



Transportstyrelsen – 2019-11-07

Martin Lindbäck – R&D Head of Additive Manufacturing

- Siemens, what do we do?
- What is a gas turbine?
- Additive manufacturing overview
- Siemens additive manufacturing
- Discussion/Questions

- **Siemens, what do we do?**
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SIEMENS
Ingenuity for life

Leading in Electrification,
Automatization and
Digitalization

379,000

Employees

€83 bn

Revenue

€6.1 bn

Net profit

11.3%

Profit margin industrial
business

In Fiscal 2018

New company setup as of April 1, 2019



Operating Companies

Gas and Power*



Smart Infrastructure

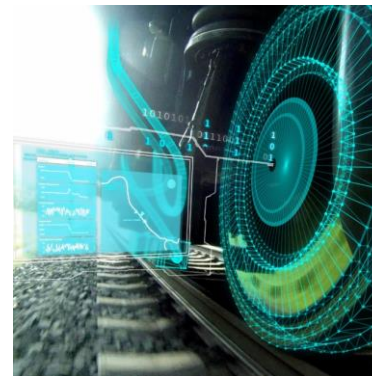


Digital Industries



Strategic Companies

Siemens Mobility



SIEMENS Gamesa*
RENEWABLE ENERGY



SIEMENS Healthineers



Service Companies (Financial Services, Global Business Services, Real Estate Services)

Corporate Development (e.g., IoT Services, Corporate Technology, Next47, Portfolio Companies)

Governance units

*Partial spinoff of Gas and Power planned; transfer of majority stake in SGRE (59%) to new company planned

The background of the slide features a large industrial turbine component, possibly a compressor or turbine section, with a complex, multi-bladed structure. The component is shown in a cutaway or semi-transparent view, revealing internal parts. The color palette is dominated by teal and blue tones, with a wireframe mesh overlaying parts of the turbine. The Siemens logo and tagline are positioned in the top right corner.

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Siemens Industrial Turbomachinery AB

Finspång, Trollhättan
Sweden

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[Siemens.com](https://www.siemens.com)

Siemens Industrial Turbomachinery AB

The power source for power engineering



We offer products and solutions for generating sustainable and resource efficient electricity. Our customers include utilities, independent power producers and companies in the oil and gas industry.

	2018
Turnover (billion SEK)	9
Number of employees	2 600



Siemens Industrial Turbomachinery AB

A story of success

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- Turbine manufacturing in Finspång since 1913
- Part of Siemens since 2003
- Turnover doubled in ten years



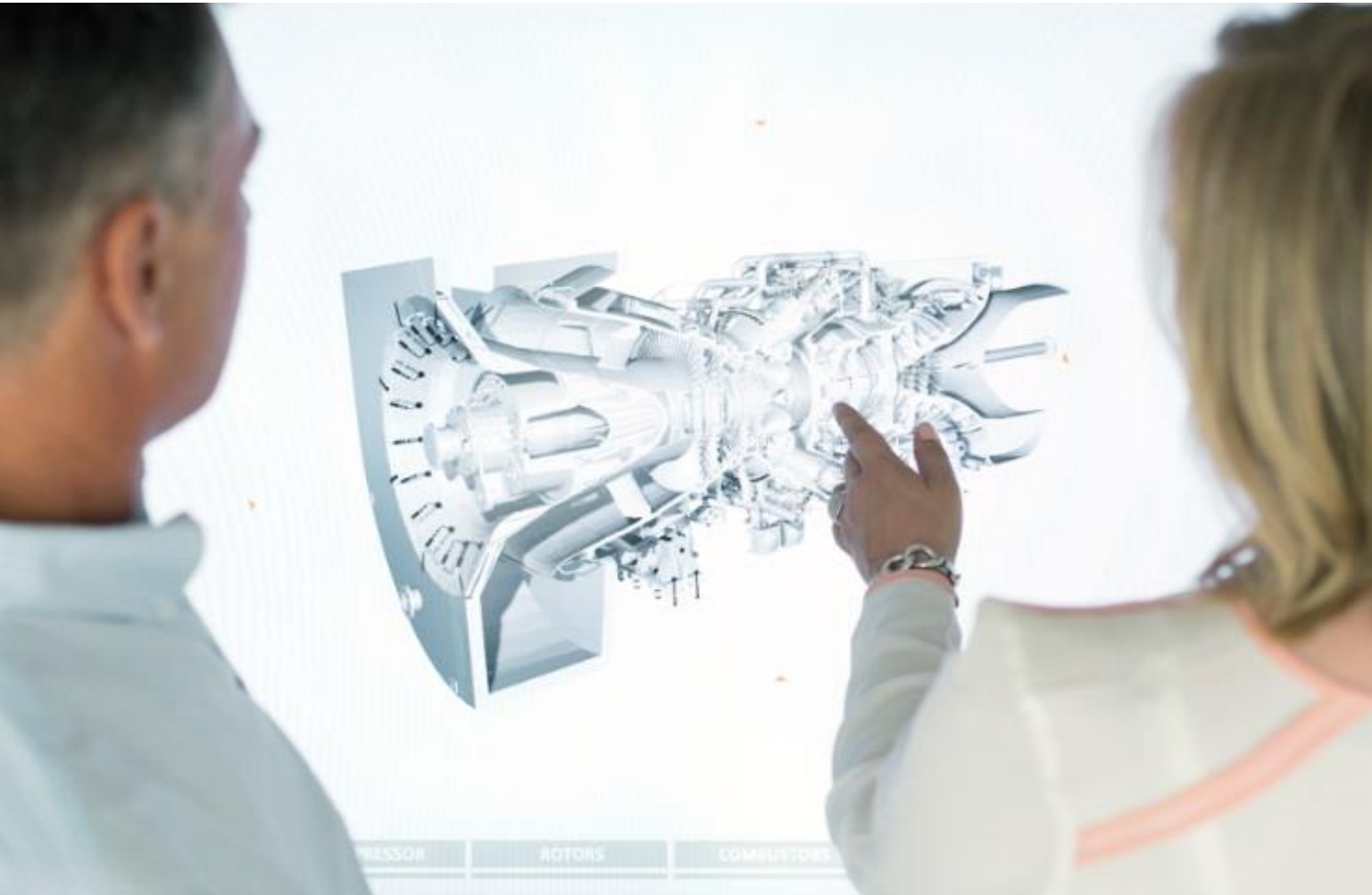
- The largest private sector employer in Norrköping and Finspång
- The second-largest private sector employer in Östergötland



Siemens Industrial Turbomachinery

Global network of competence

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2,600 employees at SIT AB

- approx. 2,600 in Finspång (HQ)
- approx. 100 in Trollhättan
- Additional agency staff, consultants etc.

4,200 employees at Siemens in Sweden

- 40 locations
- Headquarters in Upplands Väsby

377,000 employees at Siemens globally

- 200 countries
- Headquarters in Munich

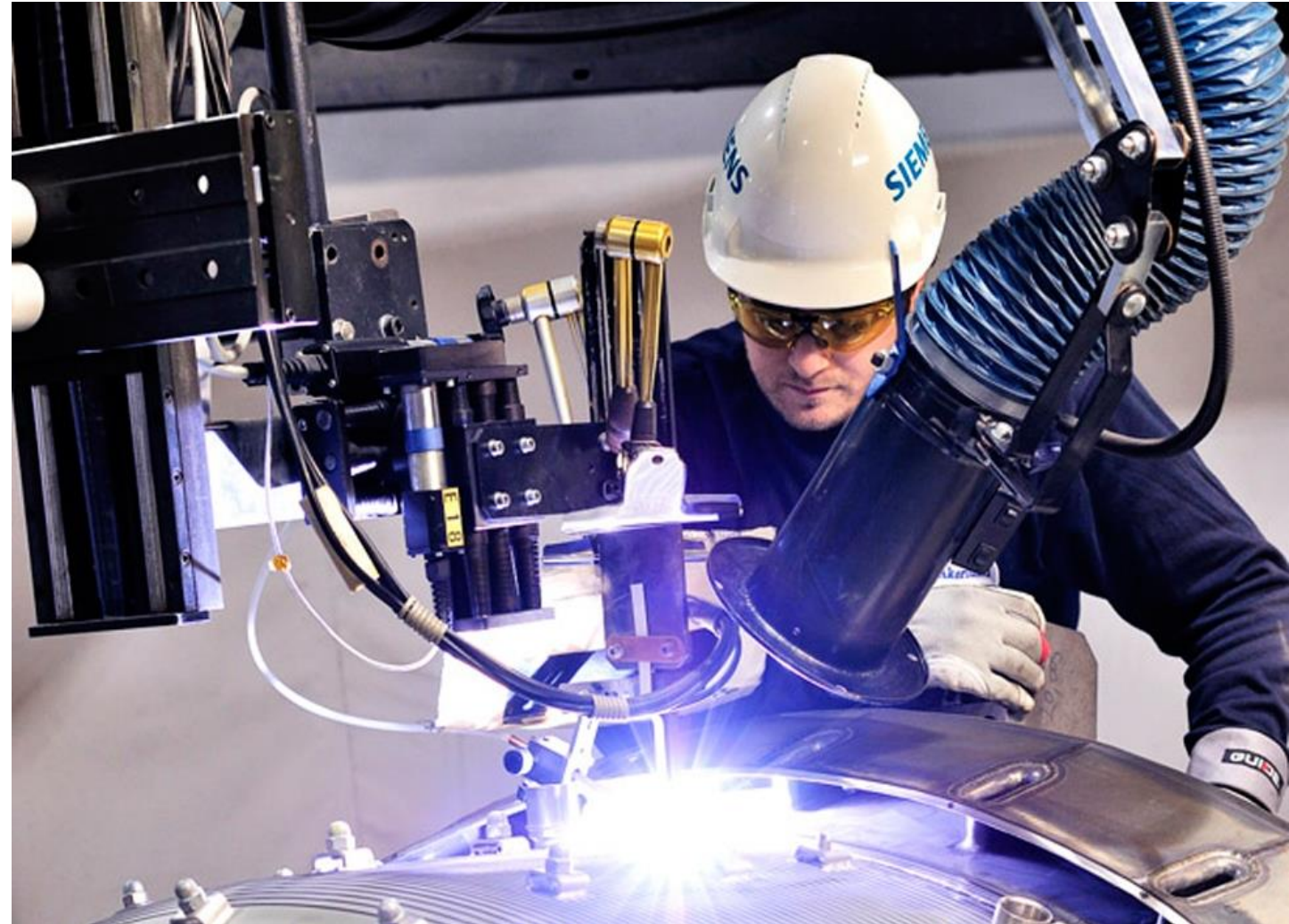
Siemens Industrial Turbomachinery Combustor Manufacturing in Trollhättan

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SIT AB in Trollhättan

- Approx. 100 employees
- 8,600 sqm workshop and offices
- Manufacturing and service of combustors which, along with the compressor and power turbines, are the core of the gas turbine
- Specialists in welding, pressing, molding and laser processing



Siemens Industrial Turbomachinery

Energy solutions of the world

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We operate where electricity, heating and power is needed;

- **within municipal and private power producers;**
from simple turbine solutions to parts of complete generation plants using both gas turbines and steam turbines
- **within the gas and oil industry;**
the gas turbine is used as a power source for compressors and pumps to, for example, transport oil and gas in pipelines

12% of the world's population still has no access to electricity

Source: [The world bank](#)



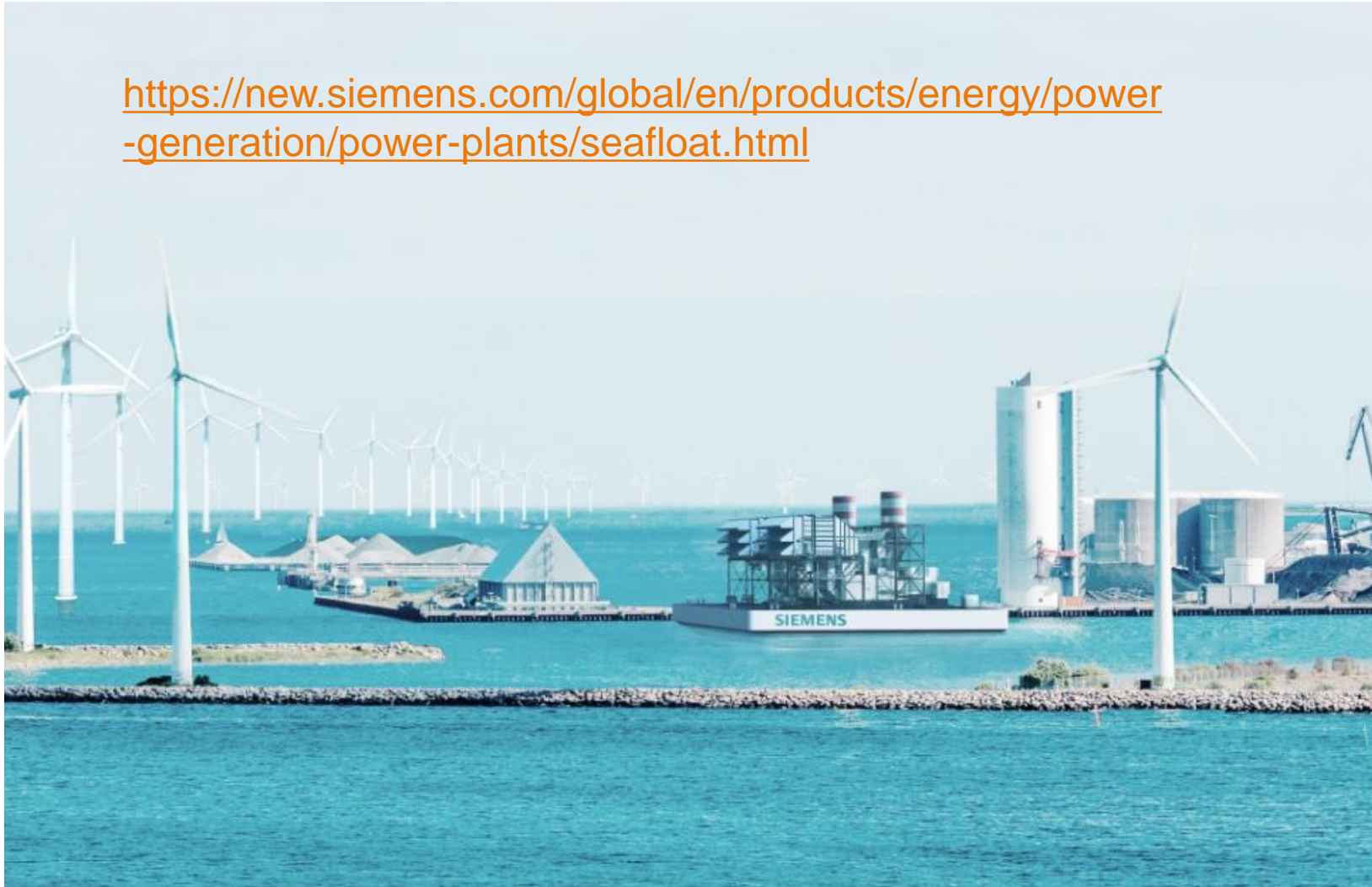
One of many power plants in Thailand equipped with gas turbines from Finspång

Siemens Industrial Turbomachinery

Energy solutions of the world – Sea Float

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<https://new.siemens.com/global/en/products/energy/power-generation/power-plants/seafloat.html>



Siemens Industrial Turbomachinery

Major exporter

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1000 gas turbines

Since the start in 1913, we have sold 1000 gas turbines, ~ 2,300 steam turbines and ~ 50 power plants

95% is exported

We export turbines across the globe, so far to more than 100 countries

90% with service agreements

In most cases, customers also purchase a service and maintenance agreement, sometimes for up to 25 years



Two gas turbines from Finspång leave the port in Norrköping to cross the Atlantic.

Siemens Industrial Turbomachinery

Gas turbines 5–60 MW

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Reliable turbines for all needs

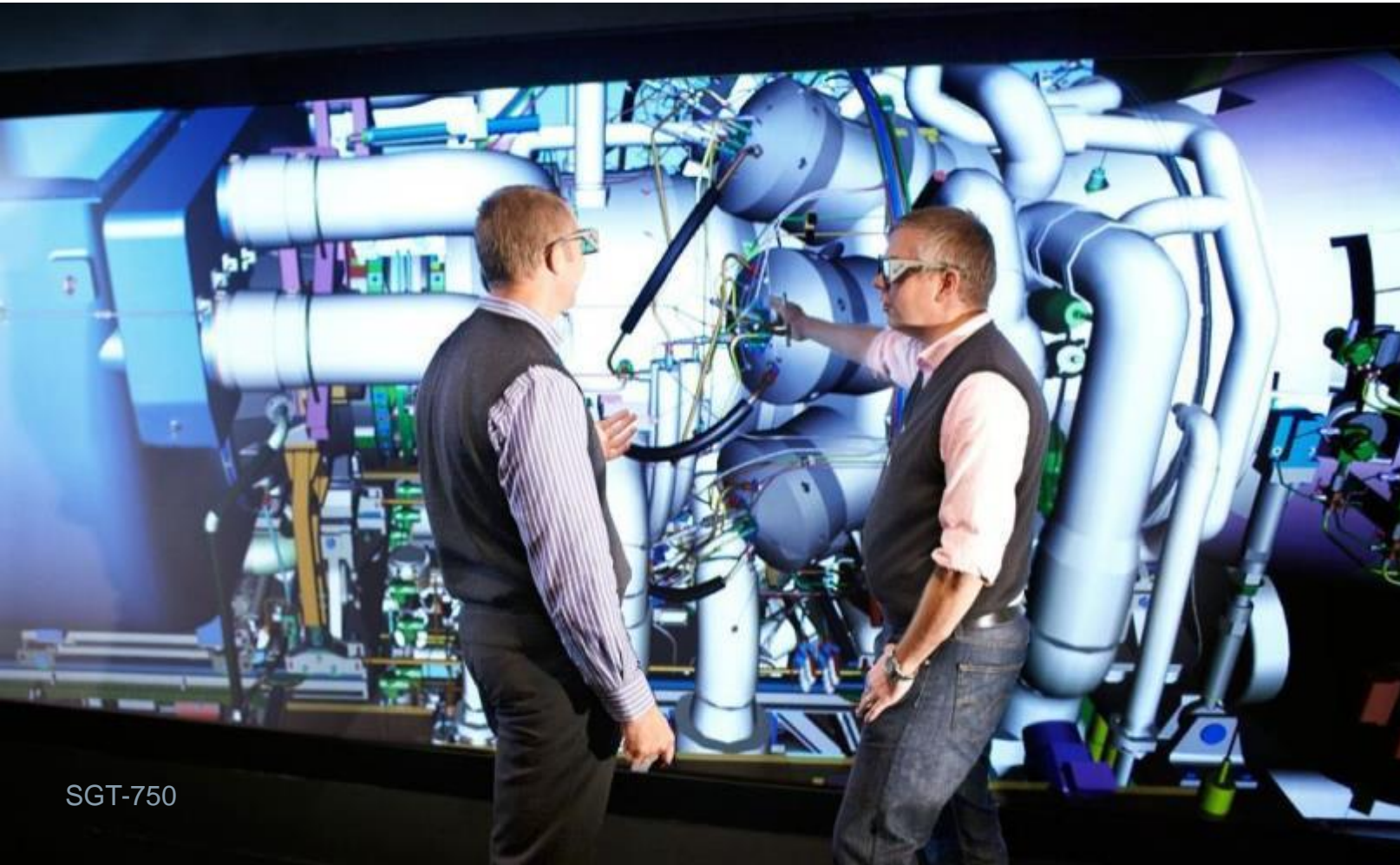
- To produce electricity/heating or as a power source
- Combined cycle power plants, with steam turbines, with very high efficiency; more power, lower emissions, same amount of fuel
- World class in terms of efficiency, reliability and environmental performance
- Industrial gas turbines 5-60 MW;
 - **SGT-300, SGT-400** manufactured in England, packaged in Finspång
 - **SGT-500***, **SGT-600, SGT-700, SGT-750** and **SGT-800** manufactured and packaged in Finspång *only service
 - Aeroderivative gas turbine **SGT-A65** (Industrial Trent 60) manufactured in North America, packaged in Finspång



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Digitalised turbines (IoT)

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SGT-750



10101000011111110000000011

- Remote monitoring, control and guidance; VR, AR etc
- 1,500 measure points in every turbine accrue 7 terabytes of data annually
- Any issues are discovered and fixed before they have an operational impact
- Lifetime analysis, planned maintenance, spare parts, customer-specific modifications and upgrades, technical advice and training, 24-hour helpdesk



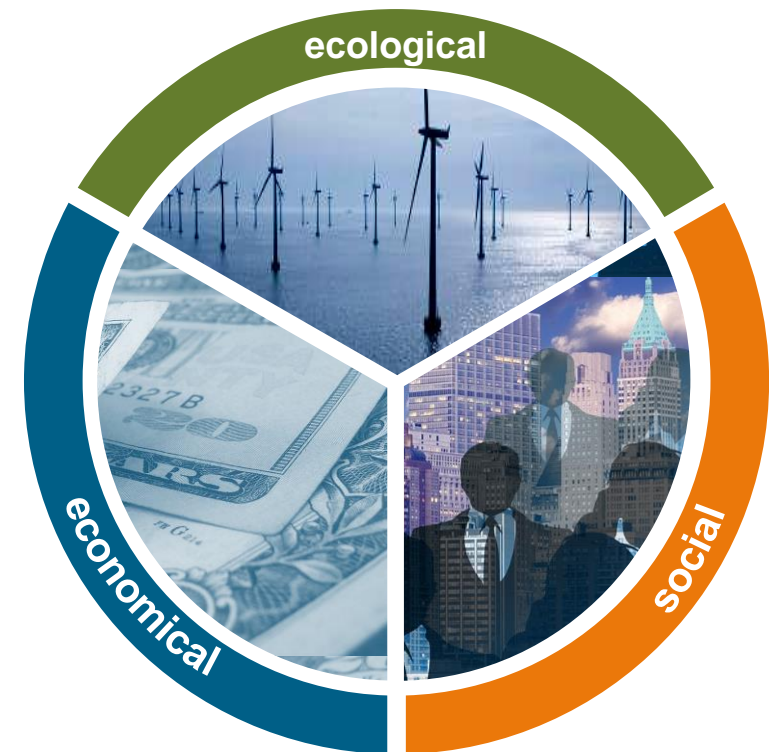
Siemens

Sustainability – a cornerstone

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- Acting sustainably is about balancing **economical, environmental and social factors** – which are not conflicting but could even provide new business opportunities.
- Many initiatives and co-operations globally and locally
- Siemens' objective: **being CO₂-neutral by 2030**
- **Siemens no 1 at Carbon Clean 200 list 2017**
- Siemens' "environmental portfolio" reduced our customers emissions by **570 million tonnes** in 2017 thanks to for instance
 - Renewable energy (e.g wind power)
 - Energy efficient solutions (e.g. gas turbines)



Siemens Industrial Turbomachinery

Example: Gas turbines from Finspång halves carbon dioxide emissions



A new power plant with two gas turbines from Finspång delivers sustainable energy in the US



Natural gas + wind replaced coal

City of Holland (“the Tulip City”) in Michigan, northern US

- approx. 34,000 inhabitants
- the largest sidewalk snow-melting system in the US
- had an older, coal-fired power plant
- had an increased need for electricity
- growing environmental regulations
- after a comprehensive analysis decided to replace coal with a combination of natural gas and wind

Two gas turbines (SGT-800) from Finspång

To achieve maximum fuel efficiency, the coal fired power plant was replaced with a combined cycle power plant with two SGT-800 gas turbines from Finspång to supply electricity and heat. Inauguration of the plant took place in 2017.

Natural gas instead of coal =

Halving of carbon dioxide emissions

Radical emission reduction

- nitrogen oxide
- sulphur dioxide
- particles



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Finspång – “the birth-place of Swedish industry”

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500 years of smart adaptation

1496: Ironworks set up in Finspång (“Finspångs Bruk”)

16th century: The ironworks is turned into public ownership (owned by the king)

17th century: Manufacturing of canons starts

- Louis de Geer I purchases the works
- Louis de Geer II builds the castle

18th and 19th century: One of the largest cannon manufacturers in the world

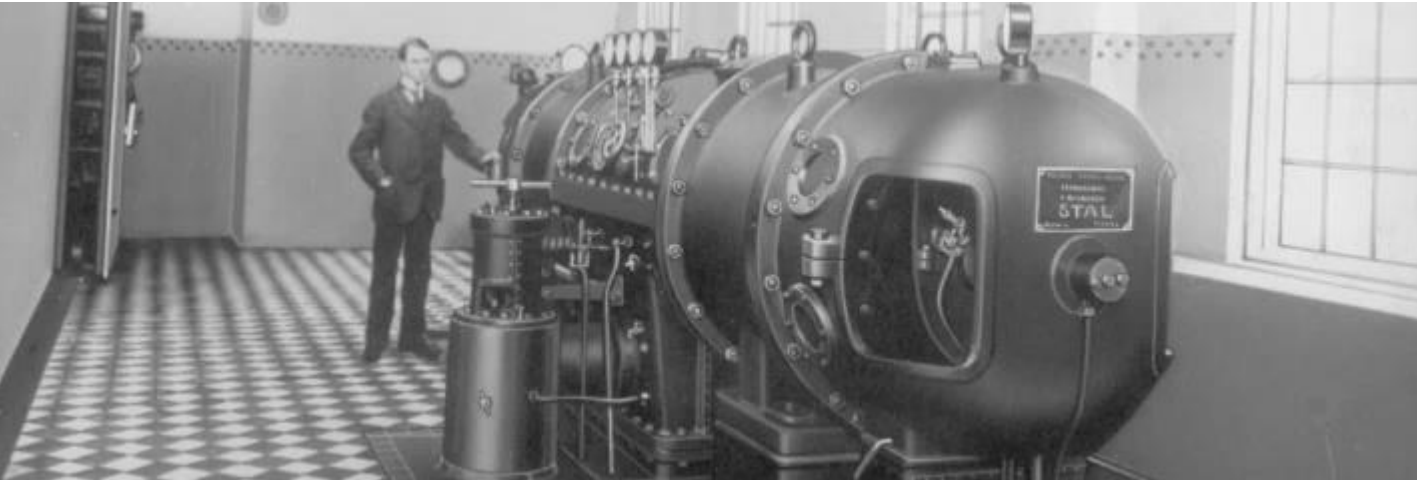
1911: The last cannon is tested in Finspång



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A story of power

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Manufacturing in Finspång since 1913

1913: The Ljungström brothers start a steam turbine factory in the empty artillery works in Finspång – the first customer is in London, the second one in Skärblacka (top picture)

1940/50's: jet engine development under Curt Nicolin's direction leads to Sweden's first gas turbine (bottom pic.)

1959: merger with De Laval steam turbines

1960/70's: steam turbines to the Swedish nuclear power industry, the largest steam turbine manufacture in the world for ships

1980/90's: strong growth in gas turbines, in part because of a reduction in nitrogen oxide emissions (low NOx burner)

Siemens Industrial Turbomachinery

The future of manufacturing

Turbine operations in the 21st century

2003: largest manufacturer of steam turbines in the world, second largest on medium-sized gas turbines; Siemens acquires the turbine operations

2005: world-leader in steam turbines for solar power; i.e. electricity without any carbon dioxide emissions (primarily to the US and Spain)

2010: the latest gas turbine is launched; SGT-750. Constructed as a full-scale 3D model; tested in a VR studio

2013: 100 years of turbine operations in Finspång

2016: new workshop for development, serial manufacturing and repairs of turbine parts in metal using 3D printing (a.k.a. AM; additive manufacturing);

- Up to 10 times faster
- Previously “impossible” constructions are now possible (“if you can dream it you can do it!”)
- Minimal environmental impact



Siemens Industrial Turbomachinery

Working at the cutting edge of development

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- ~ **400 people** working with R&D in Finspång
- Our own lab and test rigs
 - Forerunners in using 3D printers to print components of metal (picture)
 - Development of components for carbon dioxide-free fuels such as hydrogen gas
- ~ **38,000 people** within R&D at Siemens globally

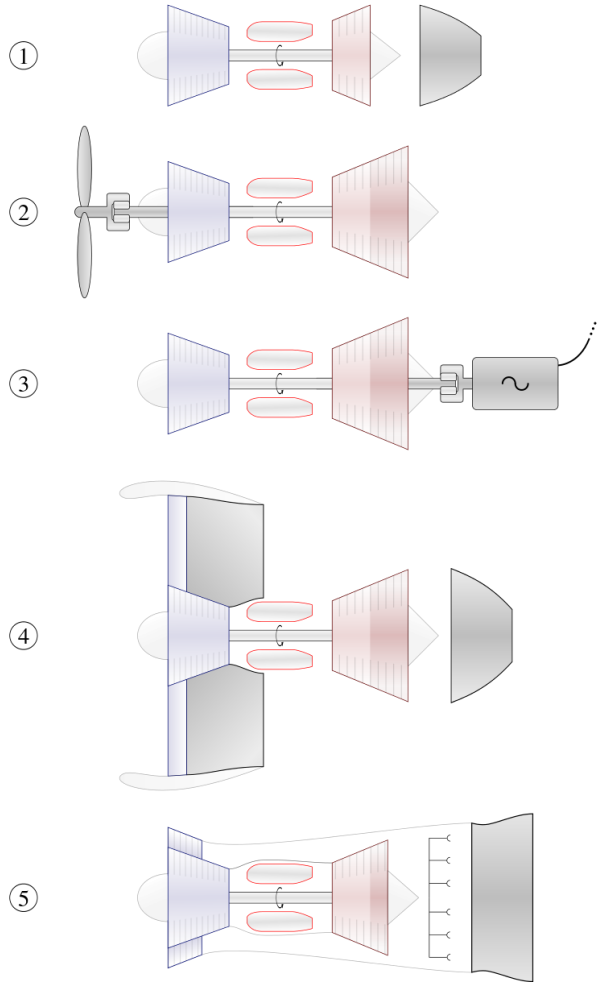
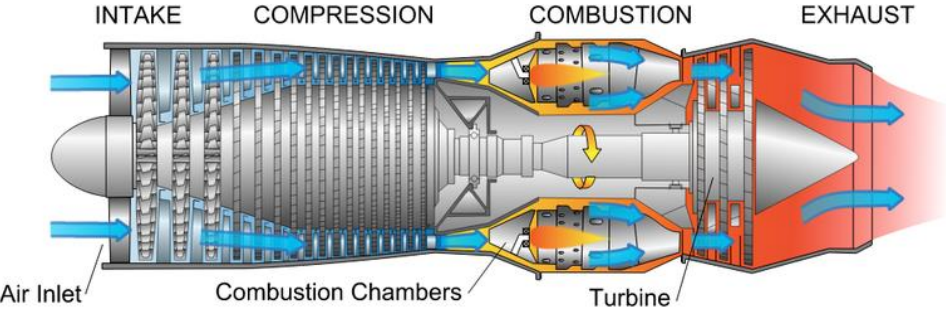
 **7 400**
inventions

 **60 000**
patents



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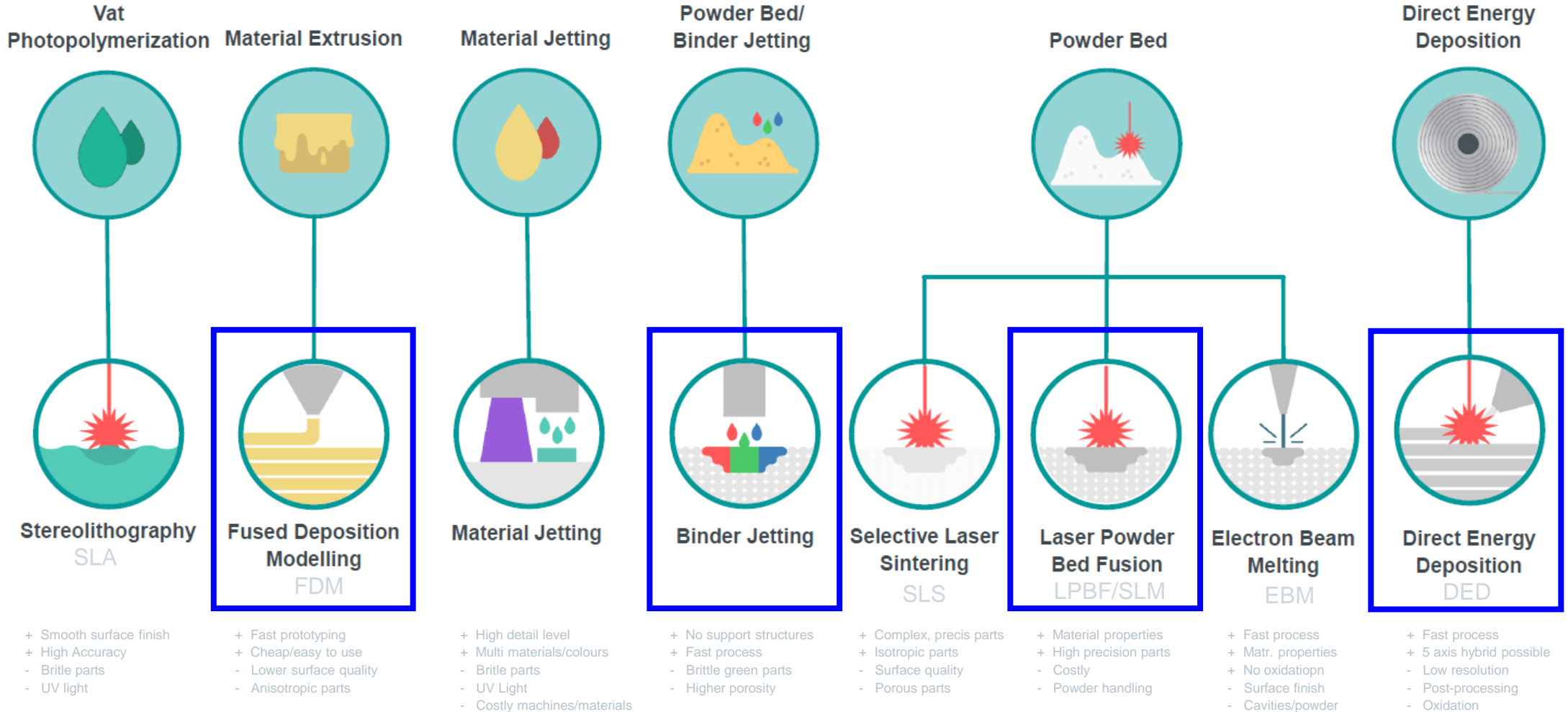
What is a gas turbine?



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3D Printing

Different processes



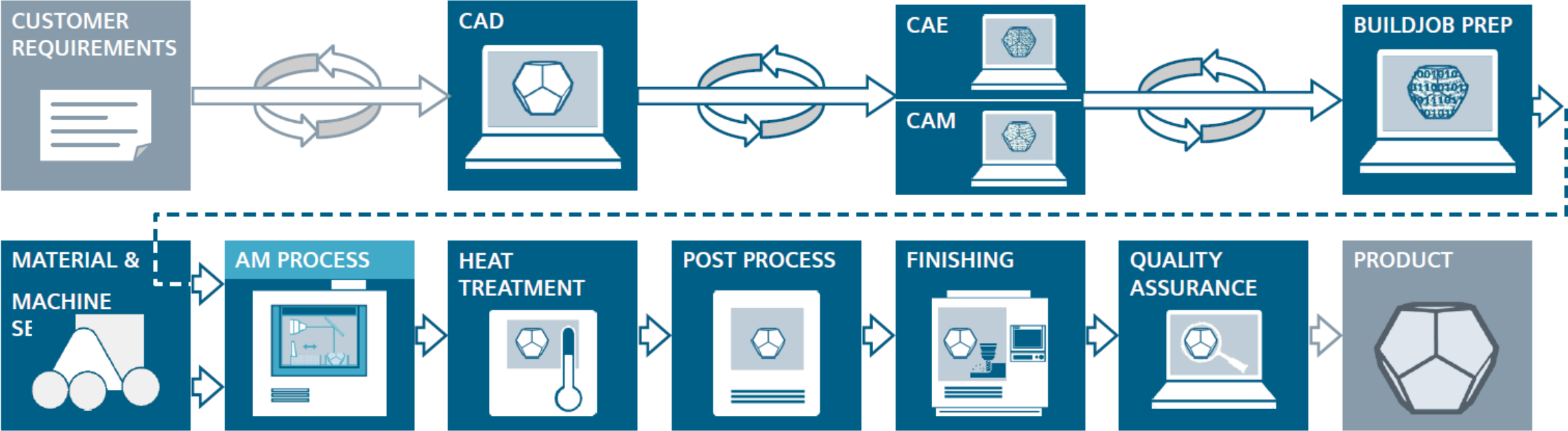
3D – Printing

Wide applications

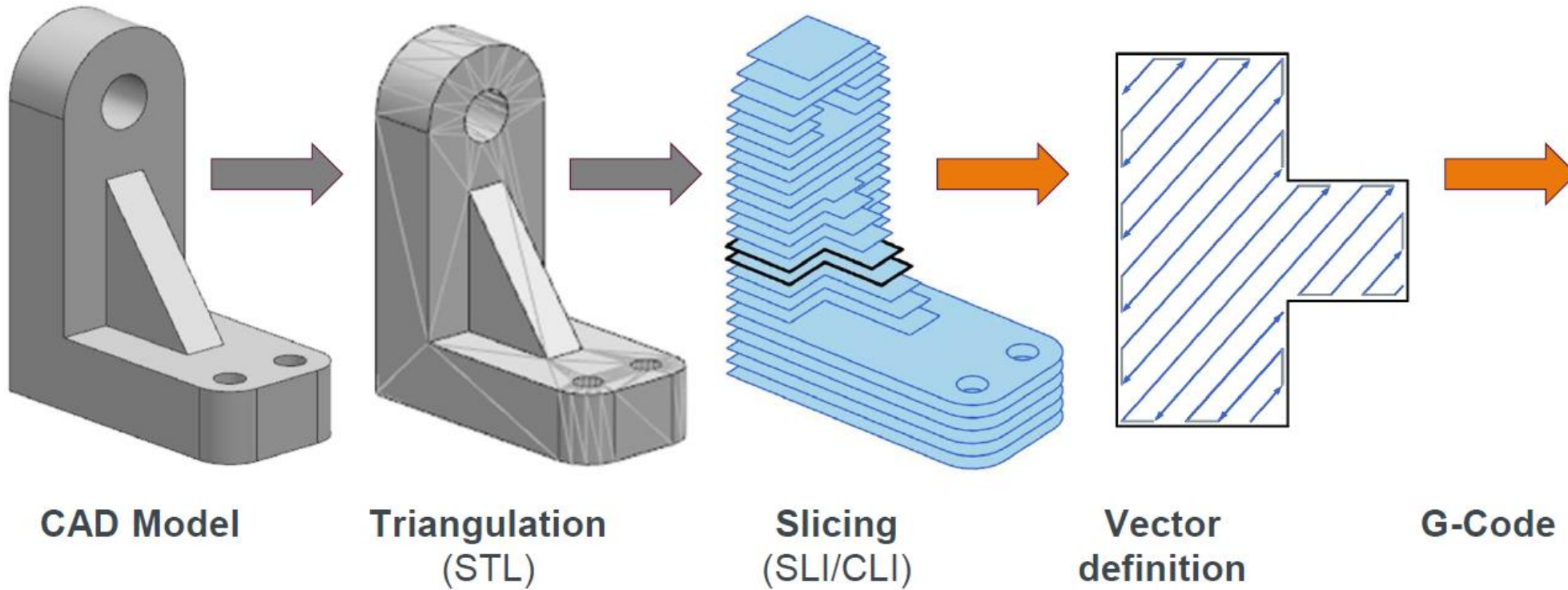
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3D Printing Workflow

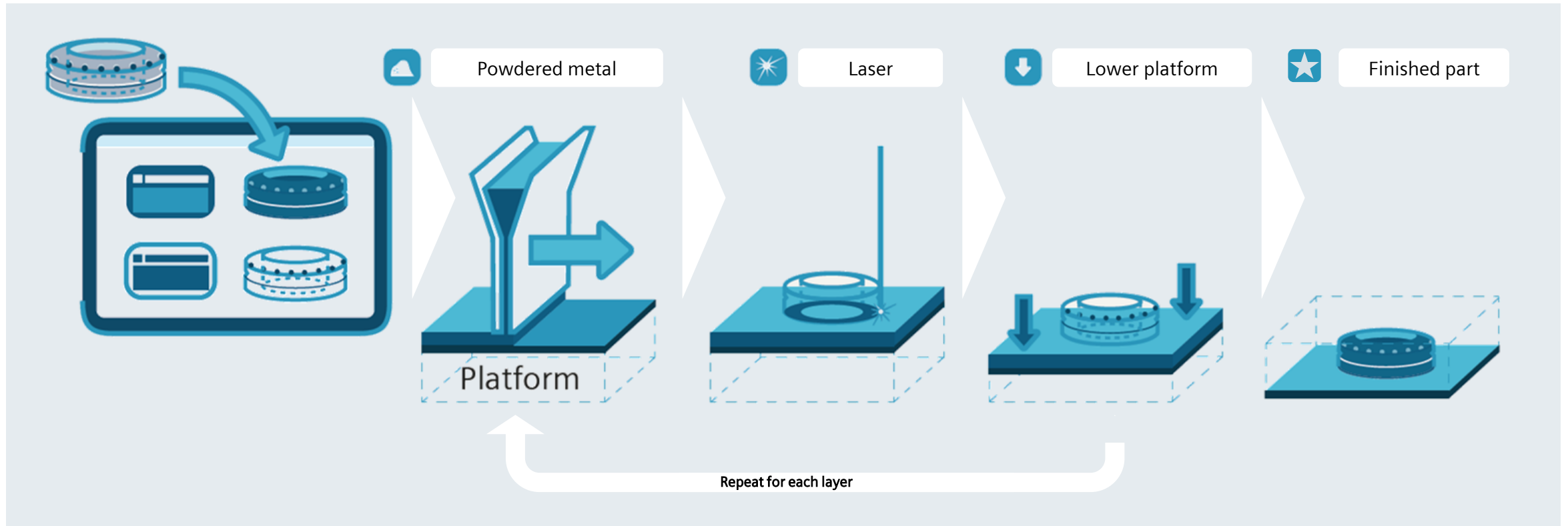


Data Workstream



Selective laser melting - SLM

<https://youtu.be/8j86P2GKPvM>

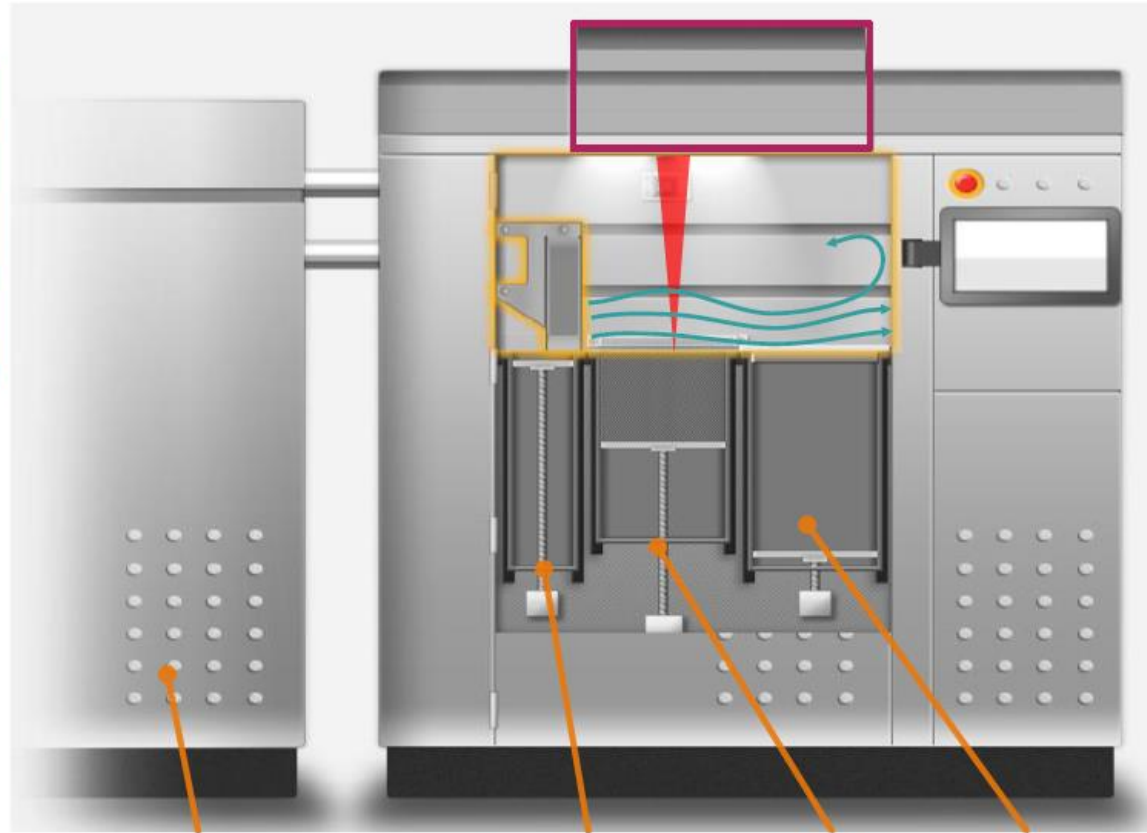
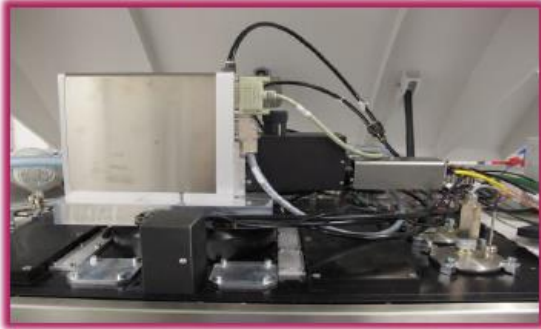


Additive Manufacturing (AM) refers to a production process in which components are created layer by layer on the basis of digital 3D design data.

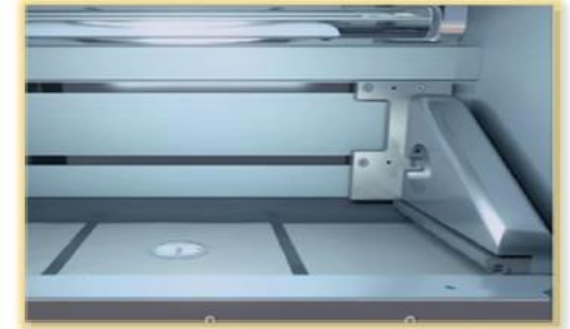


AM – Hardware Printer

Optical unit



Build chamber



**Recirculating
filter system**

**Collector
piston**

**Build
piston**

**Feed
piston**

AM – Hardware

Auxiliary hardware

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Source: EOS

Lifting truck



Source: EOS

Conveying module



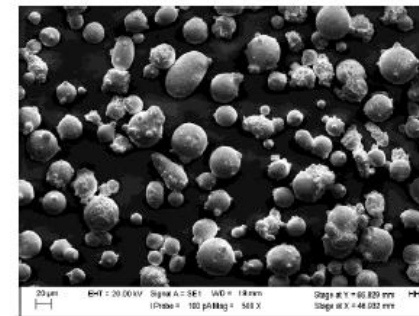
Source: EOS

Sieving module



Source: denios.at

Inert gas



Powder

AM – Hardware

Auxiliary hardware



Source: Solukon

Depowdering unit



Source: delta-h

Industrial oven



Source: exeron

Separation cutting

- Siemens, what do we do?
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Changing the future with Additive Manufacturing

Why do Siemens work with additive manufacturing?

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Time-to-Market & Lead Time Reduction

- **Fast technology validation** & product development on demand
- Shortened process development
- Overall lead time reduction



Supply Chain & Reduced Complexity

- Mitigate single source situations on e.g. mature parts
- **Reduction of assemblies** to one component
- Small batch sizes & different parts in one build job



Cost Reduction

- **Product cost** reduction
- Simplified manufacturing & repair



Environment Benefits

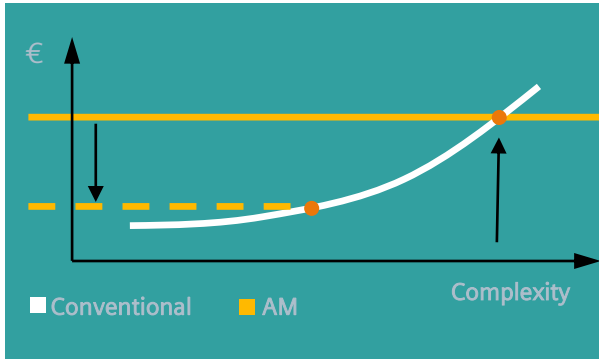
- **Reduced emissions** through improved fluid mixing, e.g. complex nozzle designs
- Reduced waste from alloys



Innovative Designs

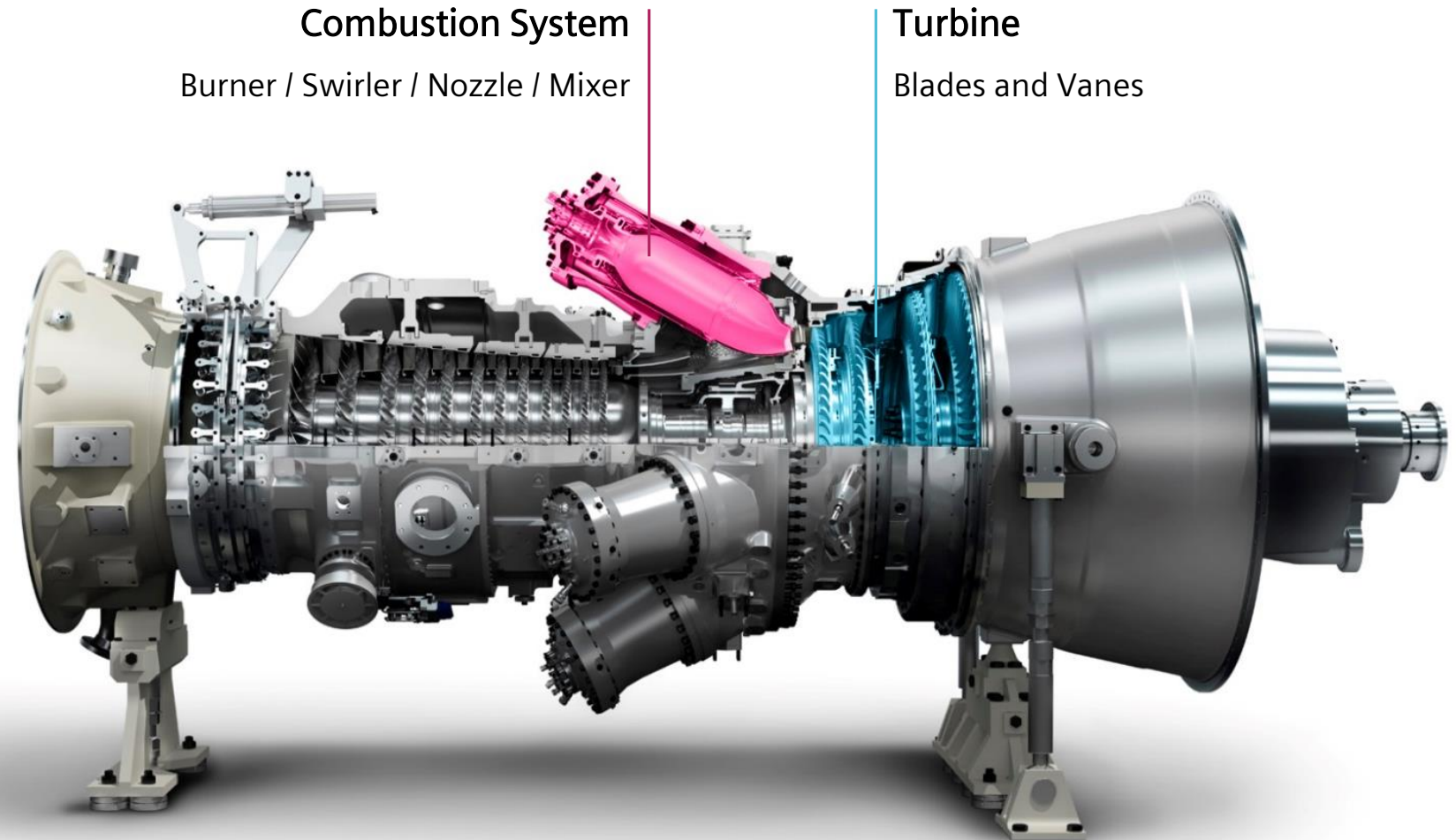
- New geometries
- Better heat transfer & cooling
- **Improved efficiency** & power output

Gas turbine focal areas for Additive Manufacturing today



High tech components
with complex design
and high potential to
improve customer
value

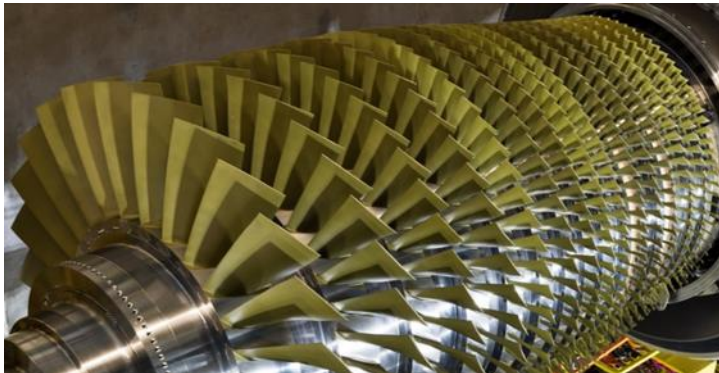
efficiency, durability,



Key factors and technologies in the development of future gas turbines

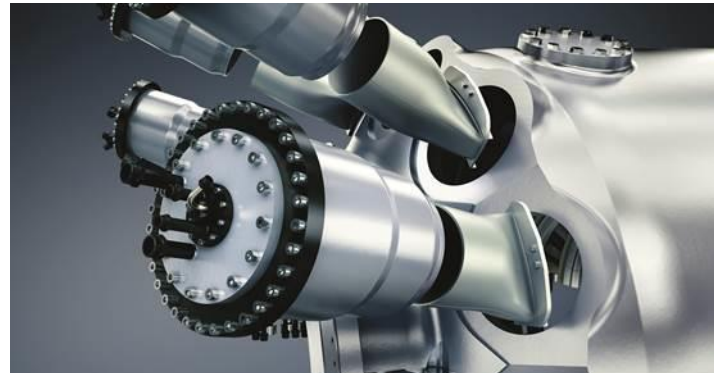
Compressor

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



Combustion

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



Turbine

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

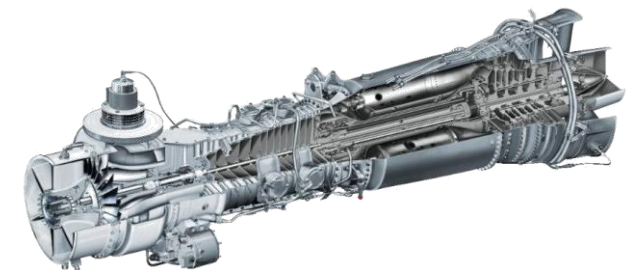
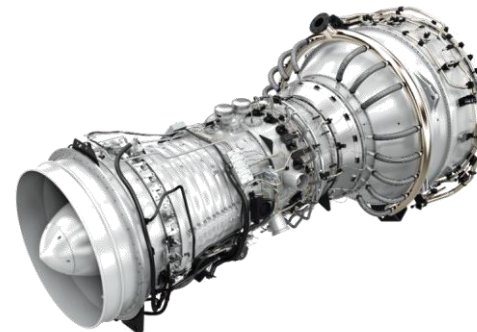
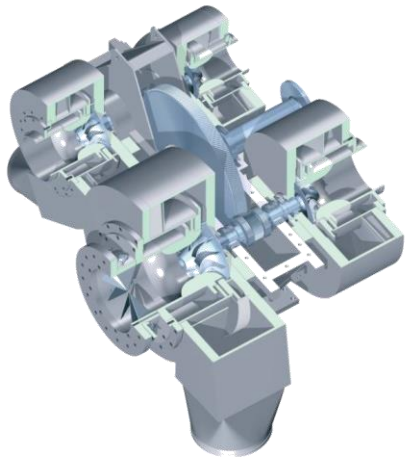
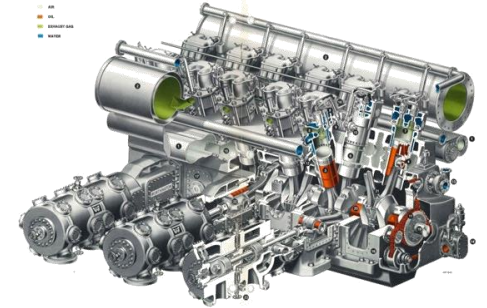
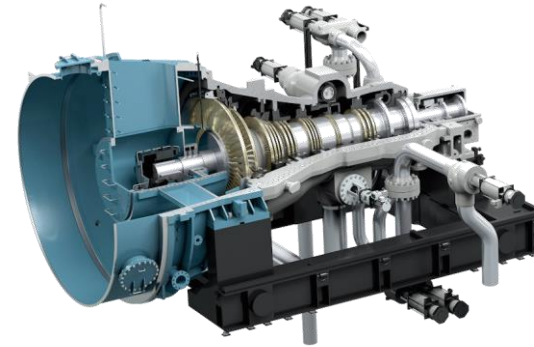
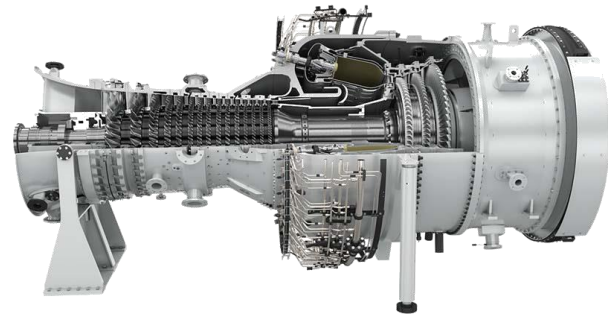
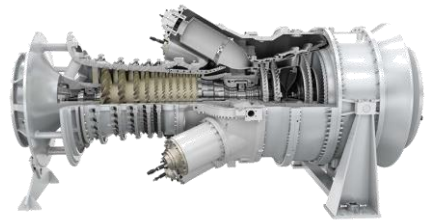


These goals cannot be reached with conventional manufacturing technologies

Product portfolio offers huge possibilities for AM!

Installed fleet of >50 000 different rotating equipment

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Siemens is a world leader in designing and producing commercial AM components for serial production

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Siemens experience covers today more than...

>1 500 000

operating hours on Siemens turbines

>40

3D printing machines
operational worldwide

150+

specialized engineers

200

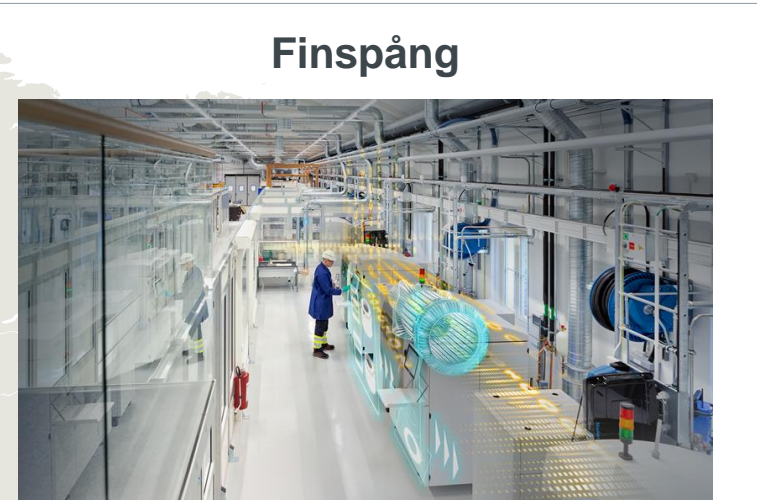
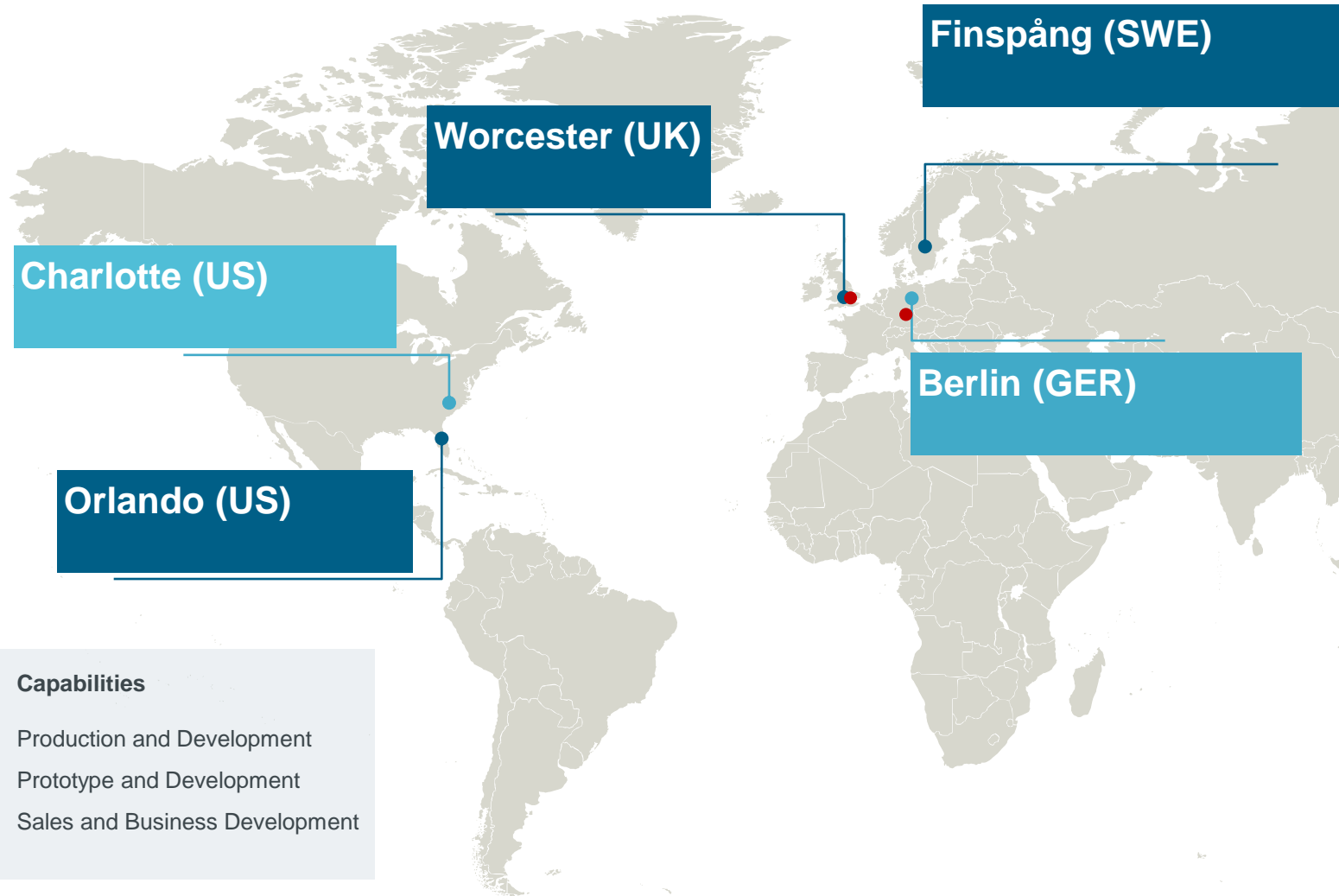
components identified
for AM until 2025

15

components already
commercially
implemented

Global footprint

Our manufacturing and engineering network spans the globe



Finspång

Significant footprint expansion



Worcester

New state-of-the-art AM facility

Siemens Additive Manufacturing

AM Workshop

Finspong



Old Curt Nicolin gymnasium

- Prototyping
- Burner repair/Serial production
- Sawing
- 5 Axis Milling
- Powder removal/cleaning
- Quality Checks
- Printing steel and superalloys

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



Outcomes



First SLM demonstrators



First SGT-800 RaBuTir
SGT-750 combustion swirlers in commercial operation



Prototyping of qualification parts for LGT, IGT, AGT, IST



SGT-1000F Burner head in commercial operation



Turbine blade printed & tested in engine (SGT-100)



SGT-700 Burners Commercial operation

FY 2006 2009 2012 2013 2014 2015 2016 2017 2018 2019

Key enablers

Material Solutions founded in the UK

Installation of the 1st EOS M270 SLM machine in FSP



Installation of 1st EOS M280 SLM machine in FSP, specifically adapted for Burner repair

Dedicated Additive CoCs established

Development and qualification of Processes and Materials



Acquisition

Finspong Industrial workshop inaugurated



First M400/4 Installed



New WS





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

SLM: Selective Laser Melting RaBuTiR: Rapid Burner Tip Repair

Restricted © Siemens AG 2018

>1,500,000 operating hours on commercial gas turbines:
Siemens is front runner in industrializing AM



Spare Parts on Demand	"Design for AM" Burners	Burner Repair	Rapid prototyping
40% lead time reduction	H2 capability 13 → 1 parts	Leadtime from months to weeks Reduced temperature	Leadtime from years to month Improved cooling
			
New Business Models	Serial Production	Performance Increases	Iteration time

Repair of burners – RaBuTir

Rapid Burner Tip Repair

Rapid Burner Tip Repair (RaBuTiR)



Key benefits include:

- Improved cooling design brings down metal temperature
- Longer part lifetime
- Increased reliability
- Allows more customization for fuel flexibility
- Reduces the number of parts from 10+ in a new burner to just one AM repair

>1000 units have been produced – serial repair reached

iBuMa (intelligent Burner Manufacturing)

Conventional
thinking



Additive
Manufacturing
thinking



13 → 1 parts
system simplification

26 → 3 weeks
lead time reduction

22%
weight reduction

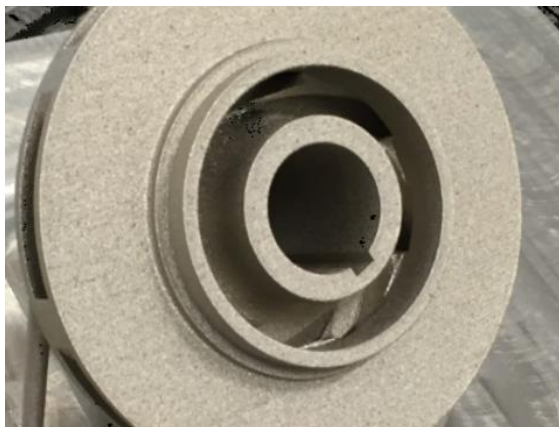


3D printed parts are already in use at Nuclear Power Plant Krško, Slovenia

First 3D printed water pump impeller is successful commercial operation at nuclear power plant

Customers benefits:

- Obsolete parts can be re-produced
- Significant lead time reduction
- Parts on demand



Plastic printing in Finspong

Parts/fixtures/tools for automotive/aero/manuf. industry

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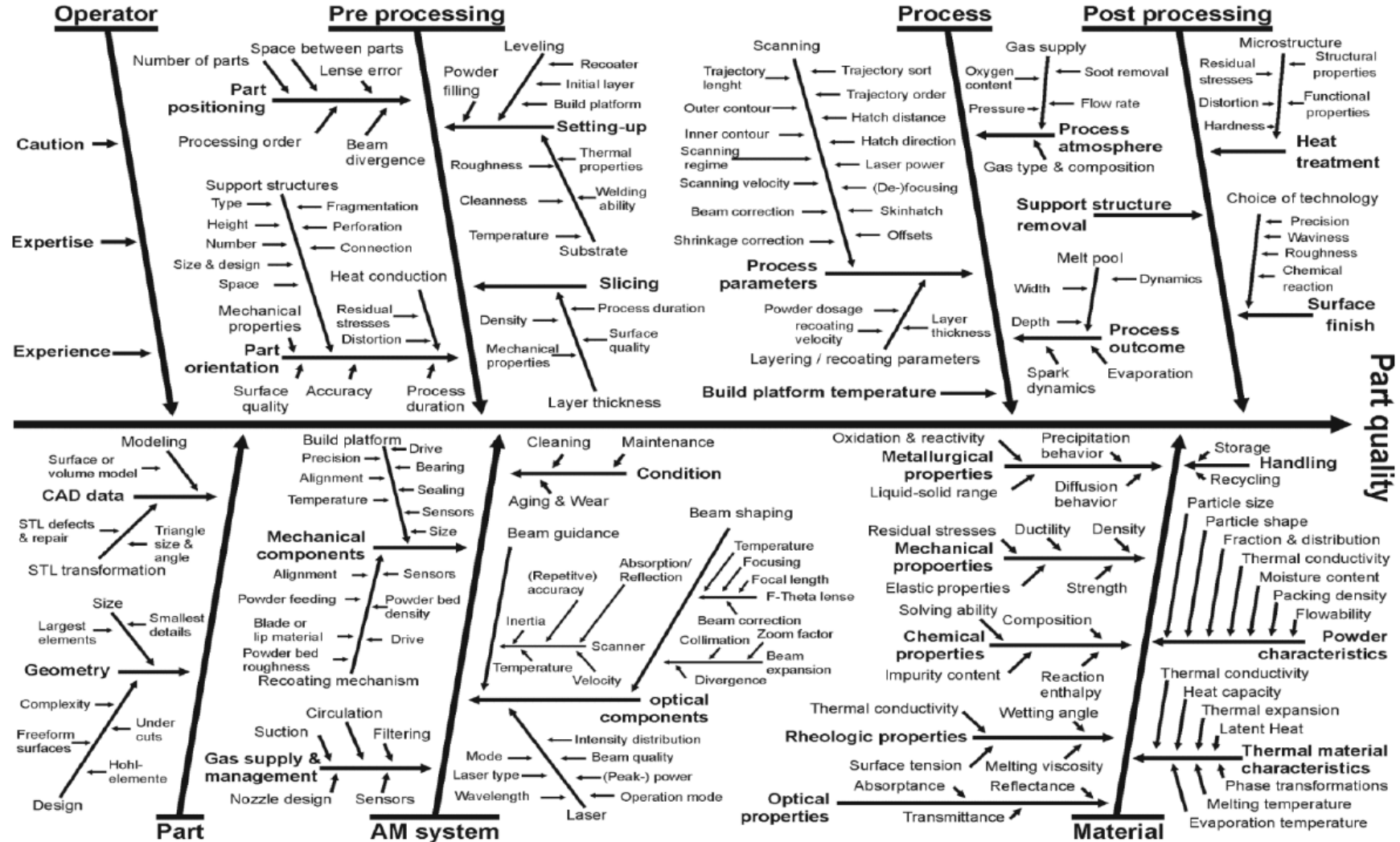
- Industrial plastic printers
- Glass or carbon reinforced fiber
- Lead time: Days to max 2 weeks
- Used for parts/fixtures/tools

Complexity of SLM

Many parameters affecting the final part quality

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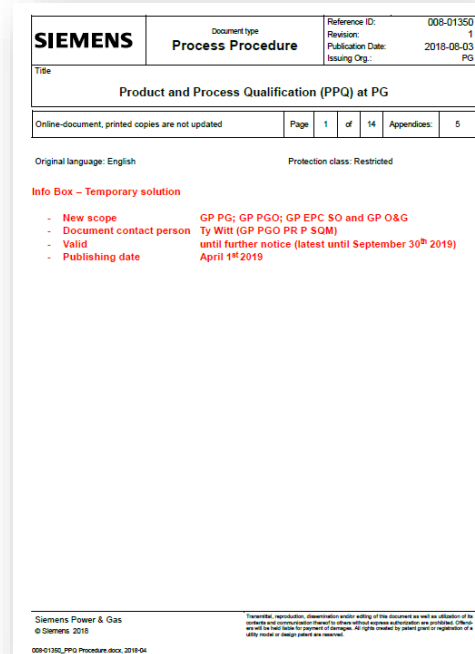


Product & component qualification

Secure serial production quality

Siemens PPQ system utilized;

- Similar to PPAP (AS9145)
- 18 elements



Element	Content
1	Product Release
2	Supplier Drawings and Specifications
3	Critical to Quality (CTQ)
4	Manufacturing Control Plan
5	Inspection Records and Data Sheets
6	Materials Data
7	Destructive and Non-Destructive Testing
8	Metals Joining Documents
9	FMEA
10	Process Capability
11	Gage R&R
12	Tooling and Gages
13	Discrepancy Reports and Eng. Changes



Element	Content
14	Packaging Instructions
15	Special Process Documents
16	Miscellaneous Documents
17	Personnel & Supplier Details
18	FAI

Standards



- ISO 9001 - Quality
- ISO 14001 - Environment
- ISO 50001 - Energy
- OSAS 18001 - Occupational health/EHS



- AS 9100 - Aerospace
- Various AMS Standards



AM Digitalisation Vision:

“Autonomous”, closed loop and self healing processes, gas turbines order spare parts by themselves

Autonomous Workshop 2025

- Autonomous micro factories
- Autonomous planning, control and learning in AWAREnet

Intelligent Workshop

- Personnel governed digital workshop.
- Automated process correction

Learning Workshop

- Digitally assisted personnel.
- Process improvement through machine learning.

Connected Workshop

- Digitally informed personnel.
- Process governance and understanding

Traditional Workshop

IoT for AM



“Intelligent Workshop” through **Robots, VR/AR, AI**



“Learning Workshop” through **Big Data Analytics** and Machine Learning



“Connected” through **MES** and Use **Build Job Simulation**



Siemens offerings within Additive manufacturing

Both a service provider and a user

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Printing services

- Metal and plastic printing
- Prototypes and serial manufacturing
- New parts, repairs, spare parts on demand, obsolete parts



Design services

- Design workshops,
- Access to design expertise
- Complete dev. from CFD, MI, Design to drawing/printing



Testing/Validation

- Mechanical testing, HCF, LCF, metallurgical investigations
- Heattransfer/Flowtests in advanced in-house rigs
- Access to Siemens network



Software solutions

- NX – CAD/CAM, e2e process chain, Simcenter
- AM Monitor, MES – Manufacturing Execution system
- Control systems

The value delivered by Additive Manufacturing

Value



30%

Reduction of
greenhouse gas
emissions



65%

Less resources
in production
process



75%

Reduction of
development
time



Flexibility
for design
of parts



60%

Faster
repairs



50%

Reduction of
lead time



Status

- First industrial Siemens facility for power generation components
- Fully industrialized
- Components in commercial production





Contact:

Martin Lindbäck

Head of Additive manufacturing

martin.lindback@siemens.com

+46(0)122-81770