Siemens Gas and Power
Overview of additive manufacturing, benefits and challenges industrial approach for AM

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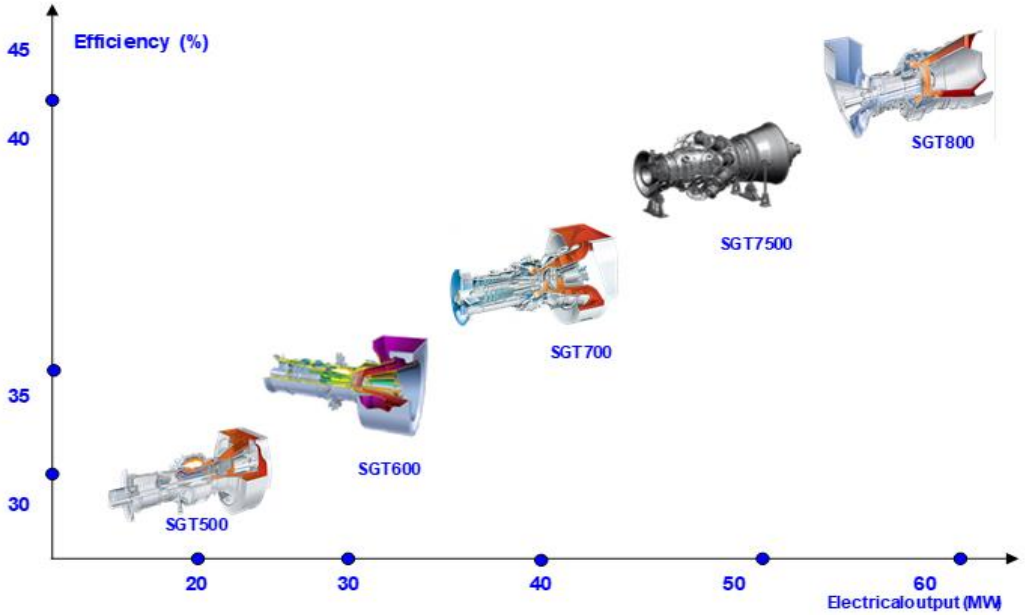
NRC Workshop on Advanced Manufacturing

2020-12-07

Siemens Gas and Power



Turbine manufacturing in Finspong-Sweden since 1913, over 100 years experience

2700 Siemens Energy employees of which 75 different nationalities 300 R&D resources

Part of Siemens since 2003 and from 2020 Siemens Energy AB

- **~ 1,000 gas turbines ; ~ 2,300 steam turbines; ~ 50 power plants; ~ 50 delivered heat pumps**

Pioneering Additive Manufacturing

Dedicated workshops in Finspång for development, serial manufacturing and repairs of turbine parts in metal using 3D printing (Additive Manufacturing)

- Pioneers in 3D printing
- Previously “impossible” designs are now possible
- Minimal environmental impact
- Development of components for CO_2-free fuels such as hydrogen
- Enables the use of biogas in our own gas turbine testing facility in order to become fossil-free in 2030

70% reduction in use of resources
46% reduction in the impact on the climate
90% shorter lead-time

Repairs to burner tips using 3D printing compared with conventional methods

Siemens Gas and Power
Key factors and technologies in the development of future gas turbines

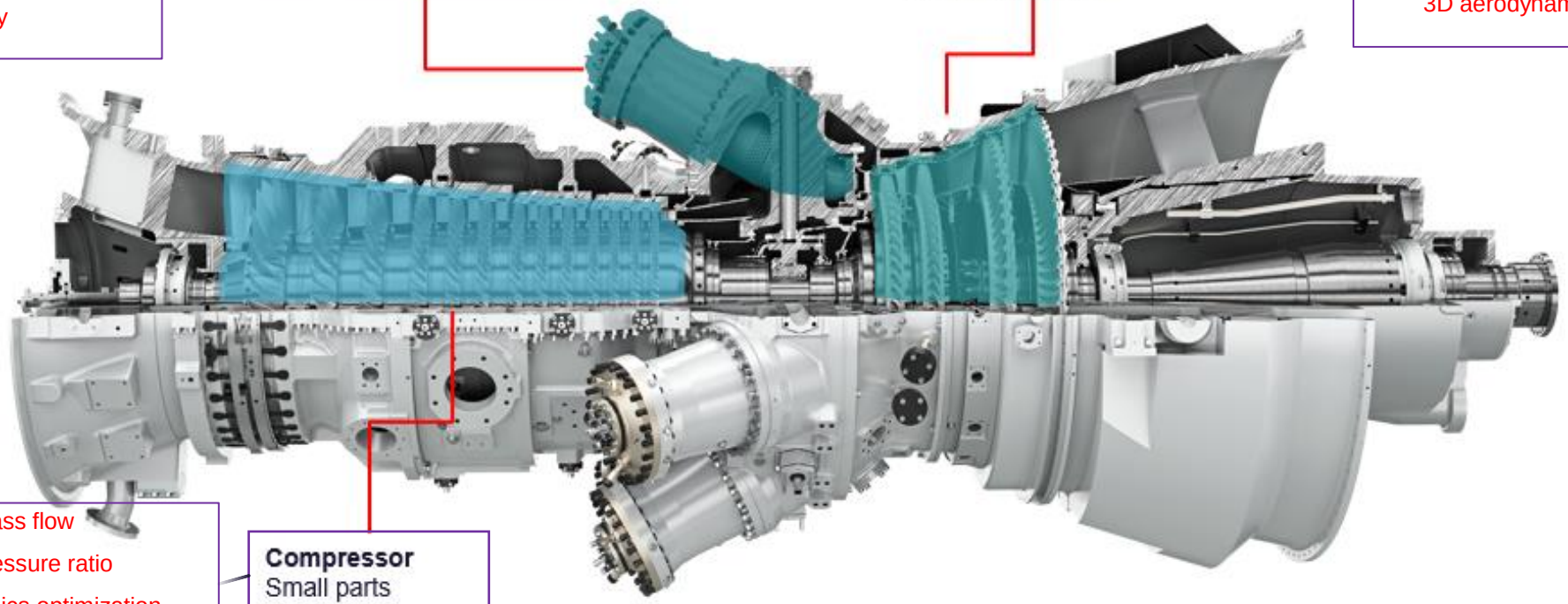
*Gas turbines with it's **complex parts** in **expensive material***
and
*relatively small volumes **makes AM very attractive!***

Higher combustion temperatures
Optimized burner (fuel flexibility)
Reduced emission
Increased efficiency

Combustion System
Burner / Swirler / Nozzle / Mixer

Turbine
Small parts
Blades and Vanes

Higher turbine inlet temperatures
New materials and coatings
Improved cooling and sealings
3D aerodynamics, loss reduction



Increase of mass flow
Increase of pressure ratio
3D aerodynamics optimization
Reduction of aerodynamic losses

Compressor
Small parts

Siemens was an early adopter of SLM AM technology and have successfully scaled its production

From R&D to serial parts production with SLM technology in 10 years

Outcomes

- **2006** — First Selective Laser Melting demonstrators
- **2012** — First SGT-800 Rapid Burner Tip Repair
- **2013** — SGT-750 combustion swirlers in commercial operation
- **2015** — Prototyping of qualification parts for LGT, IGT, AGT, IST
- **2016** — SGT-1000F Burner head in commercial operation
- **2017** — Turbine blade printed & tested in engine (SGT-100)
- **2018** — SGT-700 Burners Commercial operation
- **2019** — SGT-800 Heat shield
- **…** — *Blades*, *Vanes*, *Ring Segment*

FY 2006 | 2009 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | …

Key enablers

- **2006** — Material Solutions founded in the UK
- **2009** — Installation of the 1st EOS M270 SLM machine in FSP
- **2012** — Installation of 1st EOS M280 SLM machine in FSP, specifically adapted for Burner repair
- **2014** — Dedicated Additive CoCs established
- **2014** — Develop-ment and qualification of Processes and Materials
- **2016** — Acquisition (Materials Solutions, A Siemens Business)
- **2016** — Finspong Industrial workshop inaugurated
- **2018** — First M400/4 Installed
- **2019** — New M400/4 Shared modules Installed
- **2019** — New workshop

SLM: Selective Laser Melting

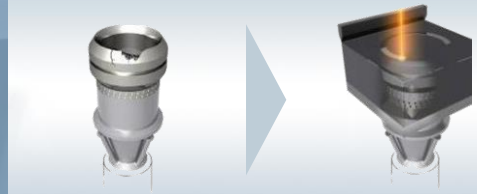
Fields of use and application

Rapid Manufacturing

- **Product**: SGT-700/800
- **Component**: Burner
- **Benefit**:
  - Higher performance
  - 85% lead time reduction
- **Status**: Final testing phase

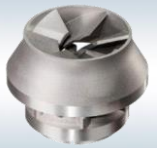
Rapid Repair

- **Product**: SGT-700/800
- **Component**: Burner tip
- **Benefit**:
  - 90% lead time reduction
- **Status**: In commercial application since 2013



Spare parts on demand

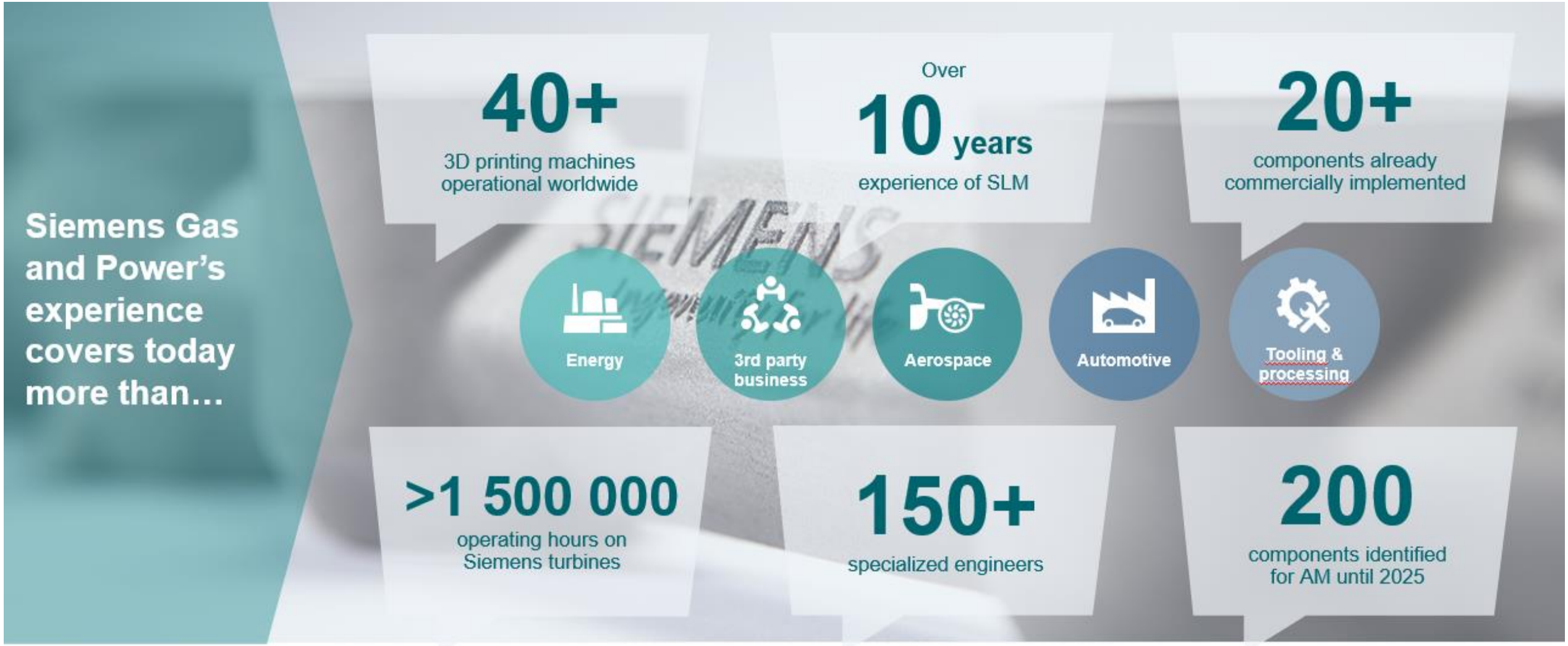
- **Product**: SGT-1000F
- **Component**: Burner head
- **Benefit**:
  - Reduced lead time by up to 40%
- **Status**: In commercial application since 2016



Rapid Prototyping

- **Product**: SGT5-4000F
- **Component**: Turbine Vane
- **Benefit**:
  - Development time reduction by 75 %
  - Early validation of NextGen Designs
- **Status**: Tests ongoing

Siemens Gas and Power is one of the world leaders in designing and producing commercial AM components for serial production



AM challenges and opportunities

Challenges

- *Material knowledge*
- *Design culture*
- *Stand-alone software*
- *Training*
- *Machine performance*
- *Quality issues*
- *Health and Safety concerns*

Disappointment:
"It is not just 3D-Printing!
It is much more complex.."

Autonomous AM 2025 +
IoT for **AM**

Intelligent AM
"Intelligent" through **Robots**, **VR/AR, AI**

Learning AM
"Learning" through **Big Data Analytics, AM Monitor, Virtual Storage** and **Machine Learning**

Connected AM
Connected" through **MES, AM Network, Digital Twin** and Use **Build Job Simulation**

Traditional AM

Innovation trigger — *2009*
Peak of inflated expectations — *2015*
Trough of disillusionment — *2016*
Slope of enlightenment — *2018*
Plateau of productivity — *2020+*

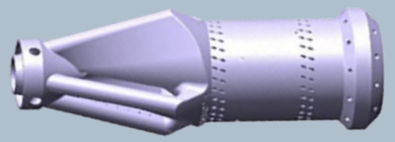
AM burner manufacturing for flexibility, shorter lead time and improved lifetime

Approach

- Manufacturing of SGT-700 / 800 burners by means of SLM
- Redesign of existing burners for SGT-700 / 800 to utilize the design freedom offered by SLM
- Full scale engine test performed
- Commercial operation in 2018

Conventional

- 13 parts / 18 welds
- TBC on front
- 26w lead time



SLM burner

- 1 integrated part
- No TBC due
- 3w lead time

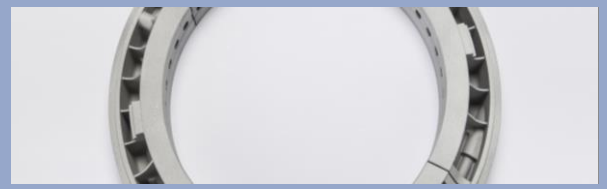
Benefits

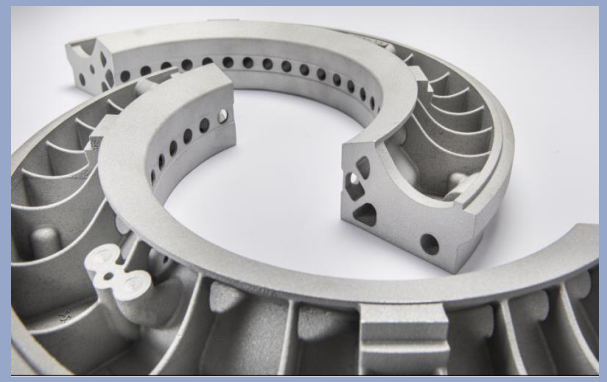
- Reduced lead time by 23 weeks
- Enabling customization for fuel flexibility
- Removal of TBC

Some of our references

Sealing rings SST-300 industrial steam turbine

Customer	JSW Steel Ltd. plant in Salem
Country	India





Challenges

Challenging environment and need of the customer

Solution

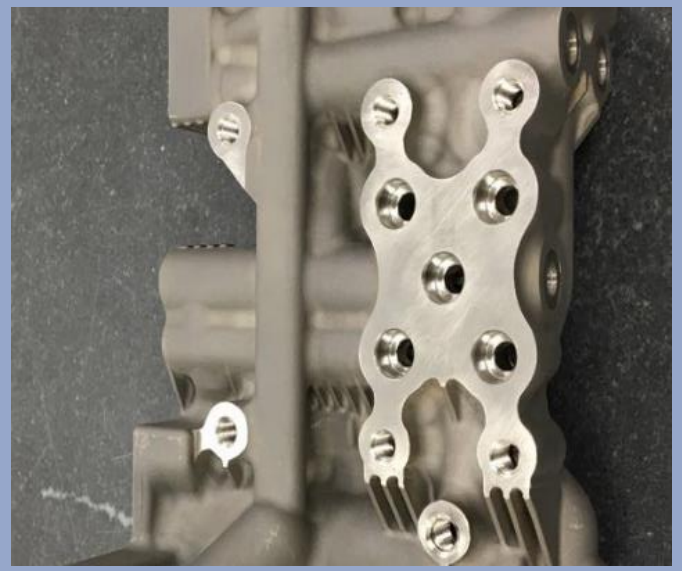
Optimized design and performance

Customer Benefits

Reducing weight, lead-time, high quality materials

Titanium high pressure hydraulic manifold for passenger aircraft

Customer	Sumitomo Precision Products Co., Ltd.
Country	Japan



Our Unique Propositions

One of the largest Metal AM Printer fleets in the world

Printers
EOS (M280;M290;M400-4)

Post processing
- Ultrasonic Cleaning
- 5 Axis Machining
- Blasting
- EDM Cutting/Bandsaw
- 3D GOM Scanning
- CMM
- Flow testing
- Coating
- Heat treatment
- Heat treatment
- Brazing

Unique capability

Qualified print process
- Nickel Superalloys
- Ferrous alloys
- Cobalt alloys
- Titanium alloys

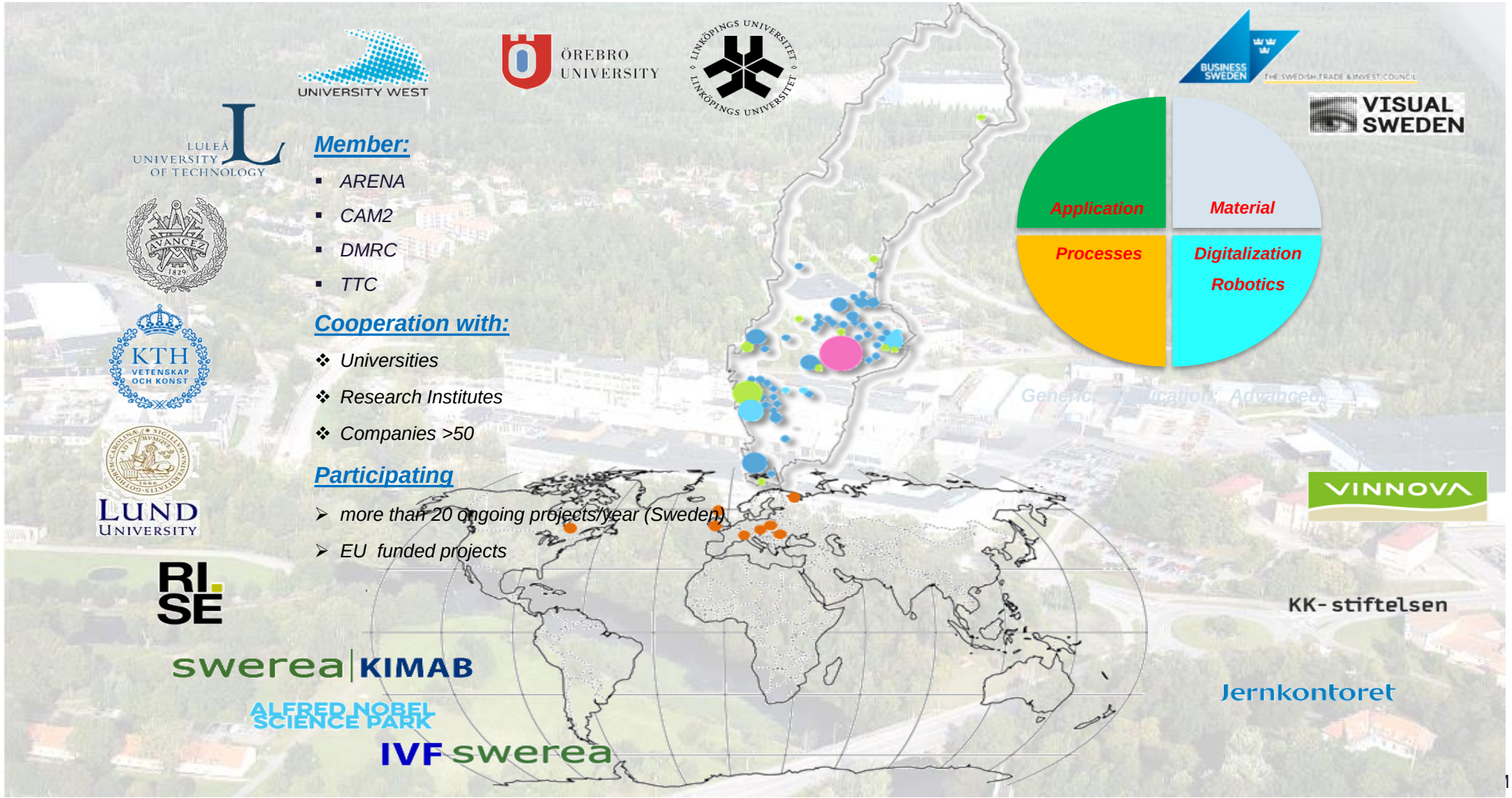
Fully qualified with design data

Aim at highest quality

One of the industry leading within Quality Assurance

Validation and Qualification

Siemens Energy and University cooperation in AM area



The projects as a result of cooperation with universities and research institutes

Several aspects related to AM automation

- Analyze and create directives and guidelines for what and in which situations AM production should be automated.
- Adapt the automation based on the need, not the need based on the automation of AM
- Automation level of AM, what is the company's policy ?

Collaborative robots for cleaning of machines chamber

Selection of the Criteria for Parts

- Dimensions & Weight
- Material
- Design features & complexity
- Function
- Loading
- Inspection requirement
- Accessibility
- Risk of failure
- Consequence of failure

The document states requirements

- The material produced by additive manufacturing is evaluated against the internal Siemens Energy quality document.
- Scope and procedures for metallurgical examinations (Material identification (powder alloy / material chemistry to certify the composition of the actual material)

Process Validation:

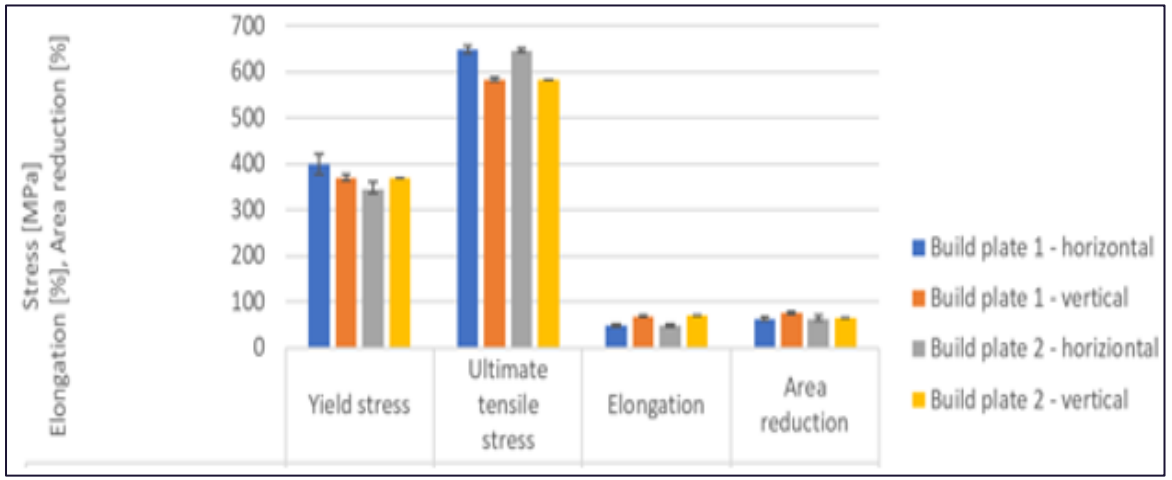
The components prints together with Test Specimens on the same building Plate

Scope and procedures for testing as per Siemens Energy standard material and quality requirements)

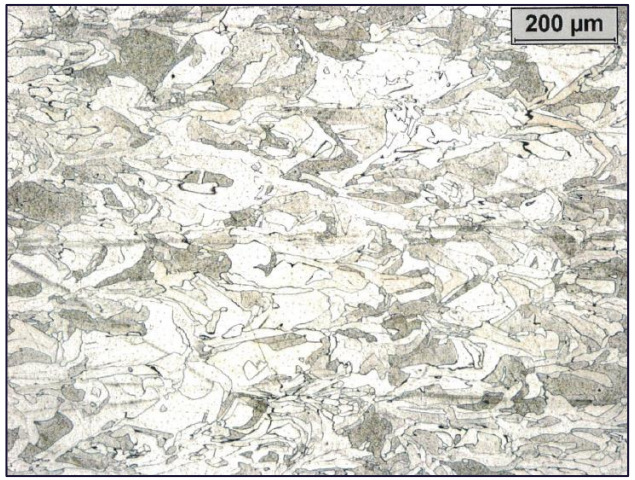
- Destructive testing
  - Tensile testing
  - Charpy testing
  - Hardness testing
  - Metallography (porosity, lack of fusion, contamination, hot cracking)
- Non-destructive testing
  - Radiographic testing (RT)
  - Ultrasonic testing (UT)
  - Penetrant testing (PT)
  - Inspection

- Scanning of components after important operations (printing, separation from building plate, heat treatment, machining…)
- Requirements for traceability (powder, component, process)

The document states requirements for:



Results from tensile testing of witness coupons in the two build jobs for the current project (average values).

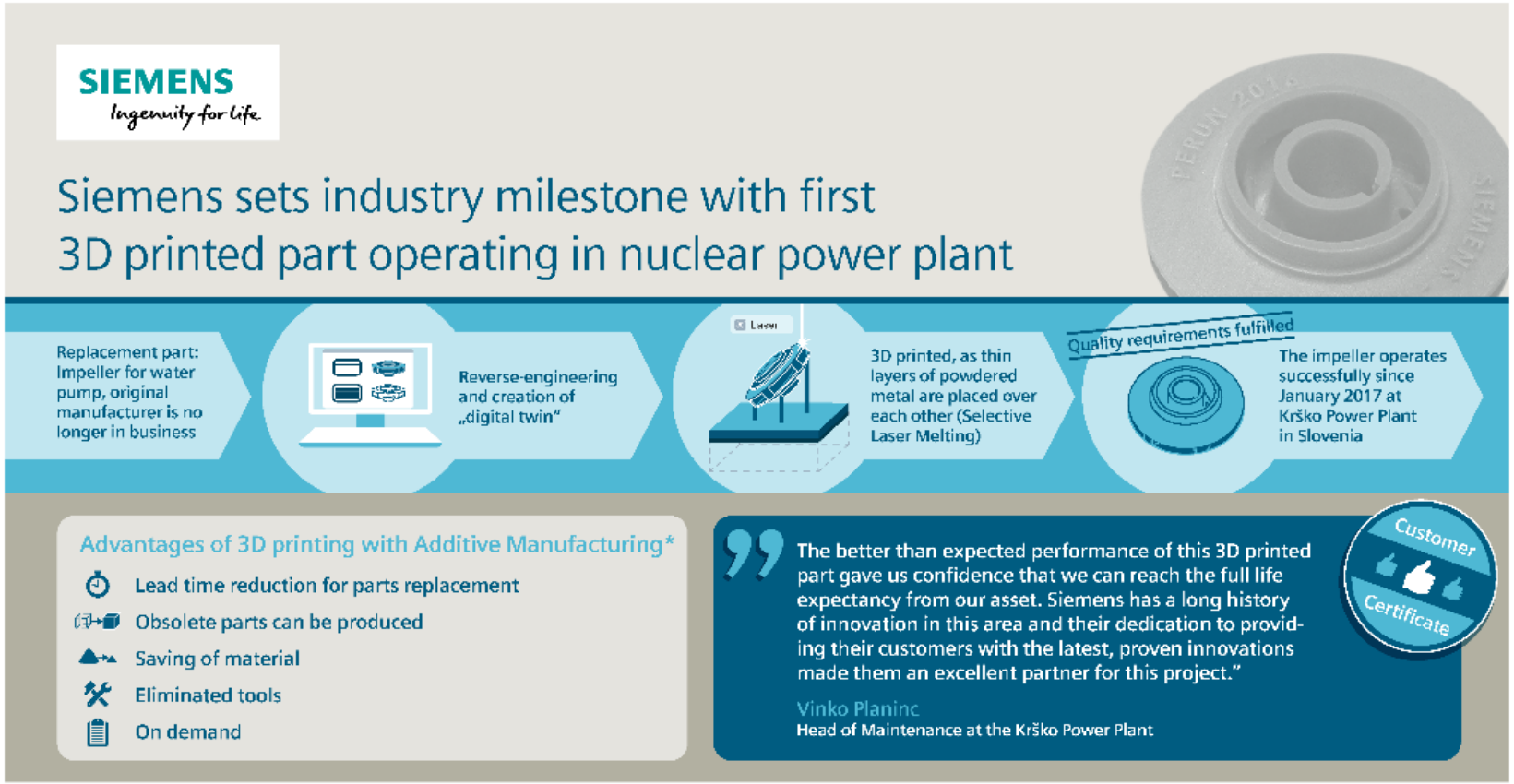


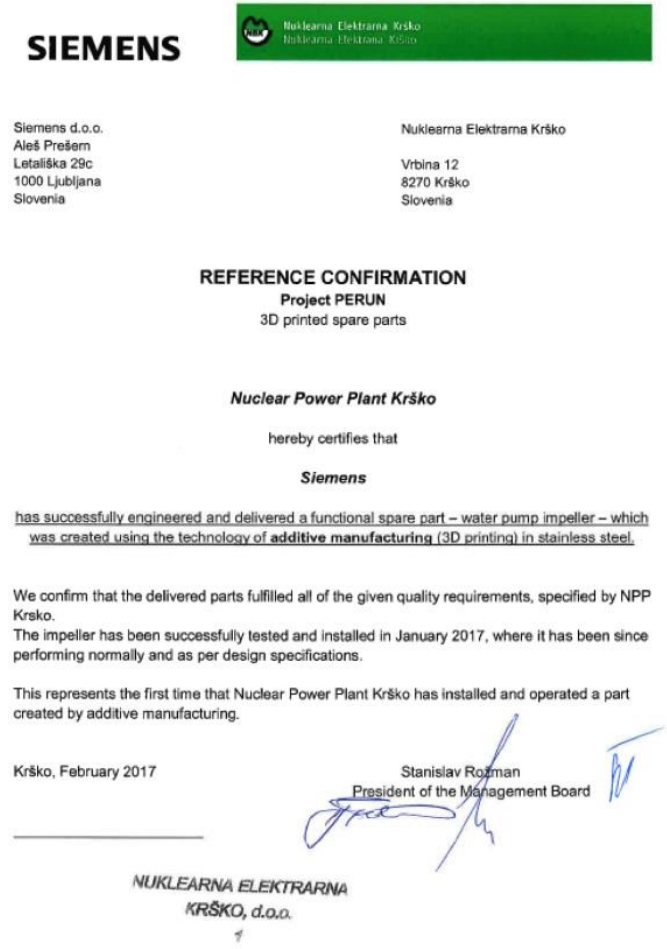
Microstructure example (witness coupon)

From the performed investigations (witness coupon) it can be concluded that:

- The material is within chemistry specifications
- The material fulfils quality control material properties
- The microstructure is normal for the process/material
- The Mechanical properties from two build jobs are in the same range

3D printed parts are in use at Nuclear Power Plant Krško, Slovenia





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Vrbina 12
8270 Krško
Slovenia

REFERENCE CONFIRMATION
Project PERUN
3D printed spare parts

Nuclear Power Plant Krško

hereby certifies that

Siemens

has successfully engineered and delivered a functional spare part – water pump impeller – which was created using the technology of **additive manufacturing** (3D printing) in stainless steel.

We confirm that the delivered parts fulfilled all of the given quality requirements, specified by NPP Krsko.
The impeller has been successfully tested and installed in January 2017, where it has been since performing normally and as per design specifications.

This represents the first time that Nuclear Power Plant Krško has installed and operated a part created by additive manufacturing.

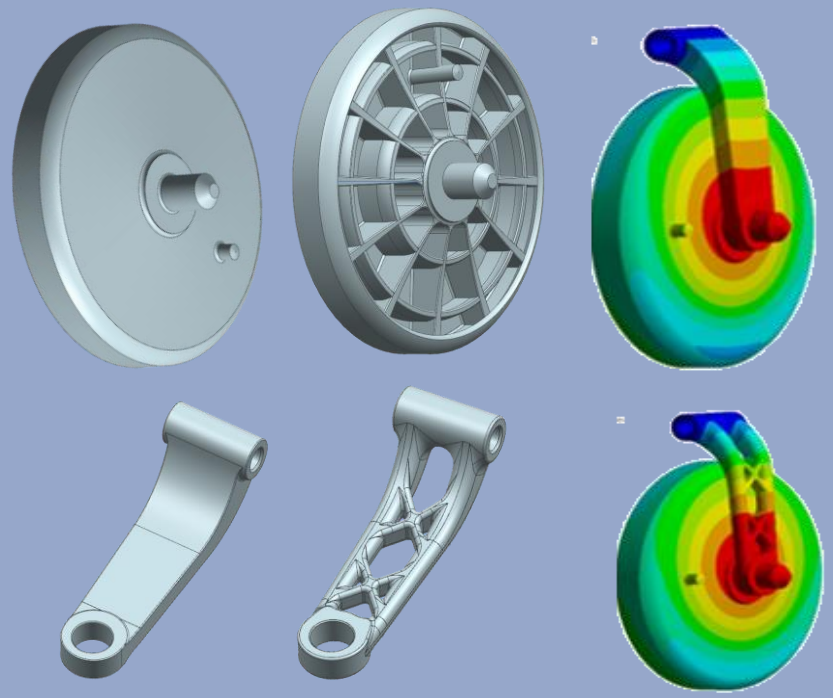
Krško, February 2017

Stanislav Rožman
President of the Management Board

NUKLEARNA ELEKTRARNA
KRŠKO, d.o.o.

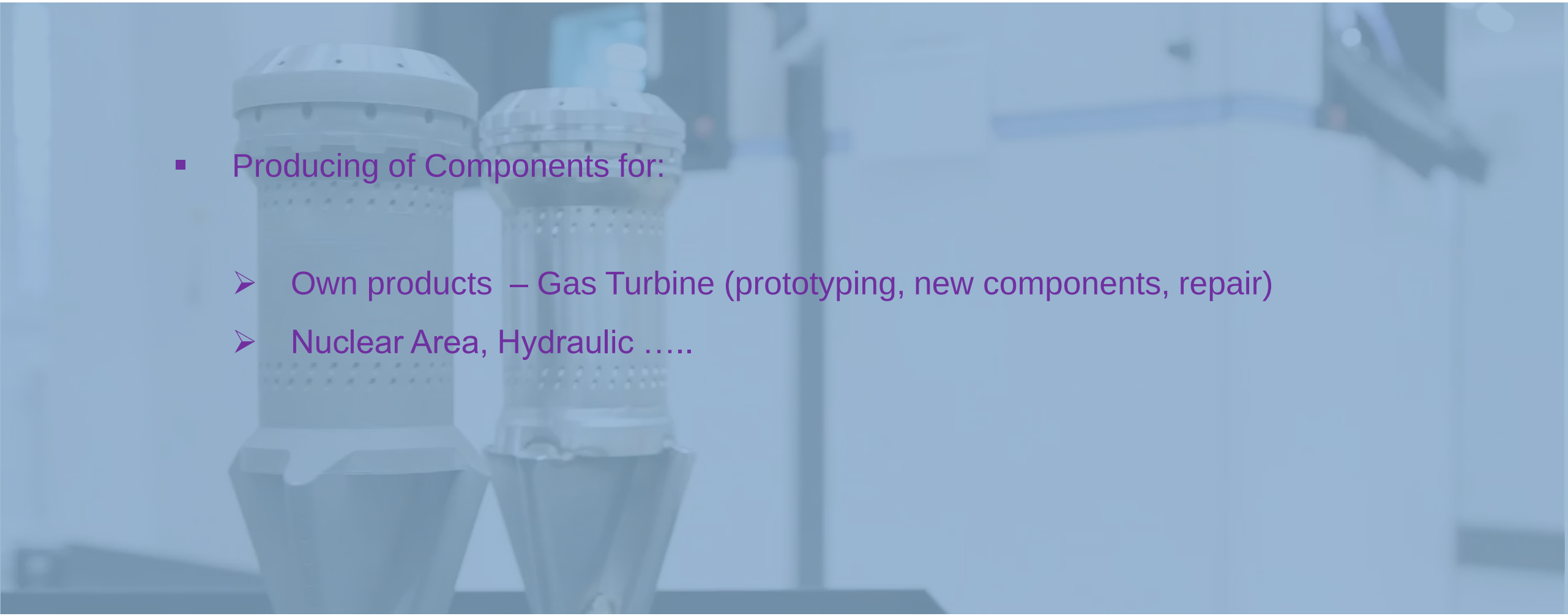
3D printed Clapper and Clapper holder

Customer	Nuclear Power Plant
Country	Spain



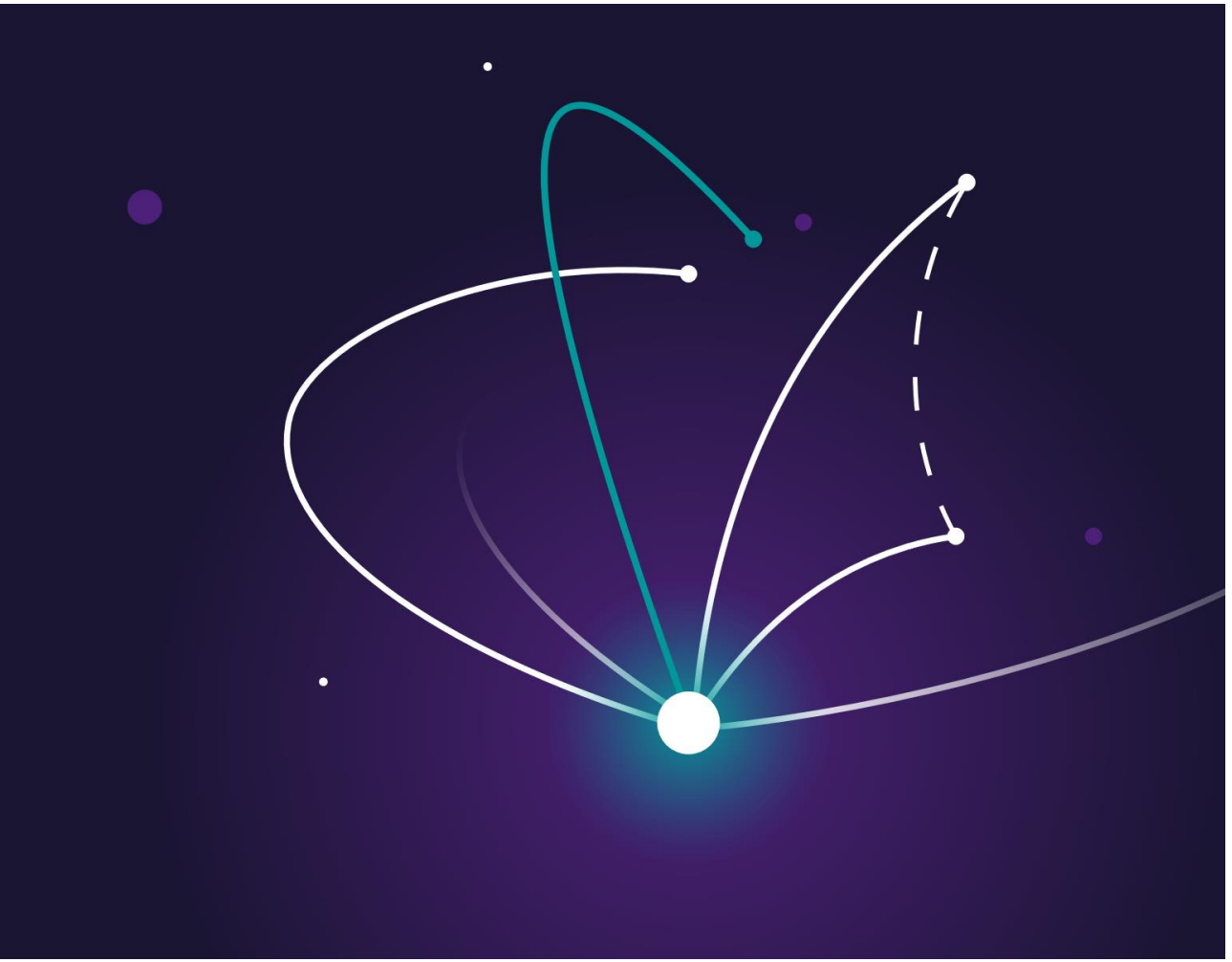
Challenges	**Obsolete part**	Obsolete part, since the original supplier no longer existed
Solution	**Reverse engineering and qualification of high requirements**	• Experts at Siemens Energy reverse engineered the Clapper and Clapper holder to produce a "digital twin" that served as the basis for the 3D printing technique • Assured qualification of part with high safety and reliability requirements
Customer Benefits	**Significant lead time reduction**	• Possibility to re-produce an obsolete part • Lead time reduction for parts replacement • Saving of material • Eliminated tools • On demand

Siemens Energy – AM Strategy



- Producing of Components for:
  - Own products – Gas Turbine (prototyping, new components, repair)
  - Nuclear Area, Hydraulic …..

Thanks you for the attention!



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