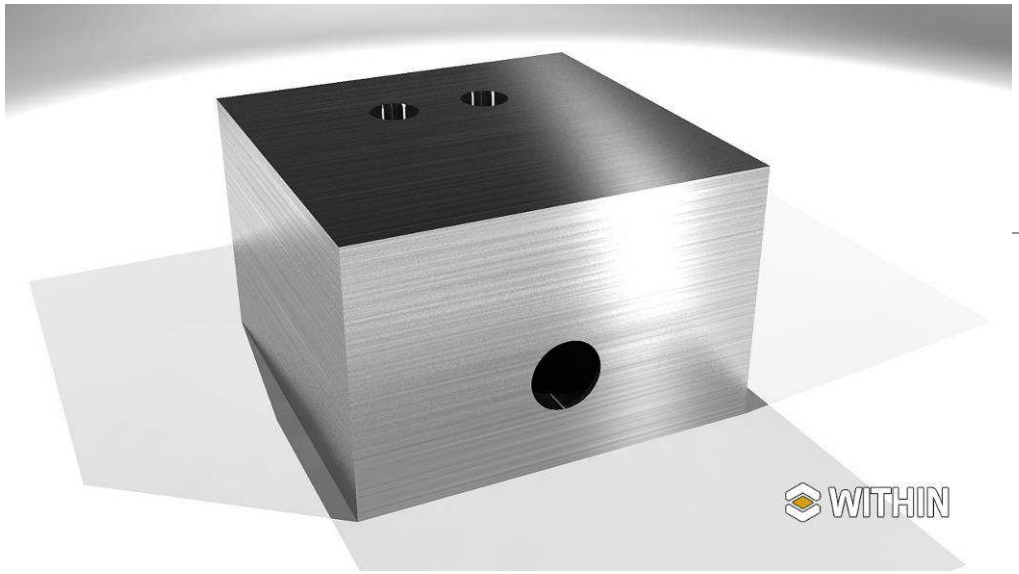
Door bracket for A380 – DML and Conventional
EOS Ti64 produced on EOSINT M 270Xt at EADS IW.

Door bracket

Advantages

- Highly complex design built as ‘one piece’
- function integration
- Significant cost reduction
- Weight reduction

Source: Evo Maganize, EADS IW Filton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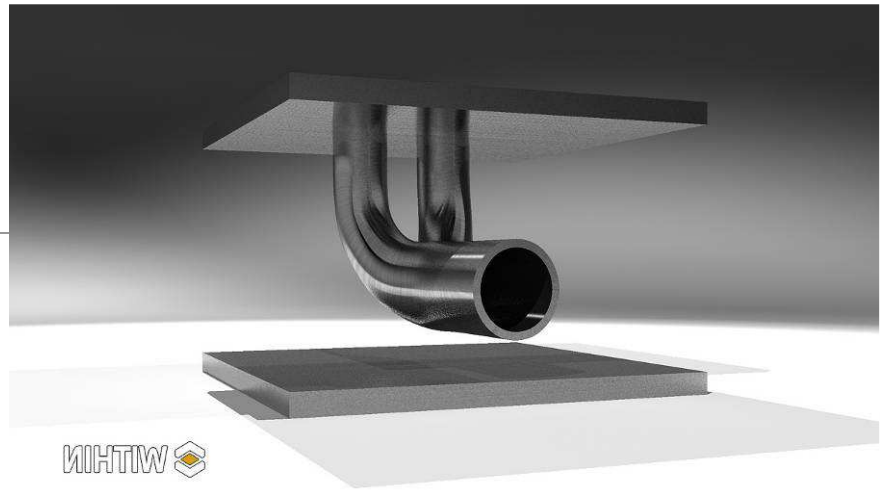
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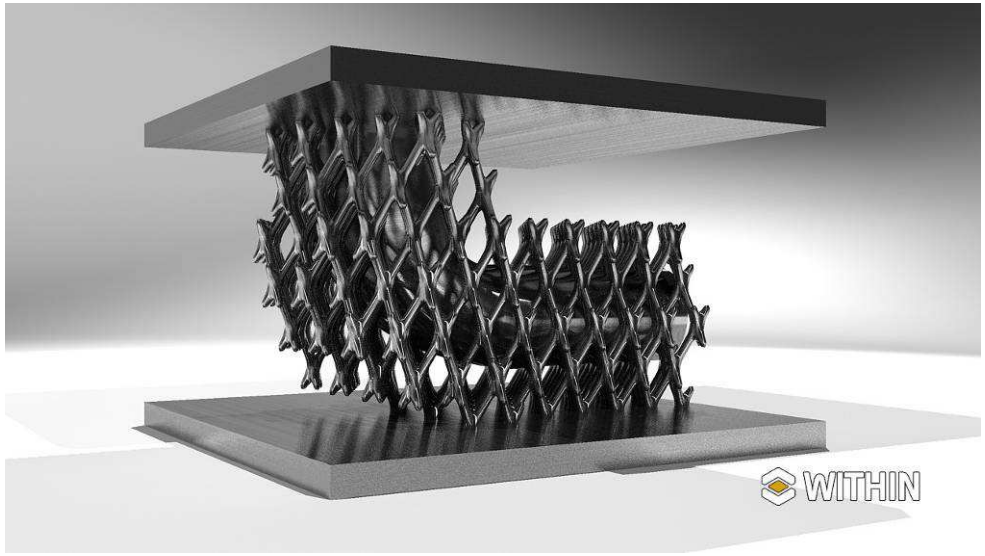
WITHIN


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Inside additive manufacturing technology for tooling

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EOS is focusing on Part Quality, Process Robustness and Industrialization

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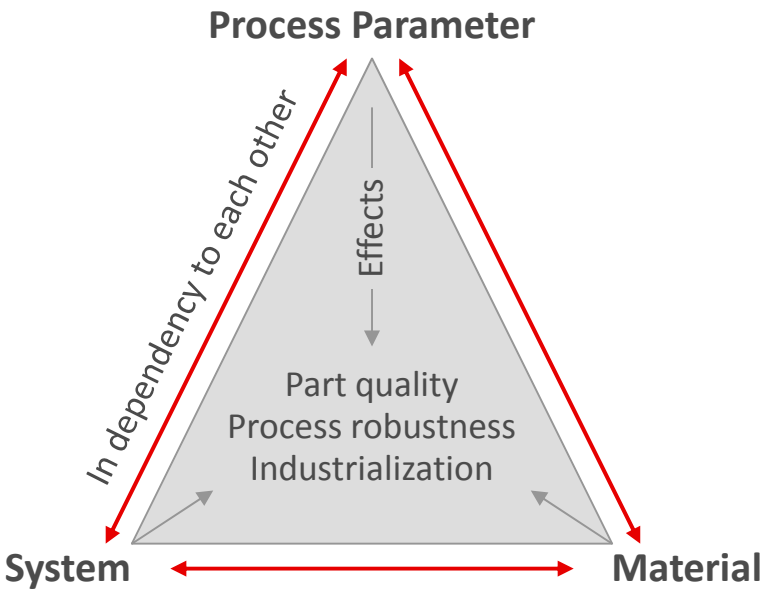
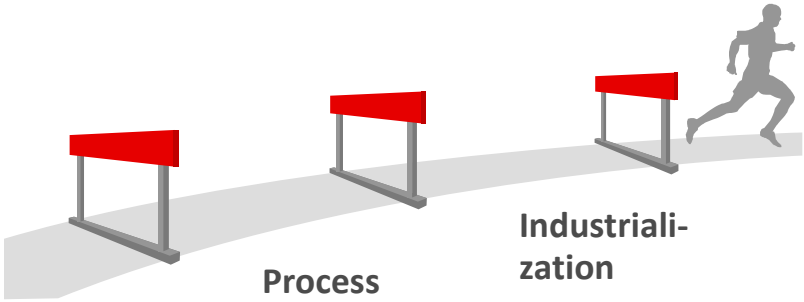
EOS Technology Focus

Balanced triangle



Hurdles to overcome



Part Quality

- Mechanical properties
- Dimensional accuracy
- Surface quality
- Density

Process Robustness

- Build platform
- Several jobs
- Several machines
- Several suppliers

Industriali-zation

- Automation
- Quality assurance
- Easy-to-Service
- Productivity / reduced cost-per-part

EOSINT M 280

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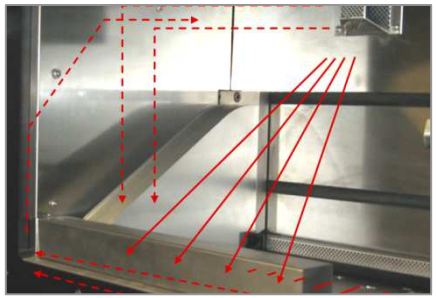
Features

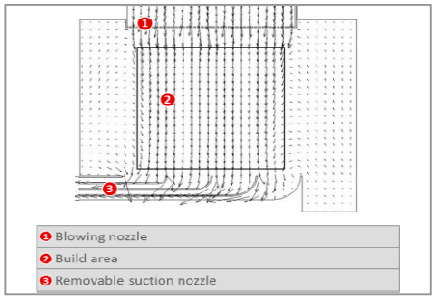
- 250x250x325 mm build envelope
- 200 or 400W laser
- Laminar flow process gas management
- Tidier process chamber
- Dual mode: reactive and non reactive materials can be processed
- Material: MS1, PH1, MP1, Ti64, IN625, IN718, AlSi10Mg, 316L(*), Corrax (*)
- Optionally with Comfort Powder Module

EOSINT M280 400W

Building chamber



Laminar flow



DMLS will be integrated in production cells to optimize process workload for customers

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EOS view for tooling in the near future

Netshape Production cells (DHE)

Challenges

- Improve productivity and speed by keeping the same quality
- Optimize interface between different systems
- Deliver process and systems suitable production environment
- Keep quality constant over the years and between the systems
- The solution is not the machine, the EOSINT system is part of the solution

DMLS systems don’t present most of the disadvantages of hybrid machines

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Consequences of heat threatment

- After the heat threatment, the insert/part is subject to deformation
- As a consequnce the parts need to be finished a second time again
- All advantages are lost

Internal roughness of CCC is positive

- Internal rugosity of cooling channels have an « auto-cleaning » effect avoiding deposit of cediment on the internal surface of the cooling channel
- Rugosity improve heat exchange
- We need turbolent flow

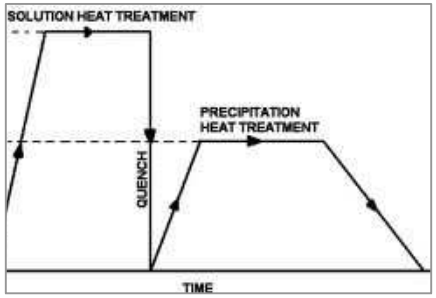
High cost per parts, bad economics

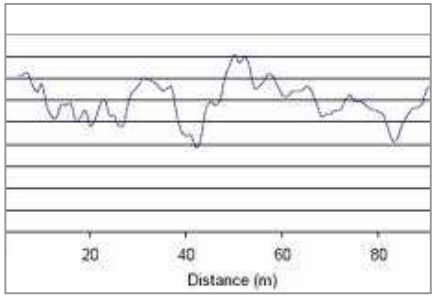
- During the LS/SLM module works, the miling machine is in stand-by (costs)
- The total cost of the parts arenrelated to the 2 systems
- The calcuation of the cost per part shows that 2 different machines in parallell are better

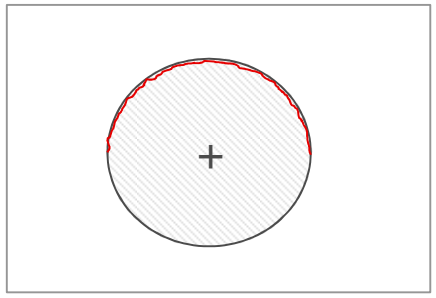
Not all structure can be internally finished

- The milling machines can only finished half of the cooling channels (« Roof effect »)
- Smooth surfaces for CCC are not usefull for heat/cooling applications
- Support still needed and to be removed afterwards

Last but not least, produced chips have bad influence on micro-structures







Existing material fits to the process and fulfill tooling requirements, more still to come

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EOS MaragingSteel MS1 - high performance steel for series tooling and other applications

Characteristics, applications, status

- Key characteristics
  - 18 Maraging 300 type steel (1.2709, X3NiCoMoTi18-9-5)
  - fully melted to full density for high strength
  - easily machinable as-built
  - age hardenable up to approx. 54 HRC
  - good thermal conductivity and polishability

MS1 – 1.2709

- Mechanical properties as built
  - UTS: 1100 MPa
  - yield strength:1000 MPa
  - hardness: 33 - 37 HRC
- Mechanical properties after age hardening (6 hours at 490°C)
  - UTS: > 1950 MPa
  - yield strength: > 1900 MPa
  - hardness: 50 - 54 HRC
  - Physical properties
    - relative density as built: approx. 100 %

Other alloys-steel

- Tool steel with improved anti-corrosion properties
- Alloy with improved heat conductivity *

EOS Maraging steel is a very performing tool steel compared to standard ones

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	Orvar supreme (1.2344)	Stavax (1.2083)	1.2343 (H13)	1.2709 (MS1)
Yield strength (Rp 0.2 %) [Mpa]	1250	1290	1400	1930
Tensile strength []	1400	1780	1600	2050
Elongation at break [%]	13	na	3-5	4-6
Modulus of elasticity [GPa]	210	210	215	200
Hardness [HRC]	52-54	48-52	52-54	52-54
Density [Kg/dm3]	7,8	7,74	7,8	8,0
Coefficient of thermal expansion [m/mK]	$12{,}6x10^{-6}$	$11x10^{-6}$	$11{,}3x10^{-6}$	$10{,}3x10^{-6}$
Thermal conductivity [W/m °C]	25	20	25	20
Corrosion resistance	yes	yes	no	yes

Source: Böhler, EOS

Conformal cooling applications: principles & argumentation lines

Additive Manufacturing (AM) offers various advantages in tooling

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AM technology key differentiators compared to conventional manufacturing processes in tooling

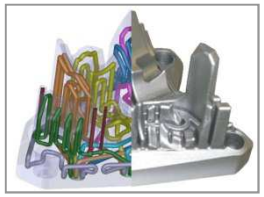
Freedom of design

Complexity

- Conformal cooling/ heating channels
- Reduction of post processing time for moulds (EDM)

Lightweight

- Focused on reducing building time for components (like blow molding), DMLS friendly design



Cost advantages

Performances

- Productivity of tools
- Better part quality
- Cost per plastic parts reduction

Tools inserts and moulds

- Cost barrier (factor 3-10)
- In average 10% of mould costs for 25% productivity increase or more

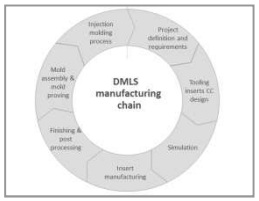
Customized manufacturing chain

Design of CC

- Tooling training with EOS partner/customer
- Software to validate CCC concept (simulation) like Moldex3D

Material

- Tool steel



Time to market

Availability of inserts

- No delivery time (powder always available) except for hybrid design
- CCC and part/insert grown at the same time
- Mould trial: reduced test time for moulds
- Design driven manufacturing: reduced setup time & adjustement

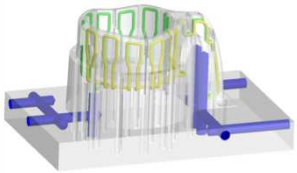


Image sources: LBC

Additive Manufacturing (AM) applications for tooling

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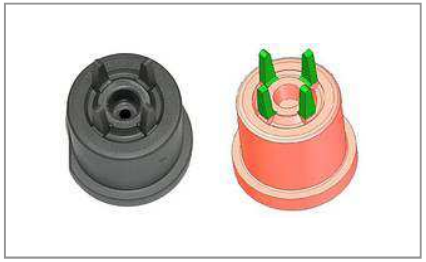
Smarter design of conformal cooling channels: cost savings, cycle time reduction, increased performance, scrap rate reduction

Injection molding

Tool insert for injection moulding

- For duroplasts, thermo-plasts, elastomere
- DMLS enables built-in, conformal cooling chan-nels that can be optimized to draw off heat more rapidly and evenly
- Result: dramatic cycle time reduction, increased part quality

Special application areas



Tool insert

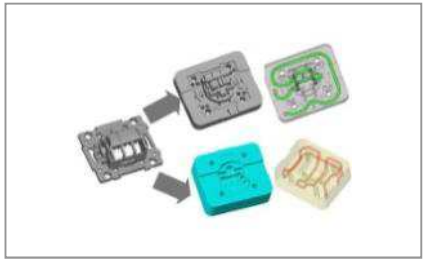
- Ideally suited for the reparation of e.g. tooling inserts, blow molding
- DMLS enables partial instead of a complete replacement of a partially damaged insert
- DMLS saves costs and reduces lead time for repair process)

Die casting

Tool insert for die casting

- Aluminum, zinc
- DMLS enables cooling system and cooling channels optimization, consequently reducing cycle time reduction and enabling serial production

Rapid Tooling



Tool insert

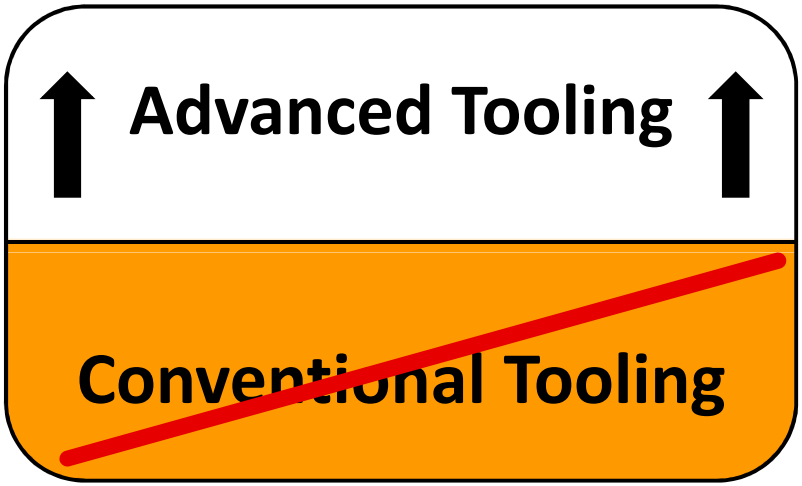
- 0 series, prototypes
- DMLS can reduce lead times compared to conventionally manufac-tured inserts
- DMLS also enables costs reduction for tool production due to faster working time, increased mould, better thermal management of mould

Sources images (left to right): LBC, Ecoparts, LBC, PEP

DMLS advantages for the tooling industry

What is today the impact of conformal cooling in injection moulding?

- **Design driven manufacturing** or freedom of design
- **Optimized** cooling/heating channels: **hot spots** and critical areas of the insert
- **Productivity** and **quality** improvement
- **Complexity is not a cost-driver:** high number of possible designs are possible
- **Reduction of cost** per plastic product
- Validation of benefits and results through simulation
- Uniformity of cooling positive for improvement of the **insert life time**



Leave under defined circumstance the area of conventional tooling and choose a new way for solving challenges

Design freedom is quite unlimited

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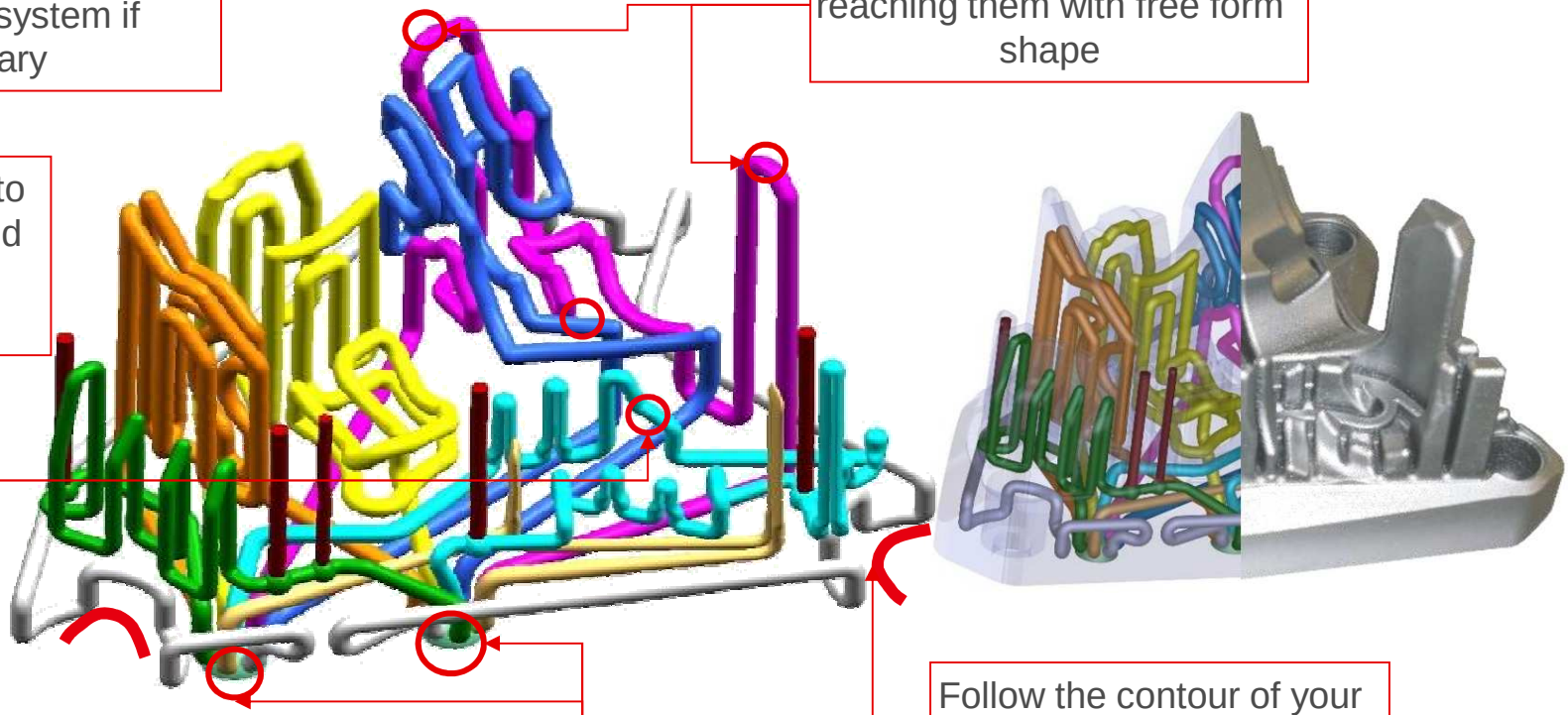
Do not hesitate to “boost” your cooling system if necessary

Cool down critical area, reaching them with free form shape

Give preferences to smooth lines, avoid right corners



Follow the contour of your insert and keep distance to surface/wall constant

If you need to split your channels, then take care of balancing them.
Characteristics: - water input/output: Ø 10 mm
- 8 splitted channels with Ø 3 mm with “equivalent” length

LBC
LaserBearbeitungsCenter GmbH

Source: LBC

Positive impact on injection moulding process

DMLS has a positive impact on the injection moulding manufacturing chain

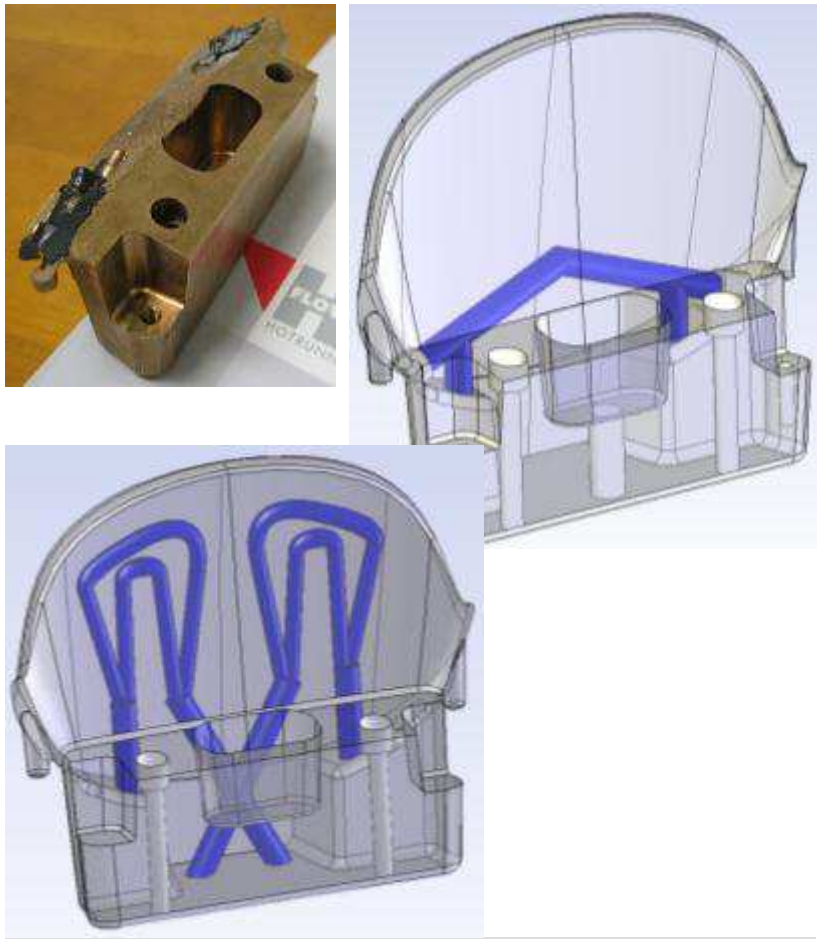
- The example concerns a thin-walled throw-away product (cheap raw material)
- DMLS has a selective effect on the costs along the manufacturing chain
- Advantages for inserts costs, productivity, cycle time, product quality and material usage
- Effects are additionally positive

Production cost distribution for product PS coffee cup

Advantages for tooling inserts

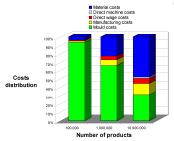
DMLS for tools costs and quality

- Complexity is not a **cost-driver**, lower price/insert thanks optimised use of the construction platform
- Reduction of Lead times (Cooling system and inserts are built at the same time)
- Hybrid approach save costs
- **Conventional existing solutions are not an alternative**
- Description: insert manufactured by DMLS and age hardened at 48-50 HRc to replace a CuBe insert broke during moulding process after 150.000 shots.
- Objective: keep or improve cooling efficiency by means of an insert structurally more resistant than the Cu-Be one.
- Results: 350.000 parts have been moulded, no break failure has occurred, cooling improved in the upside area of the tool insert.



Change in design and material: from conventional design on Cu-Be to conformal cooling with MS1 Maraging Steel

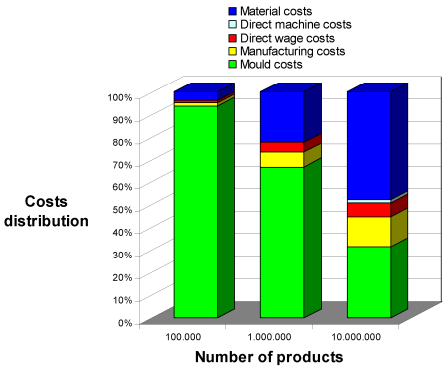
Source: Inglass



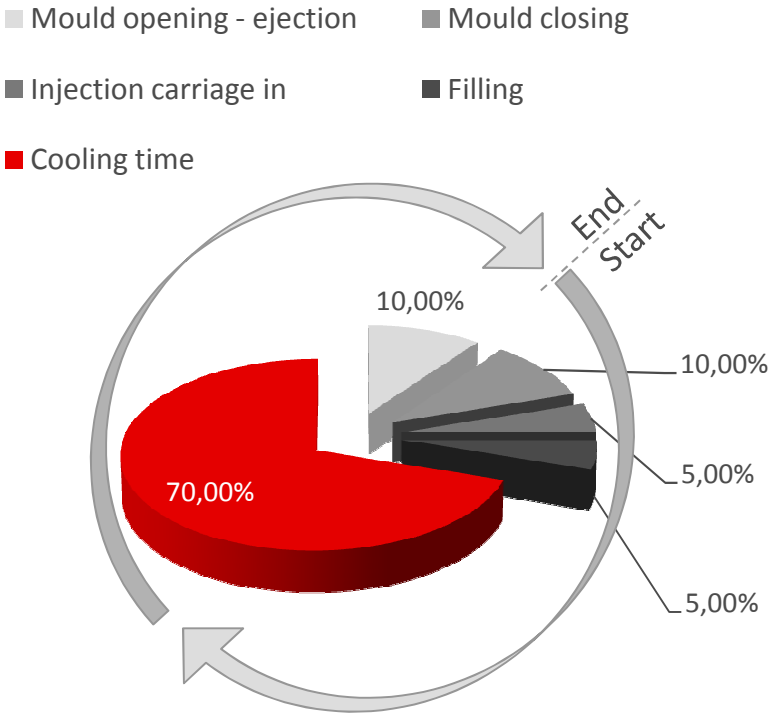
Influence on the injection molding process

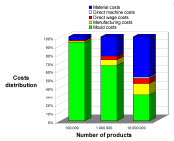
Advantages in terms of productivity

- Tempering system effectively allows up to 60% cycle time reduction
- Better control of the process
- Optimised workload and machine costs saving
- Better quality of the product



Cycle time diagram

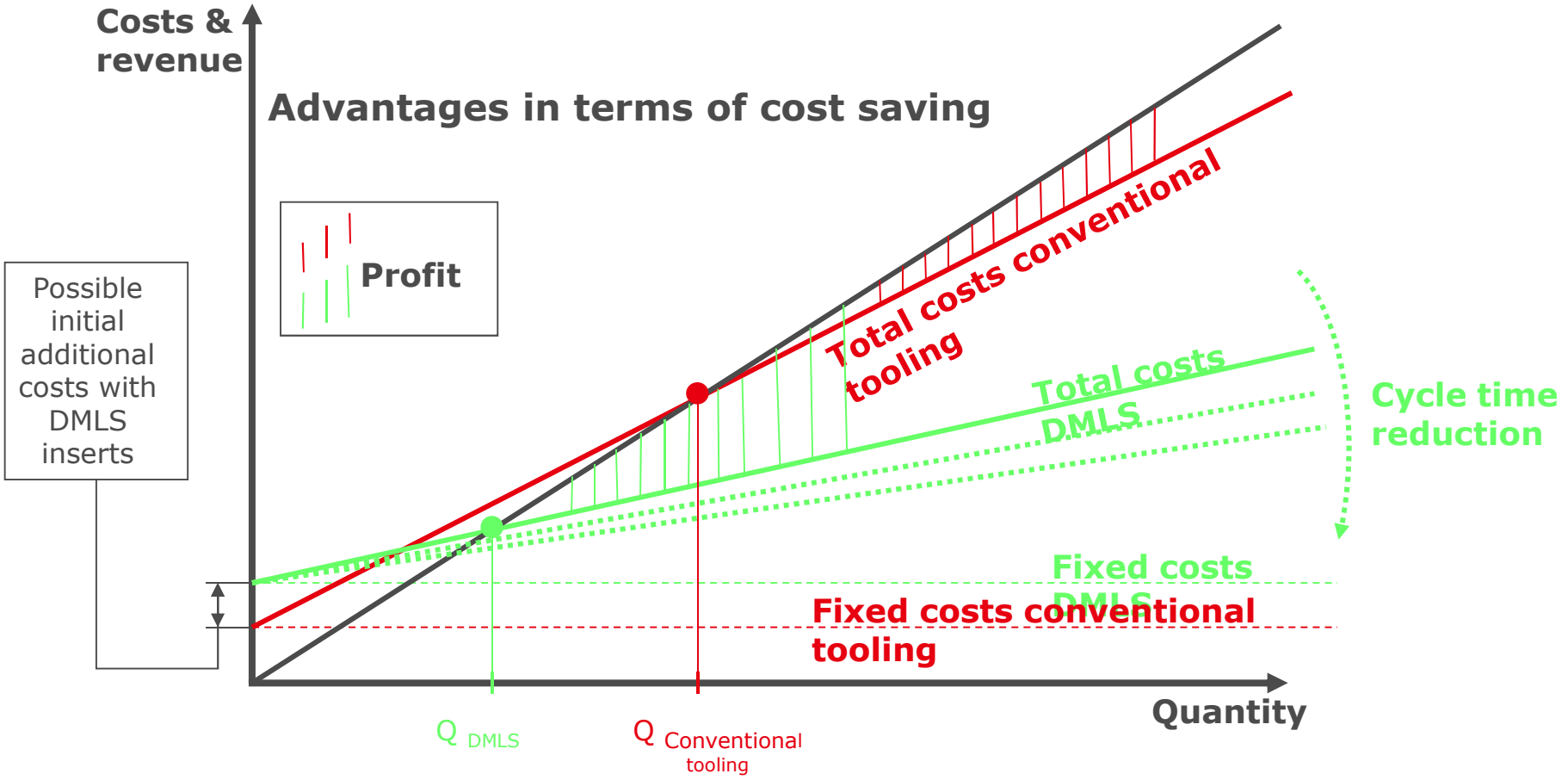




Advantages in terms of cost saving

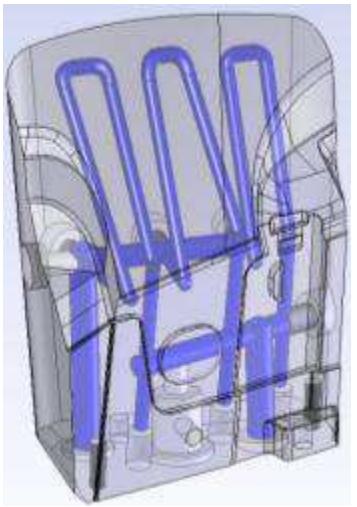
e-Manufacturing Solutions

Breakeven analysis illustrates economical benefits of DMLS in comparison to conventional tooling



Fast payback and important cost saving possible with DMLS

- **Challenge**
  - Reduce cycle time
  - Remove aesthetical problems due to bad cooling of the upper part of the insert
- **Benefits**
  - Elimination of defects on the aesthetical side of the part
  - Cycle time reduced from 66 down to 60 seconds



Waste due to scraps on production of 250.000 parts				
	% scraps	Molding process cost / piece[€]	Material cost / piece[€]	Waste for scraps [€]
DMLS	0.5%	3,000	7,000	0.055
Tradit.	2.0%	3,300	7,000	0.206

Cost of molding process for the production of 250.000 parts					
	t_{CYCLE} [s]	Pieces / cycle	Machine and direct labor cost per hour [€/h]	Press machine [tonn]	Machine and direct labor cost[€/pz]
DMLS	60	1	180,00	2200	3,000
Tradit.	66	1	180,00	2200	3,300

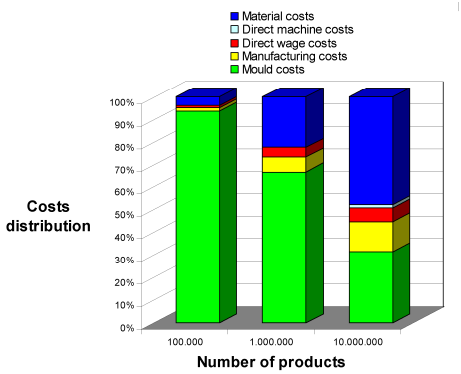
DMLS
€ -114,000.00

Examples of cooling lines on hybrid insert

Heating/cooling has the most important influence on product quality

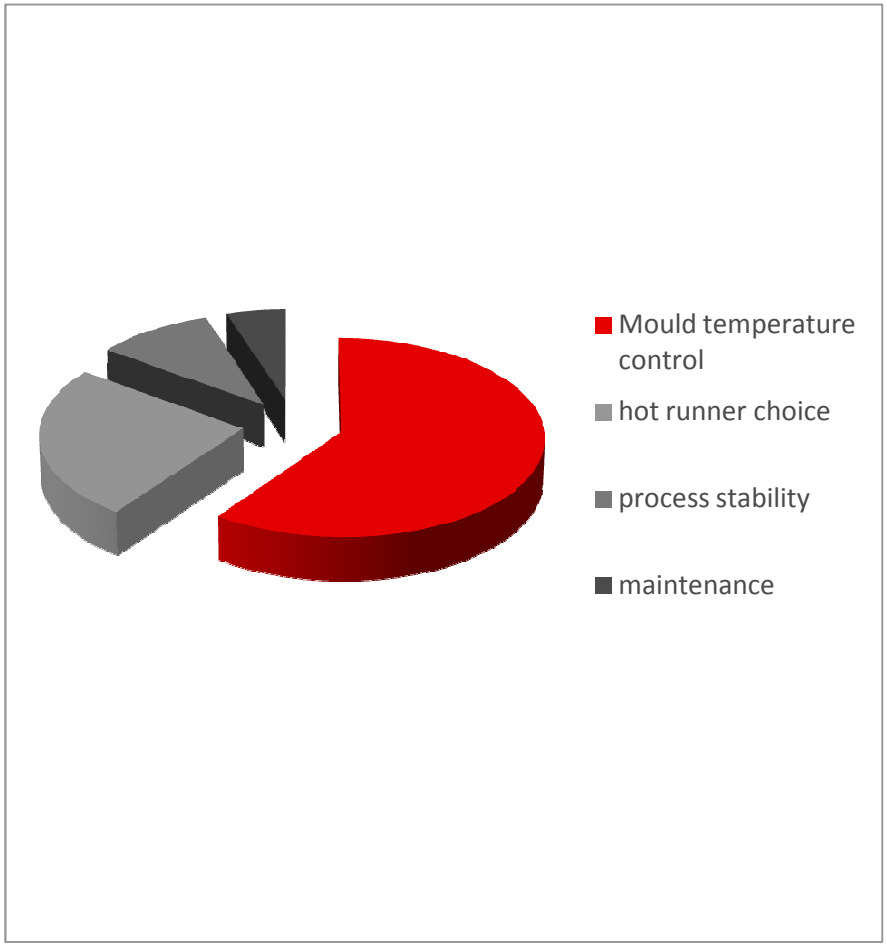
Advantages in terms of product quality

- 60% of defects on products come from wrong or not efficient mould temperature control
- 25% hot runner choice
- 10% process stability
- 5% maintenance



Source: GTT GmbH

Different factors influencing quality of product parts in injection moulding



Case Study

Hot runner nozzle with DMLS cooling bushing (Source: Inglass)

Description

- SLM bushing with conformal channels for injection gate conditioning. This device is used for molding of a PC transparent chair, weight 2.700gr, injected by single nozzle.

Objective

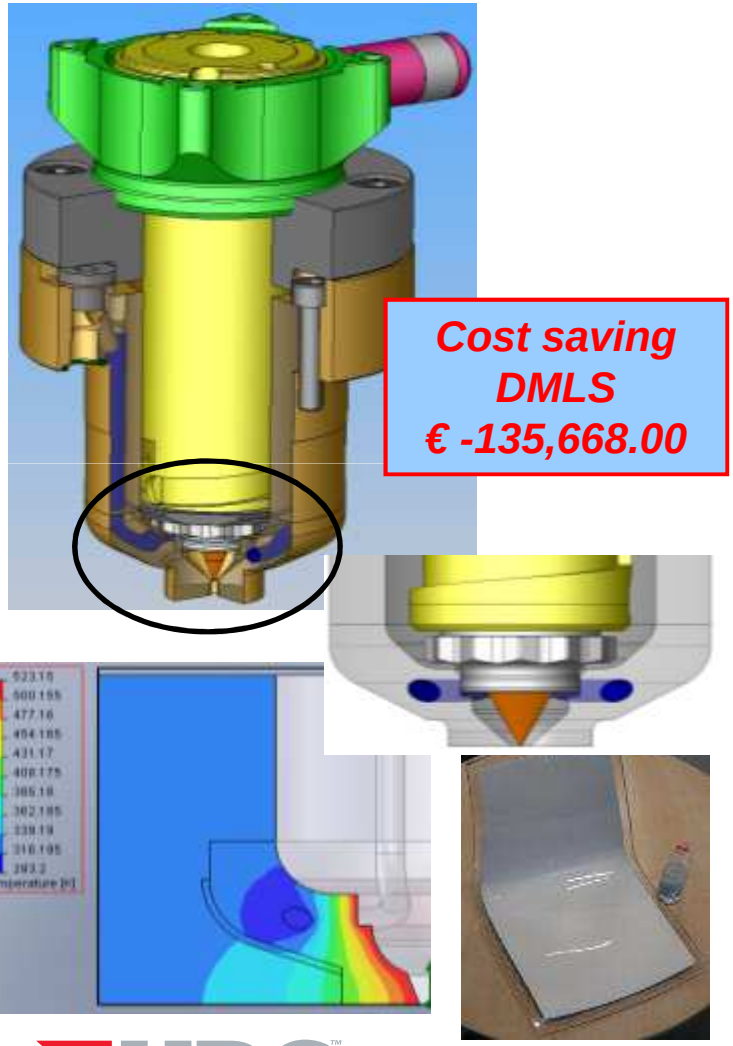
- eliminate burning defects on the injection point due to shear heating effect on the gate.

Results

- no burning defects on the injection gate,
- comparing to a similar part, cycle time was reduced from 128 down to 110 s.

Cost of molding process for the production of 150.000 parts					
	t_{CYCLE} [s]	Pieces / cycle	Machine and direct labor cost per hour [€/h]	Press machine [tonn]	Machine and direct labor cost[€/pz]
DMLS	110	1	114,00	1000	3,483
Tradit.	128	1	114,00	1000	4,053

Money waste due to scraps on production of 150.000 parts				
	% scraps	Molding process cost / piece[€]	Material cost / piece[€]	Waste for scraps [€]
DMLS	0.5%	3,483	7,0	0. 052
Tradit.	3.5%	4,053	7,0	0.387



Examples of conformal cooling applications

DMLS addresses major plastic applications

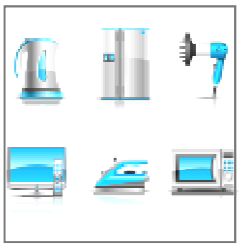
Conformal cooling in strategic markets

Packaging

- Life time of inserts
- Uniformity of performance

Electrical/household Appliances

- Life time of inserts
- Innovation in design
- Cycle time



Customer care and healthcare

- Cycle time
- Cost per part

Medical & pharmacy tooling

- Quality
- Productivity
- Complexity

Automotive

- Quality
- Productivity
- Cycle time
- Delivery time (TTM)

Toy industry

- Better quality
- Complex geometry

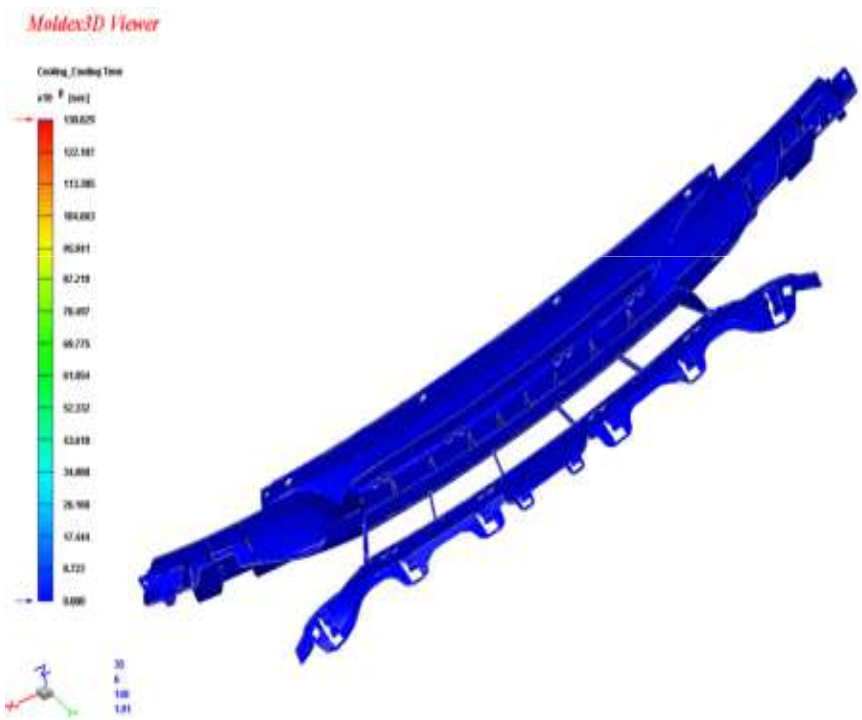
Optimized solution with hybrid design

DMLS tools and hybrid design improve quality and cycle time

Challenge

- Compare classic tool insert with hybrid technique and conformal cooling
- Look at end part quality
  - surface defects
  - Warpage
  - Scrap rate
  - Partial temperatures
- Evaluate result of end parts
- Improve part properties at critical areas

Cooling time part simulation



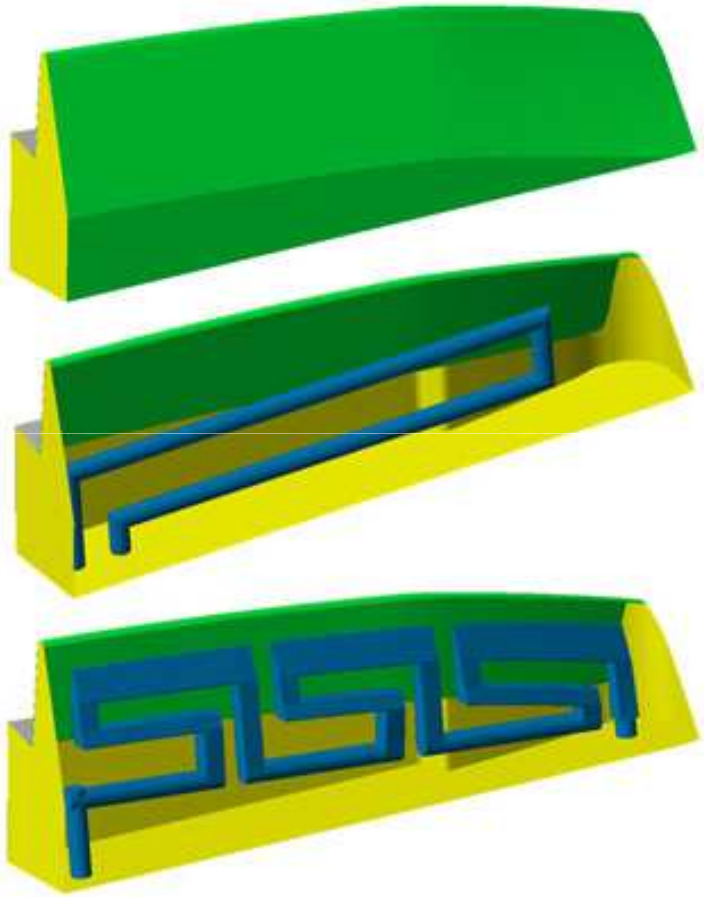
Sou BBE ENGINEERING Moldex3D MOLDING INNOVATION tec

Optimized solution with hybrid design

DMLS tools and hybrid design improve quality and cycle time

Solution

- Optimized conformal cooling channels regarding the cooling requirements
- Hybrid structure
  - lower part CNC milled
  - Upper part built on EOS M 270
- Material: EOS Maraging Steel MS1
- Building time:
  - CNC milling: 5 h
  - Direct metal laser sintering: 25 h
  - Post processing: 5 h



up: external surface; middle: conventional cooling; down: conformal cooling

Source: BBE Engineering; Prodintec

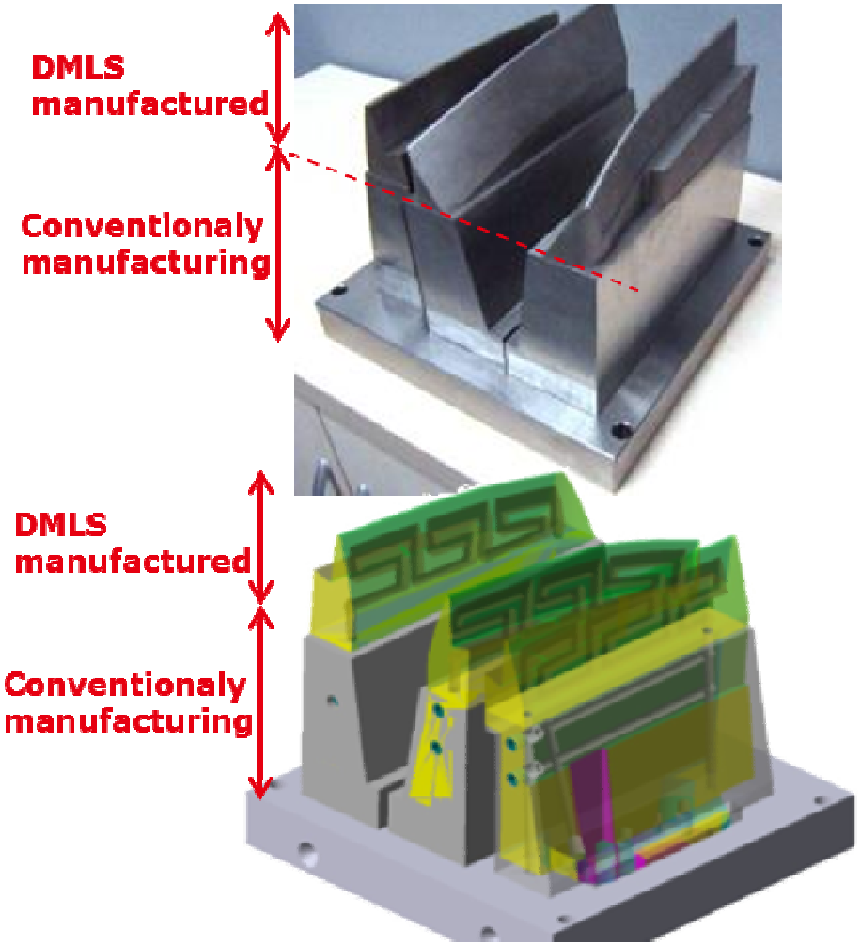
Optimized solution with hybrid design

DMLS tools and hybrid design improve quality and cycle time

Benefits:

- less warpage and better mechanical properties
- Higher surface quality
- Cooling time down from 56 to 35 s → **37 %** faster
- Cooling temperature reduce from 102°C to 82°C
- Temperature gradient lowered from 80°C to 30 °C
- Production rate increased from 1 part per minute to 2 parts per minute

Hybrid tool design: upper part DMLS; lower part conventional



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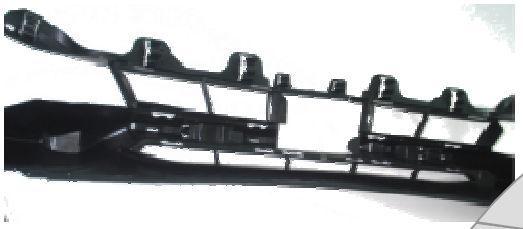
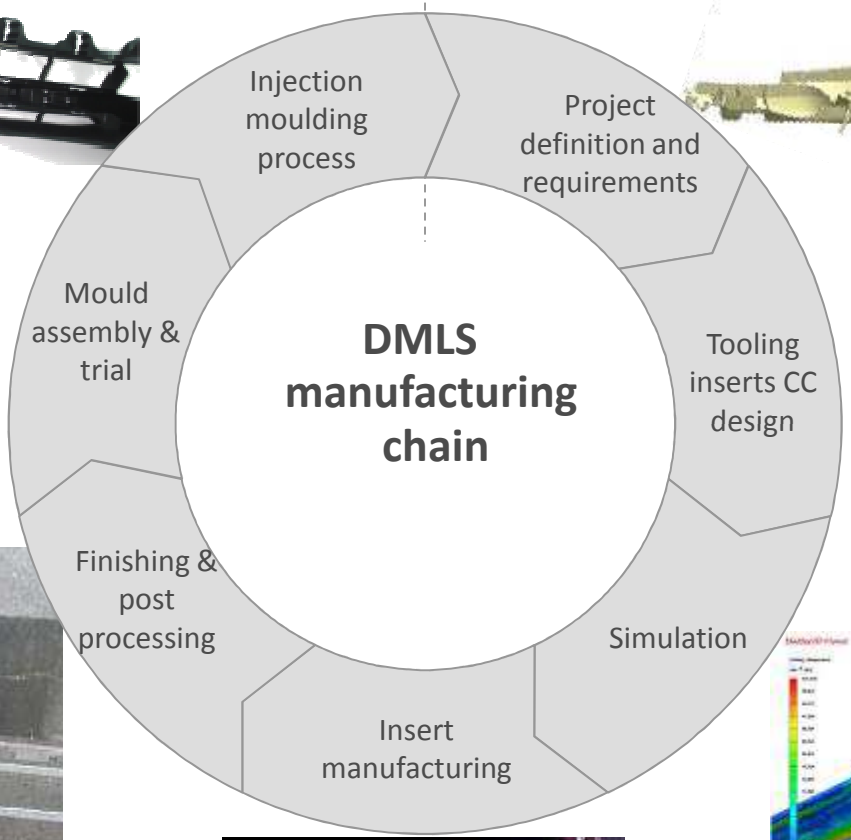
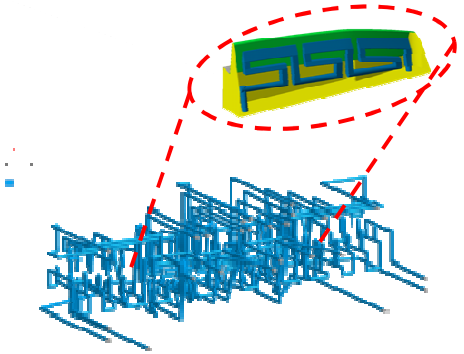
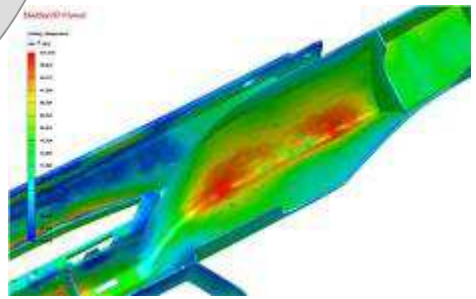
DMLS manufacturing chain







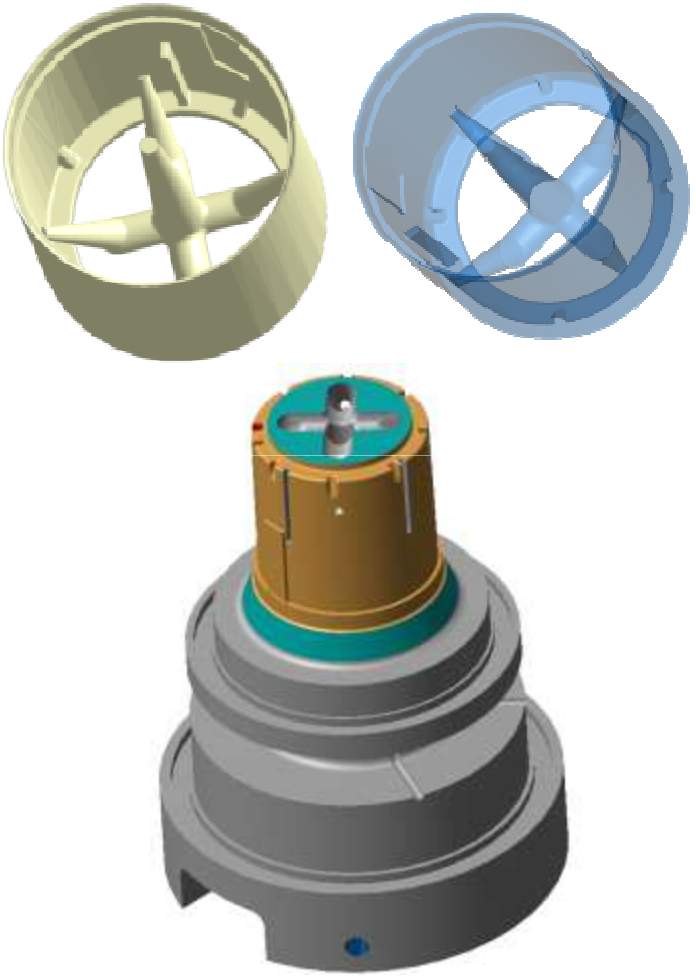


Better injection moulding process with DMLS

DMLS addresses quality and cost per part challenges

Challenge

- Cost reduction for the manufacturing of an automotive plastic product (San, Luran 368 R Crystal Clear, BASF)
- 4 cavities mould, standard solution with cupper alloy inserts
- Optimize cold Runner and nozzle gate process
- Improve quality of the manufactured part



Insert and plastic part

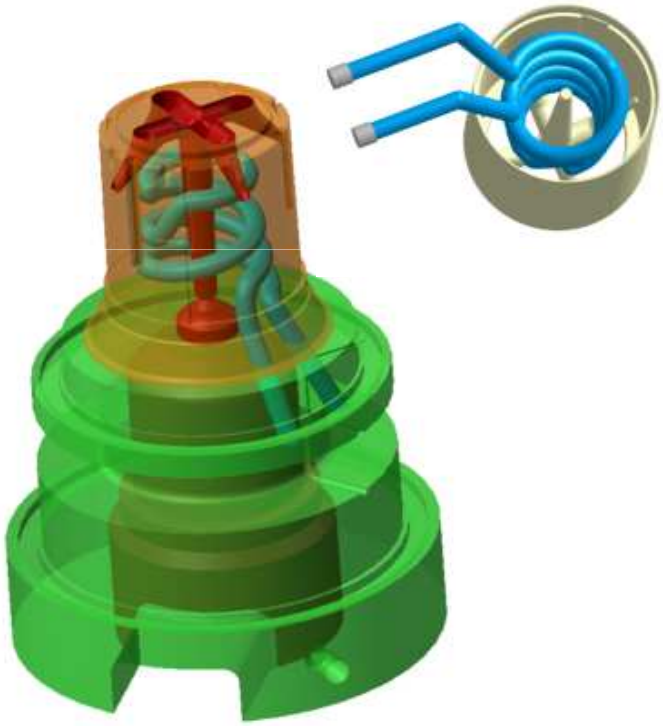
Source: BBE Engineering; Prodintec

Better injection moulding process with DMLS

DMLS tools and hybrid design improve part quality and cycle time

Solution

- Design of conformal cooling channels
- Hybrid structure
  - Manufacture the lower part of the mold by conventional process (CNC milling)
  - Upper part built on EOS M 270
- Material: EOS MaragingSteel MS1
- Validation of results with flow, fill and cooling simulation using Moldex3D => decision for final design



conformal cooling channel; design of the DMLS insert

Better injection moulding process with DMLS

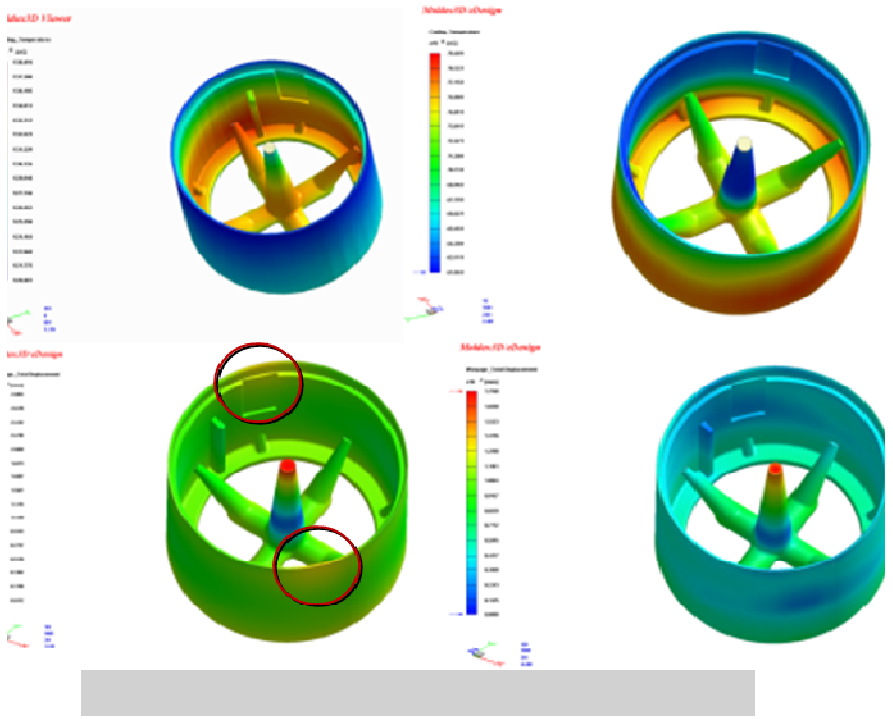
Simulation compares benefits of conformal cooling channels with conventional solution

Upper picture : temperature distribution analysis.

Bottom picture: warpage analysis

Solution

- The simulation is performed for the 2 possible solution with Mouldex3D
- Temperature distribution
  - The solution with the cupper alloy shows a maximum temperature of 107°C
  - The solution with the cupper alloy shows a maximum temperature of 79°C
- Warpage analysis
  - The conventional solution shows of max 0,25mm
  - The DMLS solution shows a warpage of 0,1



Conclusions

e-Manufacturing Solutions

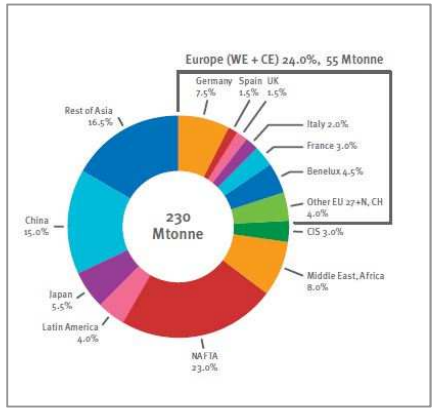
DMLS will succeed in tooling only if successfully integrated in the expanding european market

e-Manufacturing Solutions

Content

- Europe zone represents 24% of the worldwide production of plastics resins
- Software solutions offer from Moldex3D means for DMLS:
  - Proof of results
  - Optimization leverages and strategy
  - Guarantee of success
- DMLS can deliver answers to the upcoming challenges of the plastic industry: better quality, lower cost pet parts, sustainable production
- DMLS is an opportunity for innovative companies to differentiate themselves in a global context
- EOS will in the future works together with chosen partners of the manufacturing chain in order:
  - to deliver best results for common customers all over the manufacturing chain
  - Push the boundaries of the technology

World plastic production (2009)



Is the future here?

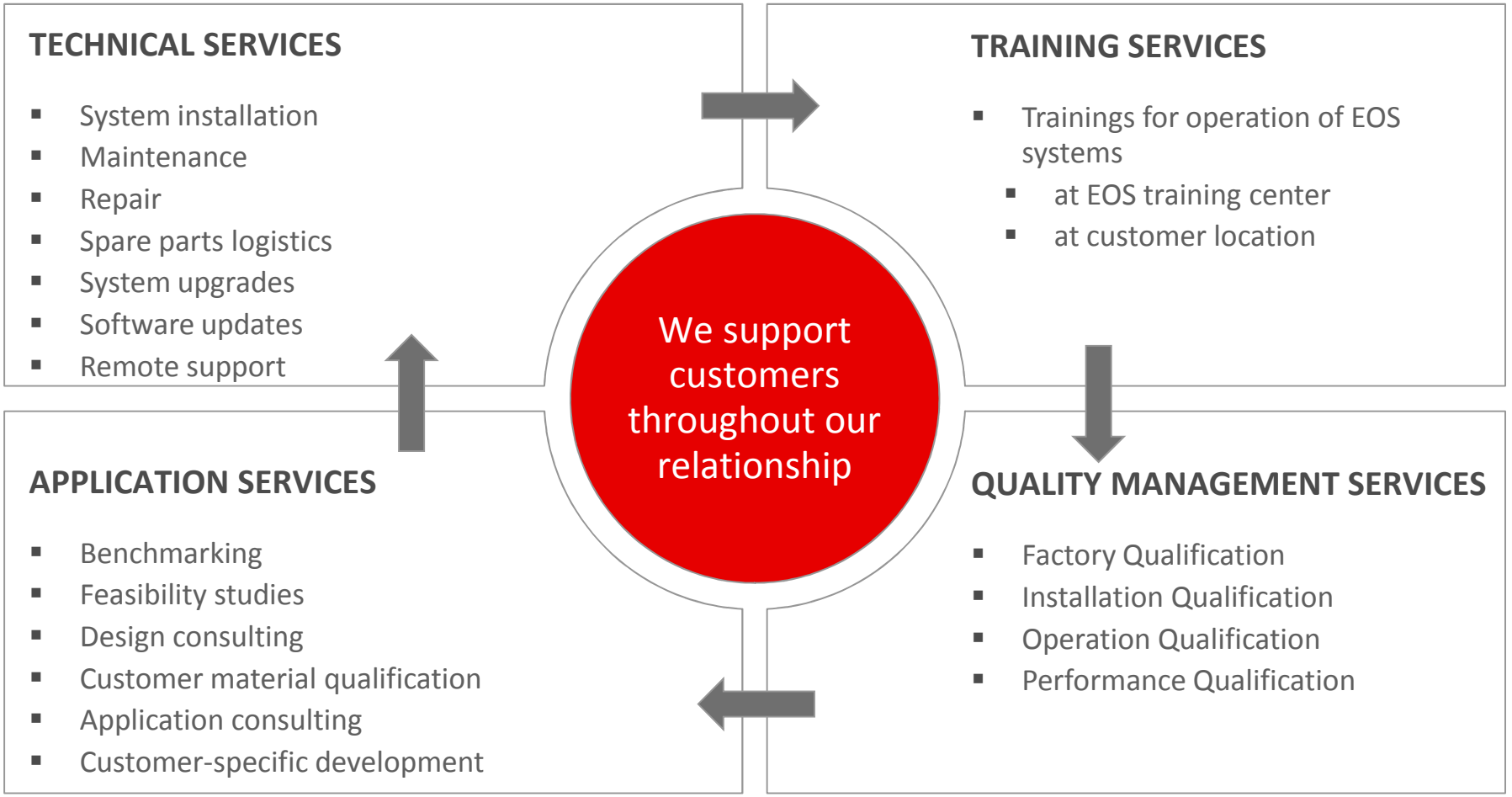
Reduced carbon footprint

Caps & closure has the most important business potential

Source: PlasticsEurope Market Research Group (PEMRG)

EOS is a solution provider with a consistent service offer

EOS: Service Offerings



e-Manufacturing Solutions

Thank you for your attention!

www.eos.info