GTEN 2019 Symposium
October 21-23, 2019 | Banff, Alberta

Industrialisation and Field Experience of Gas Turbine Components Made by Additive Manufacturing

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Distributed Generation and Oil & Gas in Canada At a Glance

Key Figures (Fiscal Year 2019)

~730 employees

~240 gas turbines installed

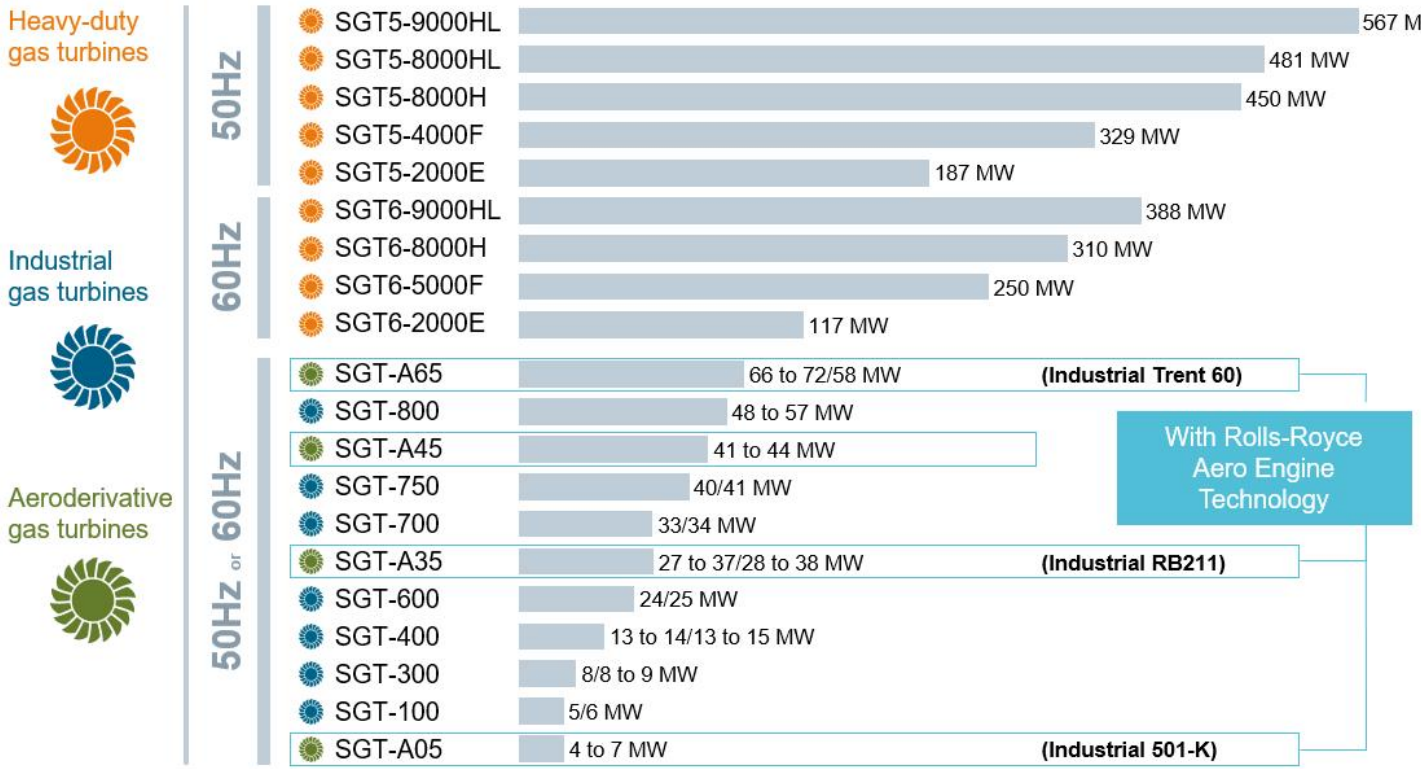
2 service centers

1 factory

~150,000 Field service and repair center hours worked per year (average)

Siemens Gas Turbine portfolio

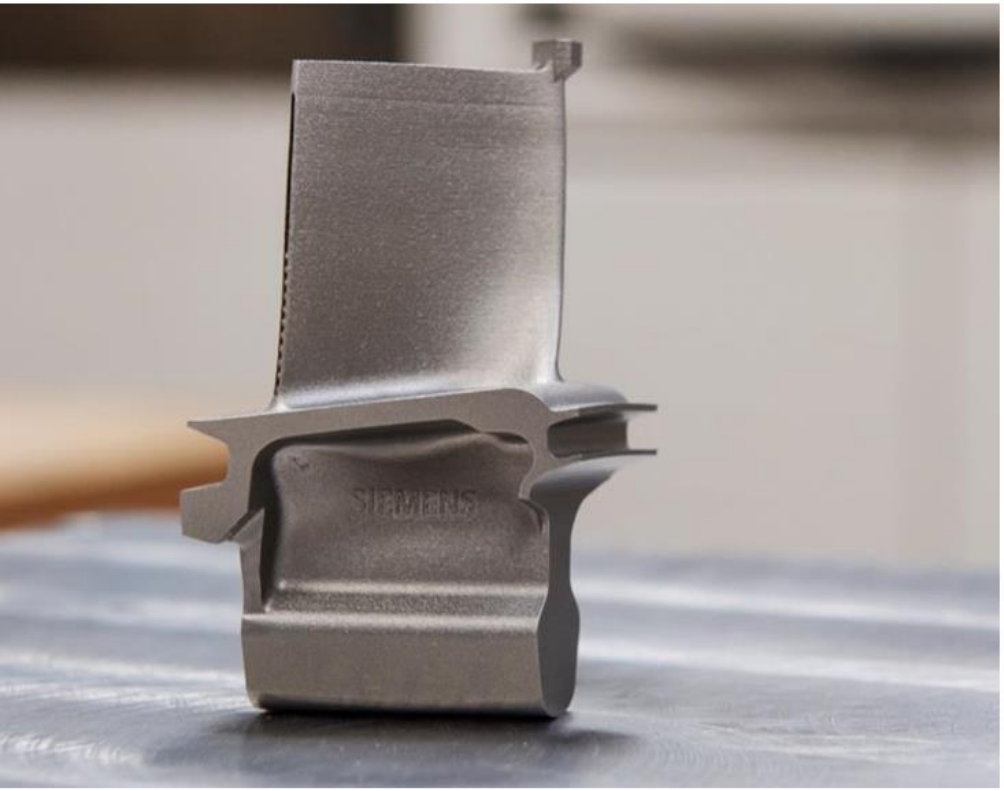
The right engine for every requirement



Power Generation/Mechanical Drive, Performance at ISO conditions

Field Experience of AM components

Siemens is a world leader in applied additive manufacturing



Siemens experience covers today more than …

150,000 operating hours on Siemens turbines

40 3D printing machines operational worldwide

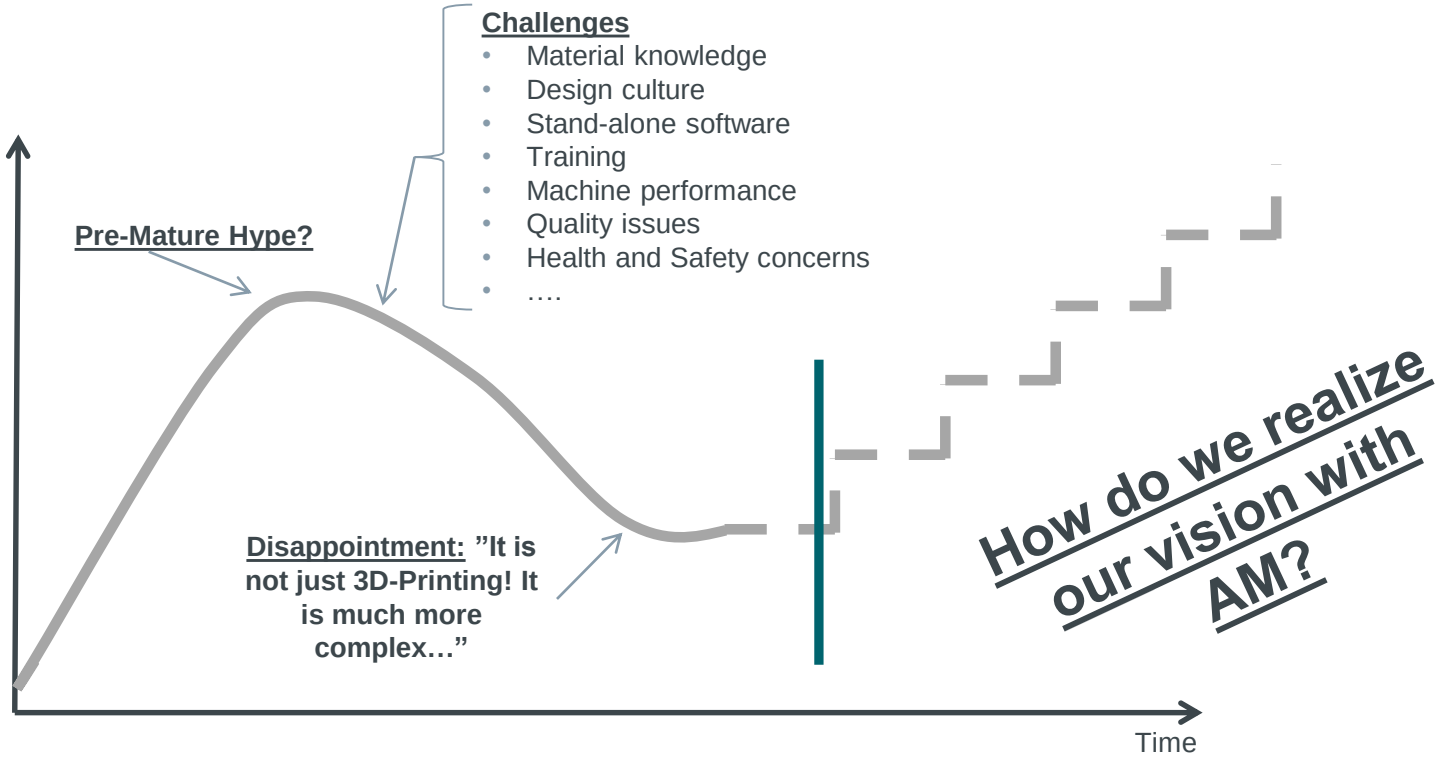
100 specialized engineers

200 components identified for AM until 2025

15 components already commercially implemented

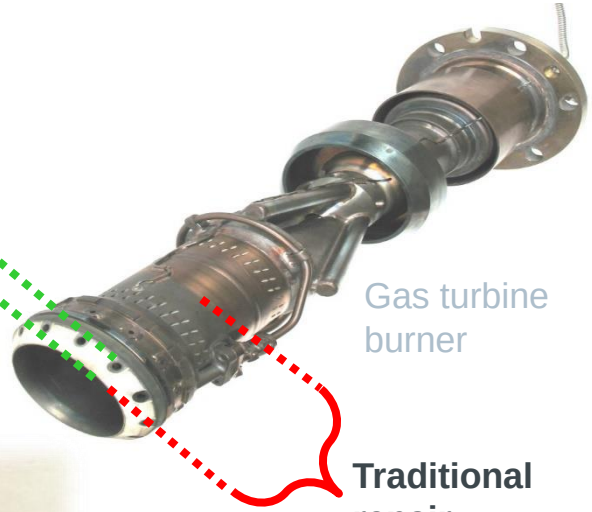
Status: June 2018

The AM journey at Siemens



SGT-700/800 Burner Tip Repair

Rapid Burner Tip Repair with Selective Laser Melting (SLM)



Gas turbine burner

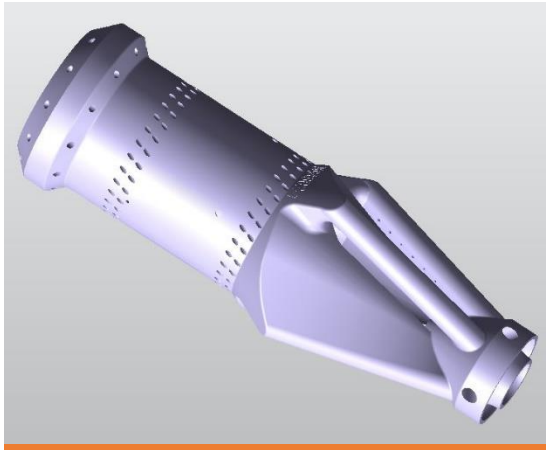
Traditional repair: replace and TIG-welding

Key benefits include:

- Improved cooling design decreases metal temperature
- Longer part life
- Increased reliability
- Allows more customization for fuel flexibility
- Reduces the number of parts from more than ten in a new burner to just one AM repair

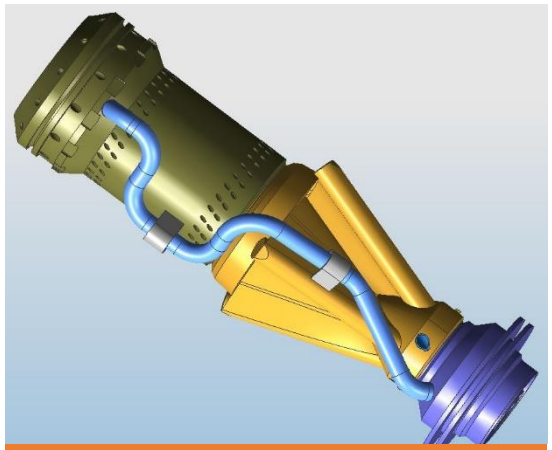
More than 1,000 units have been produced → Serial repair reached.

SGT-700/800 Burner



AM adapted burner front

- 1 single part
- Optimized cooling, possible to remove TBC
- Pilot gas feed integrated in structure
- Lead time reduction by factor 7-10
- Weight: 3,5 kg



Conventionally manufactured burner front

- 13 machined parts, joined by 18 welds.
- Thermal Barrier Coating on front surface.
- External pilot gas feed
- Weight: 4,5 kg

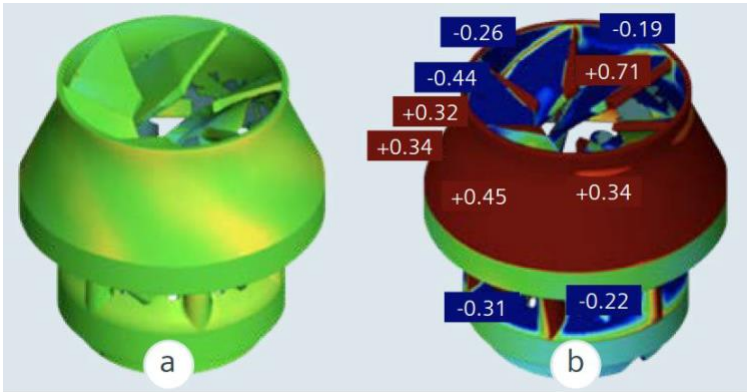
SGT-1000F Burner Head
”Spare parts on demand”

Achieved benefits of AM

- Reliable and flexible provision of spare parts on demand
- Lead time reduction 40%
- Independence from casting vendor (no extra charge for small quantities, no re-qualification costs)

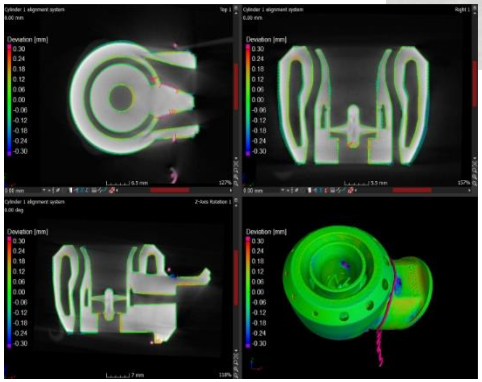
Status

- Commercial operation since 2016
- More than 11,000 EOH accumulated



Comparison between 3D-model and (a) SLM component as well as (b) investment cast component; red – positive deviation / blue – negative deviation

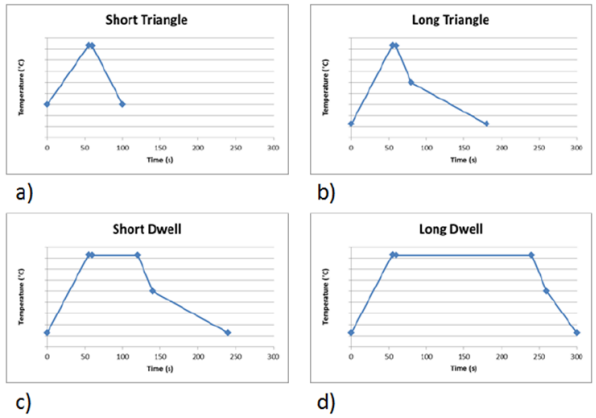
SGT-A35
Non-DLE fuel injectors

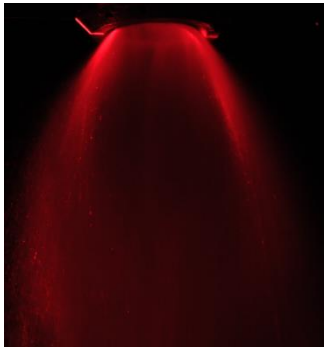


Status
• Full load, diesel and gas engine test completed • 5000+ hours operating in service • Serial production underway • This is the standard non-DLE offering

SGT-A35
Non-DLE fuel injectors - Validation

Thermo-mechanical fatigue testing reveals higher cyclic life than conventional
- *1-piece head not susceptible to cracks the way a brazed assembly is*
- Test was stopped at 7000 cycles, no cracks identified in the AM injectors





Flow characteristics (gas and liquid) validated throughout operating range

SGT-A35
DLE Dual Fuel: Central Fuel Injector

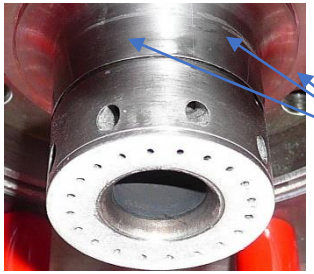
Background

- ❑ Reliability concerns with existing DF DLE design (combustion noise)
- ❑ Root Cause: positioning of gas fuel injection holes (constrained by manufacturing process)

Solution

- ✓ **Additive Manufacturing** of Central Fuel Injector – benchmarked to **proven gas-only design**
- ✓ Fuel passages optimized in ways **not viable with conventional methods**
- ✓ Combustion rig validation – **4x iterations in ~ 7 months**
- ✓ **Low-power noise anomaly now eliminated**

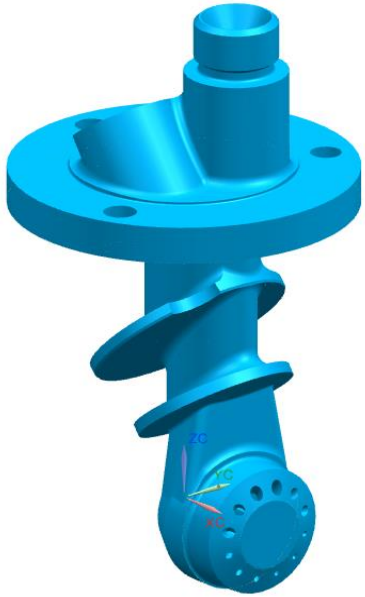
Gas-only DLE central fuel injector
9+ Million hrs proven in service



Dual Fuel DLE
central fuel injector

SGT-A35
Non-DLE Gas Only

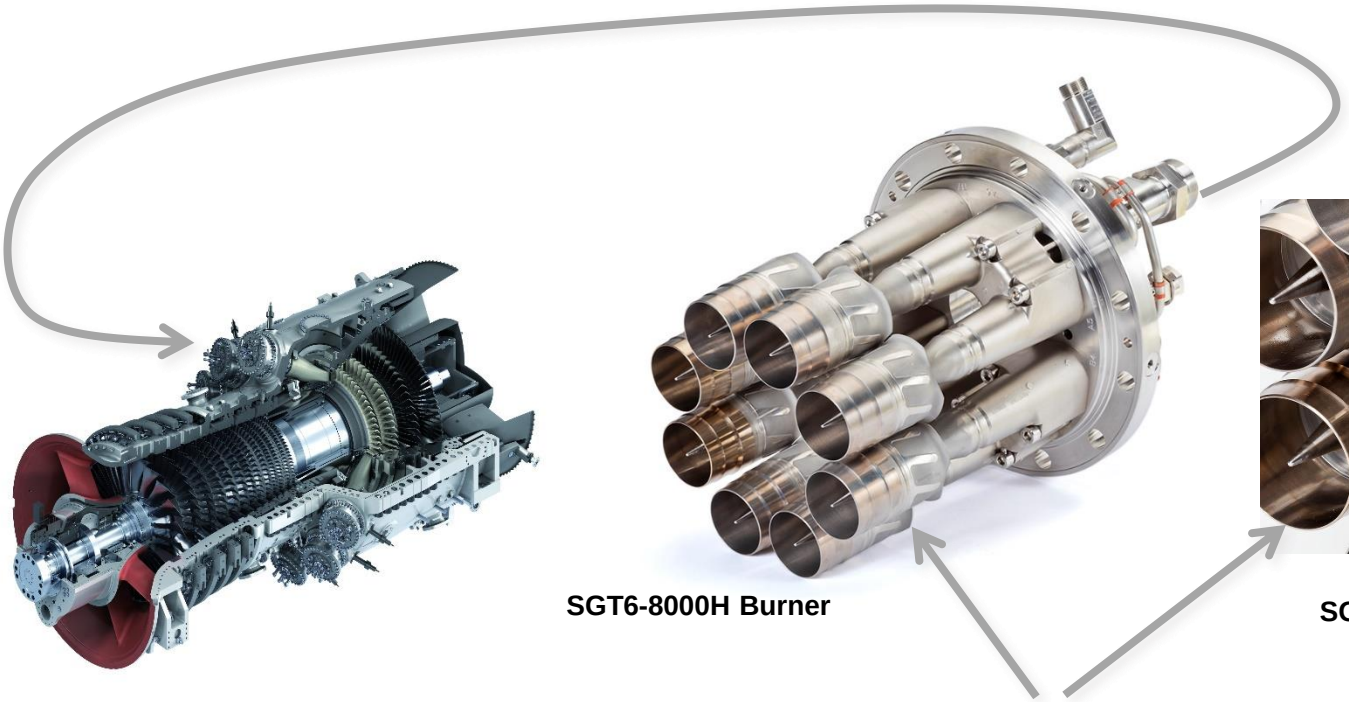
Build array of injector prototypes



3D-rendering of finished part

- ✓ Simplified one-piece design = **eliminate failure mode**
- ✓ **Validated** through extensive flow-testing to ensure gas fuel delivery is not compromised
- ✓ **Improved cyclic life,** similar to non-DLE Dual Fuel injectors
- ✓ Fast! From launch to production readiness in 6 months
- ✓ **Available as aftermarket solution**

SGTX-8000H Main Swirler



SGT6-8000H Engine

SGT6-8000H Burner

SGT6-8000H Burner close up

Main Swirler

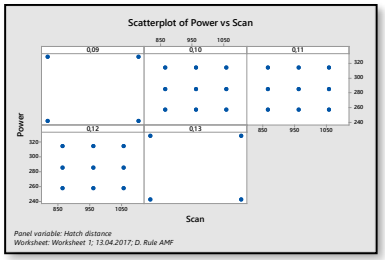
SGTX-8000H Main Swirler Challenges/Solutions

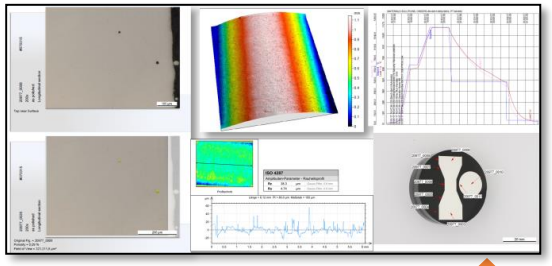
- **Build time per part reduced by 33%**:
  - Challenge: How to efficiently build such a large casted part
    - innovative parameter adaptions for individual part regions

- **Post processing time per part reduced by 80%:**
  - Challenge: Conventional manufacturing required several suppliers and manufacturing steps
    - Digital end-to-end chain eliminates process/software handovers
  - Challenge: Lengthy conventional processing times due to cast/machine/weld steps
    - Near net shape design by functional integration
    - **Part reduction from 10 to 1**
    - Less work in progress within burner manufacturing shop

Industrialisation of AM components

Generic Workflow for LPBF Process





Build parameter bulk hatching development

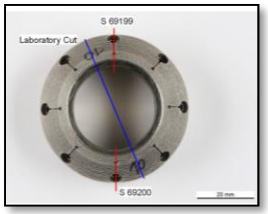
Standard Stress Relief Heat Treatment for development probes

Lab analysis
Roughness
Porosity
Crack density

Frozen parameter

Surface Quality Optimization development

Print first component demonstrators



Print test bars for limited program

Negative results, then additional development experimentation

Build heat treatment trial samples

Heat Treatment experimentation

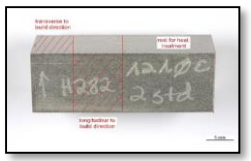
Lab analysis
Grain size
Precipitate morphology

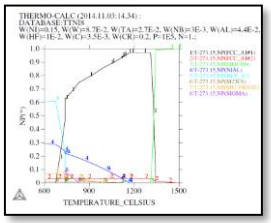
Heat Treatment selection

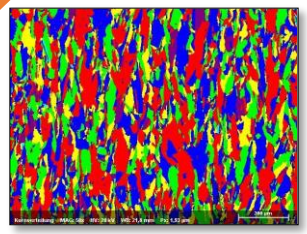
Optimized Heat Treatment for test bars

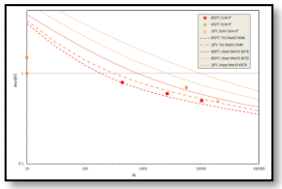
Mechanical Property Testing

Material Data Curves



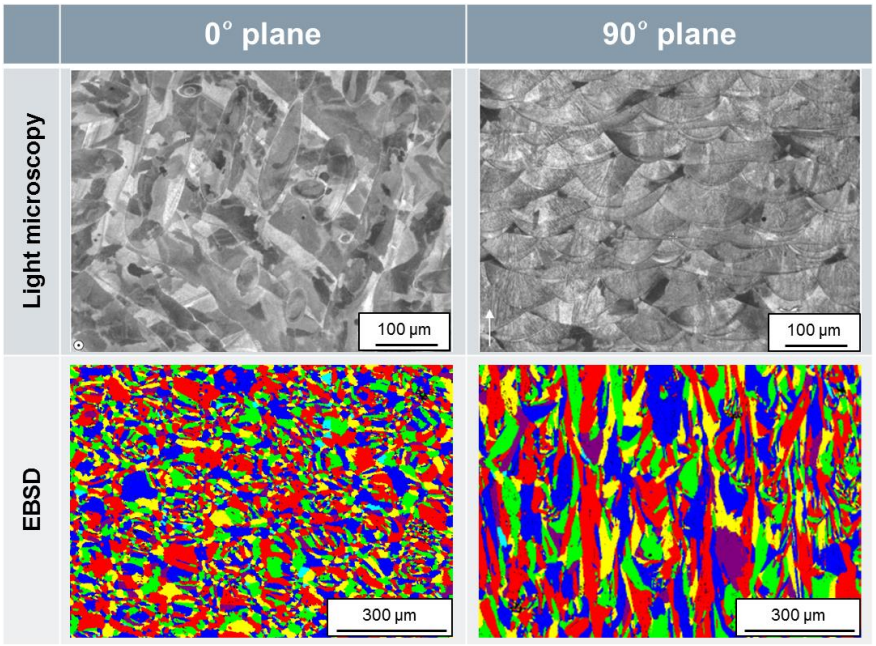


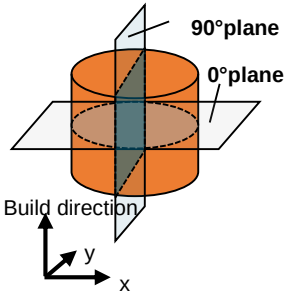


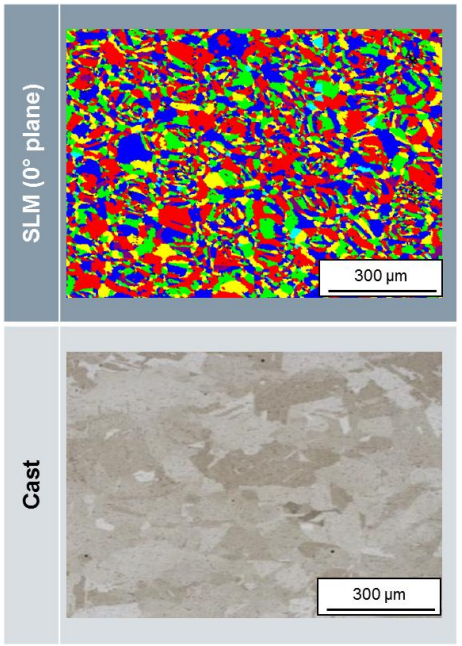


SLM microstructures (example)

Key factor for properties







SLM microstructures:

- Anisotropic grain morphology
- Significant texture
- Epitaxial grain growth in building direction across several layers
- In general, SLM processing of directed solidification possible
- SLM: significantly smaller grain size vs cast material
  (favorable for strength @ moderate temperatures)
  (unfavorable for strength @ high temperature and creep)
- Specific heat treatments can improve high temperature properties of SLM materials

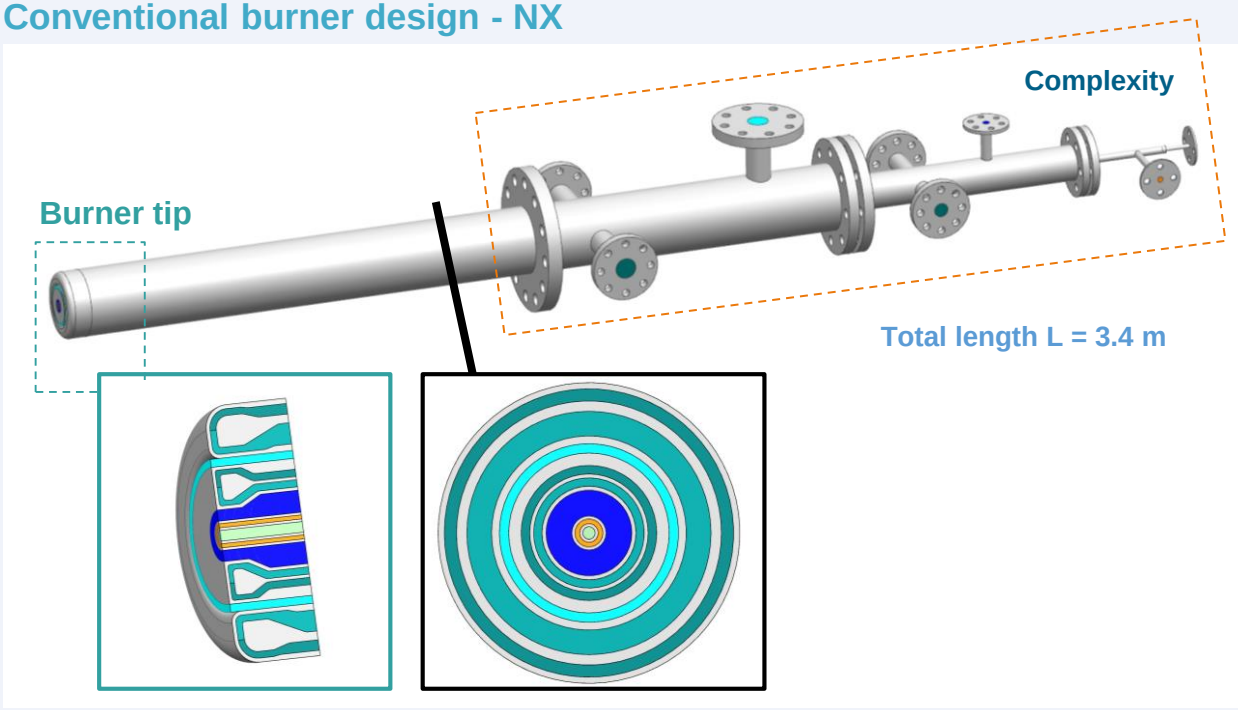
Designing and analyzing Additive Manufacturing components requires a change in mindset and digitalization approach

Conventional thinking

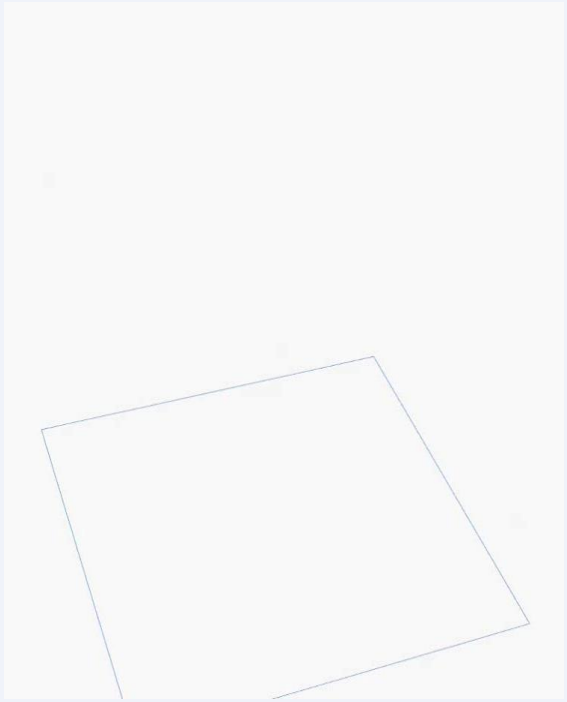
Disadvantages:

- Complex supply system
- High manufacturing cost
- Long lead time
- Complex assembly
- Costly maintenance, repair
- Excessive size
- Many parts, flanges, welds
- Nested, ring-shaped fluid channels

Conventional burner design - NX

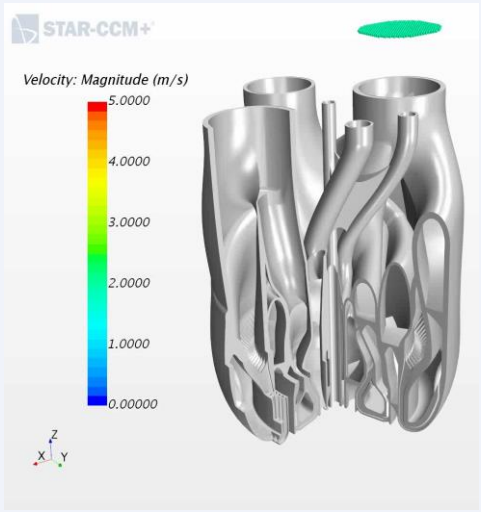


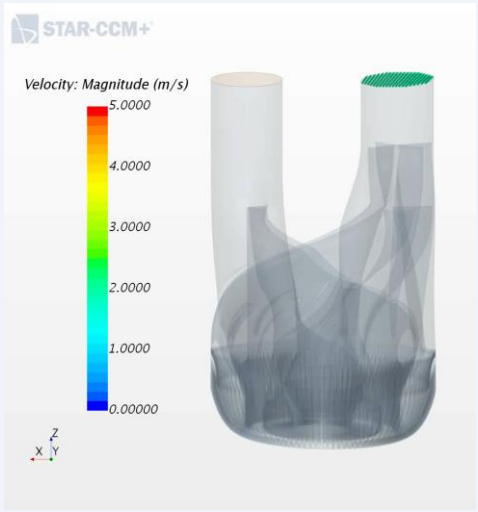
Inspiration



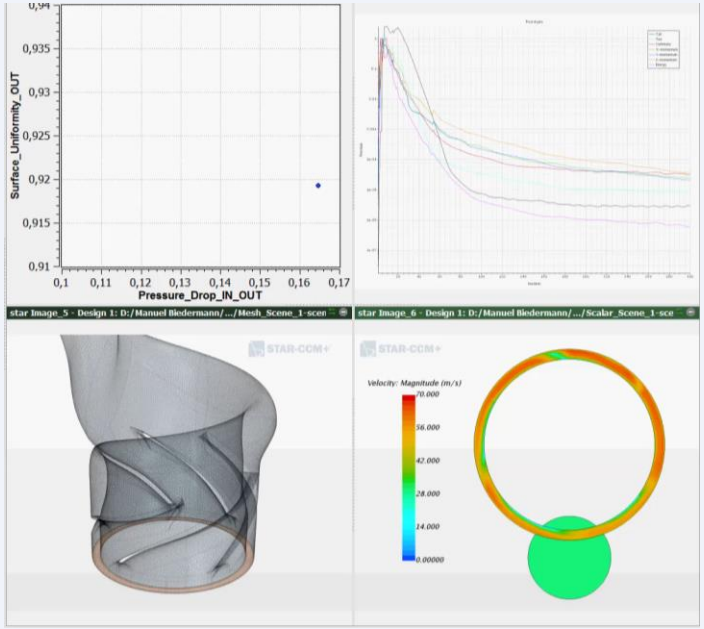
Simulation-driven generative design for one discipline

Computational fluid dynamics (STAR-CCM+)





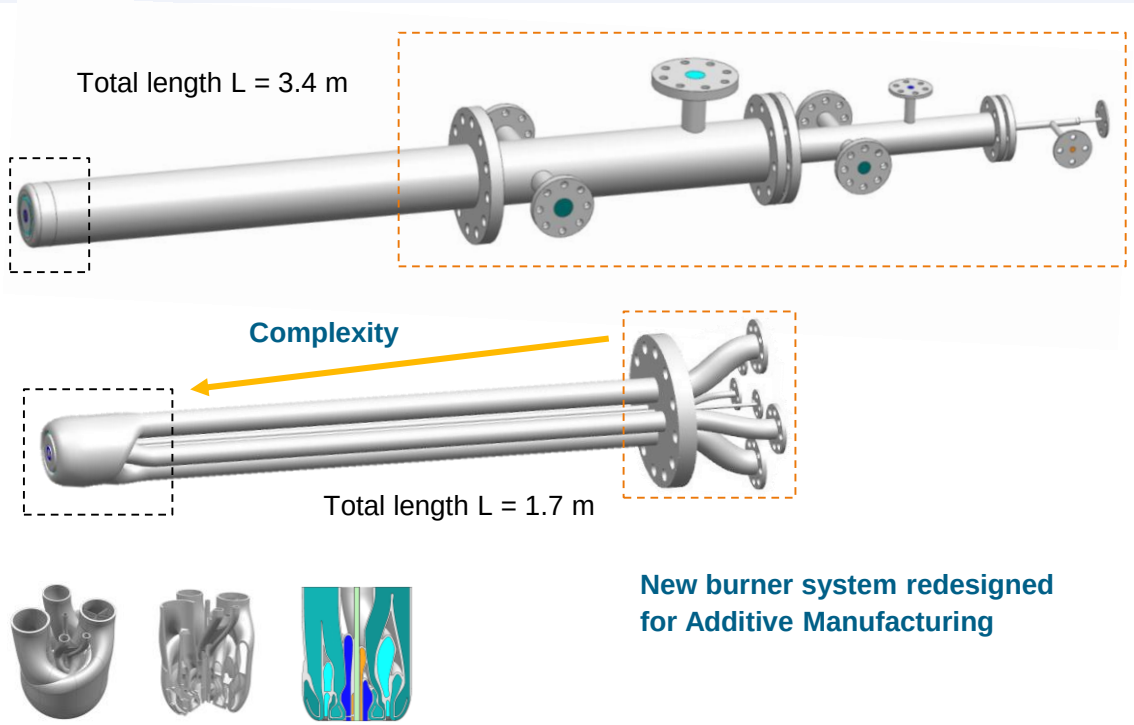
Design space exploration (HEEDS)



Result: Reimagined system

AM Thinking:

Vast improvement opportunities in every area of design, manufacturing and business



New burner system redesigned for Additive Manufacturing

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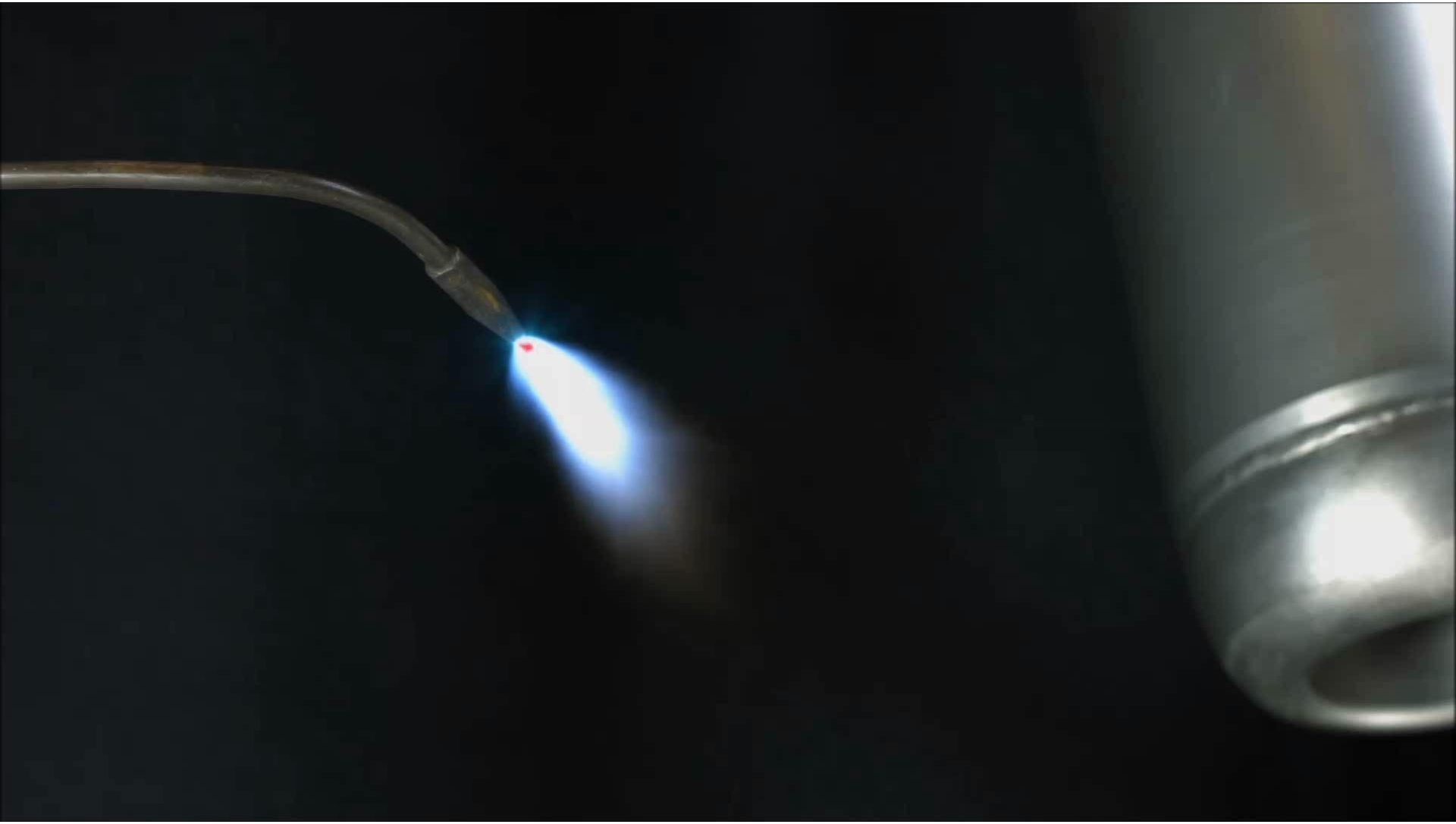
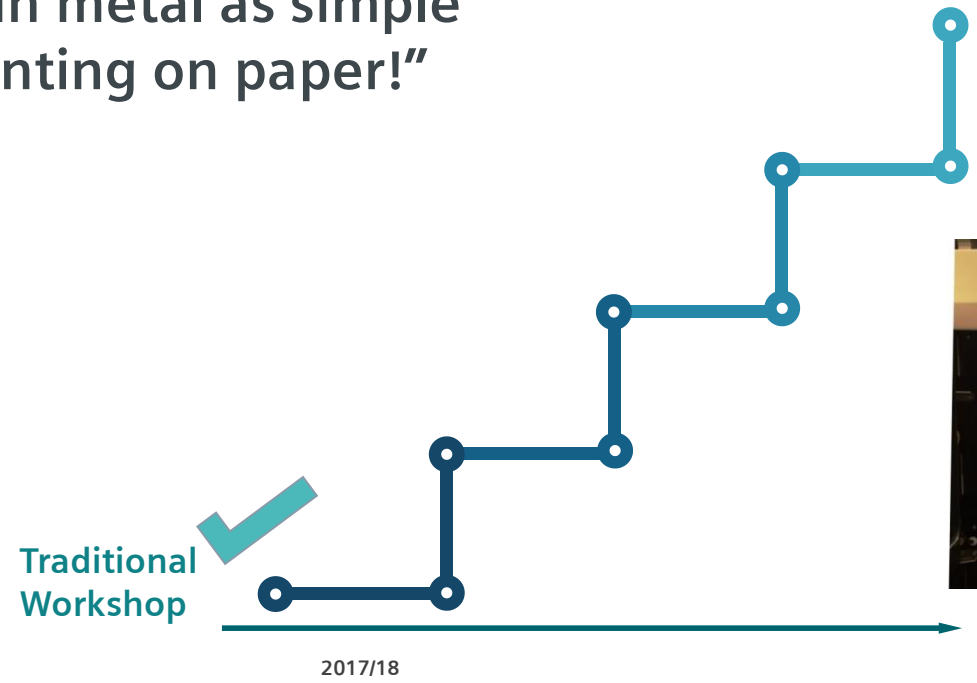
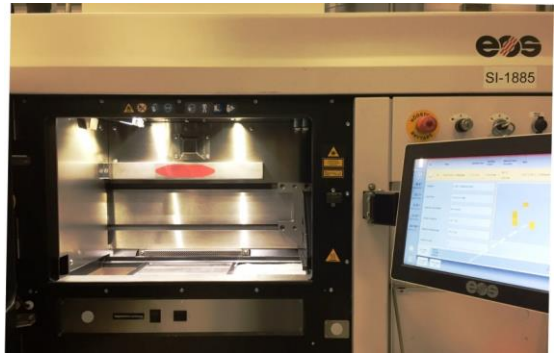


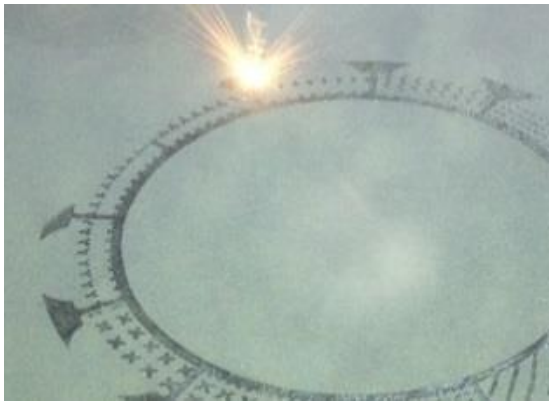
Starting Position: 2017

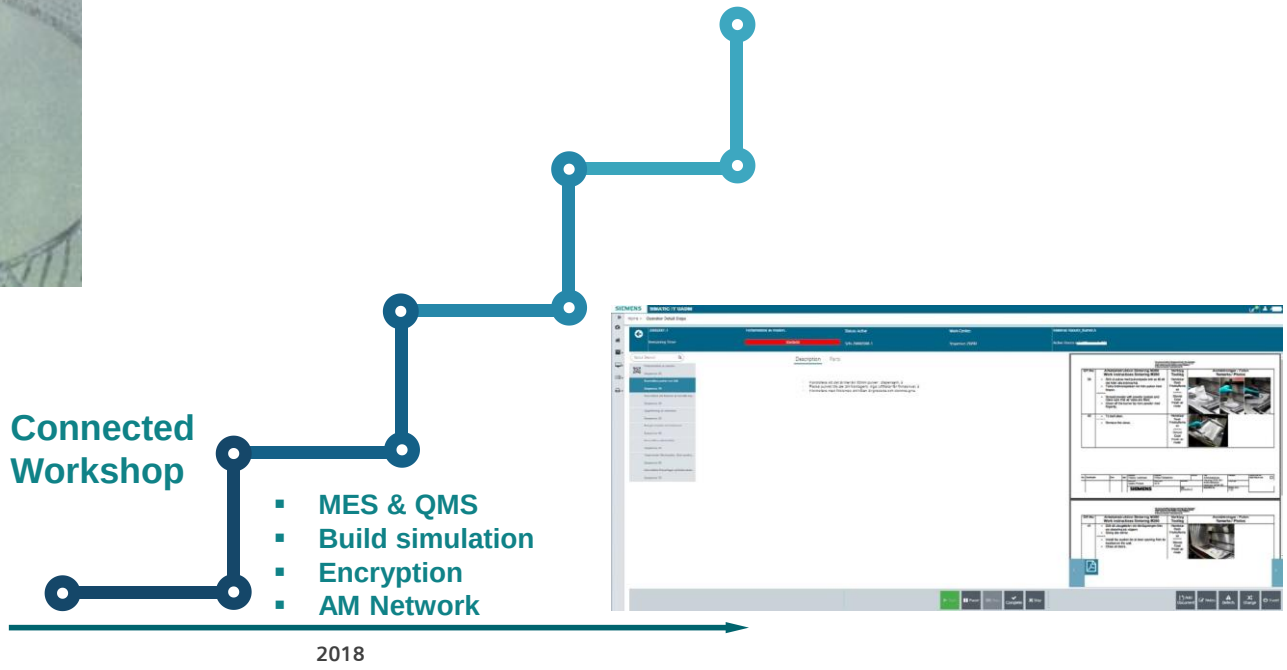
“Siemens wants to make 3D-Printing in metal as simple as 2D-printing on paper!”



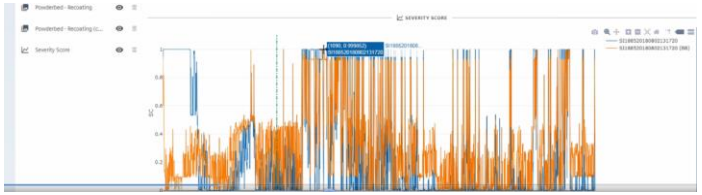


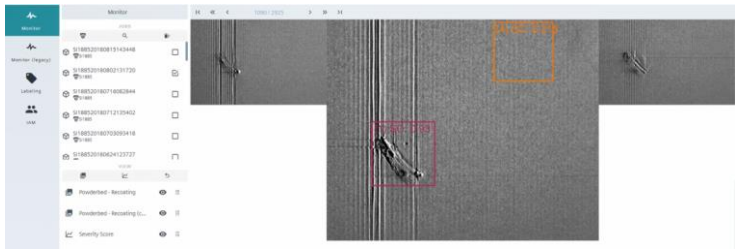
Step 1 (Today): Become ”Connected” through MES and use build job simulation

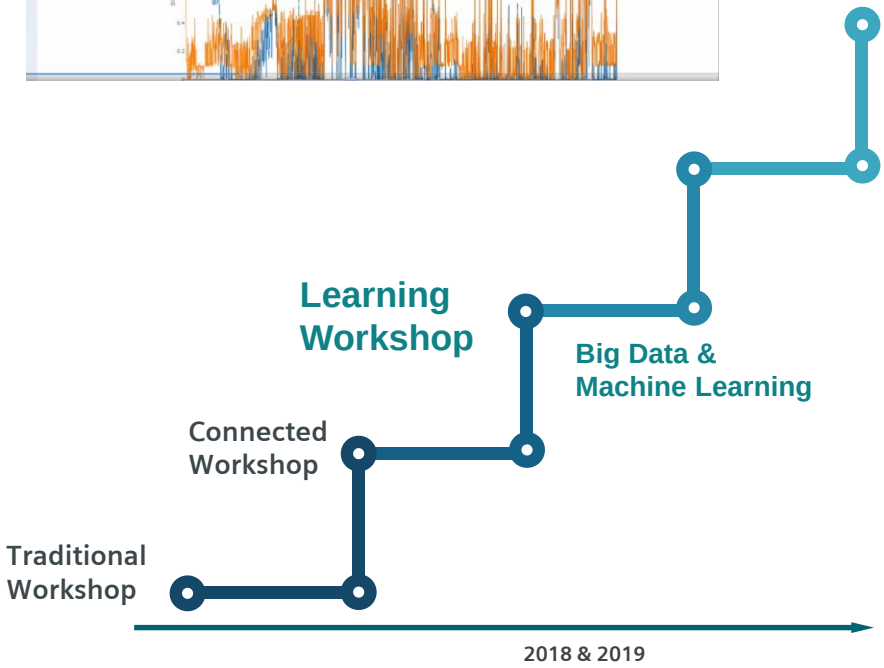




Step 2: Become ”Learning Workshop” through big data analytics and machine learning

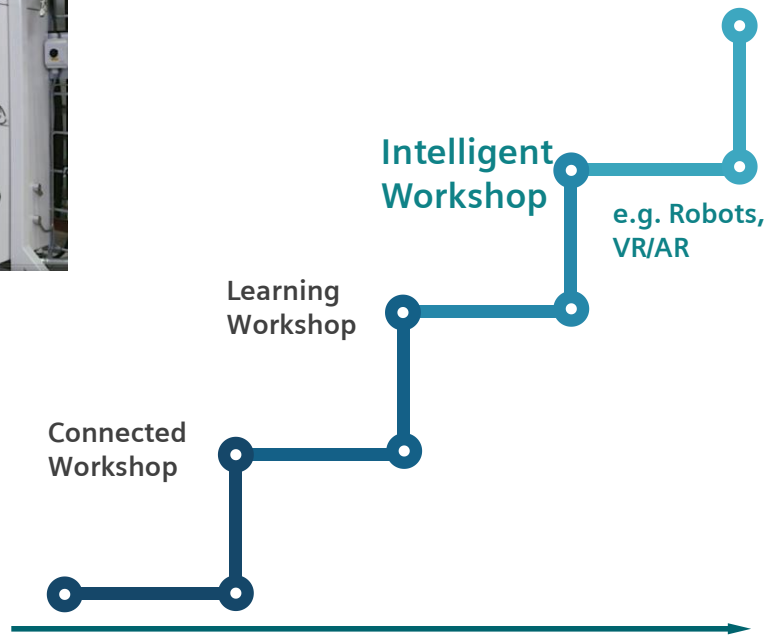


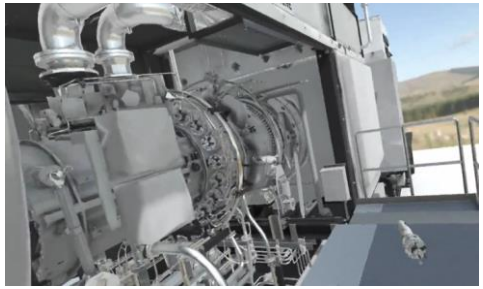




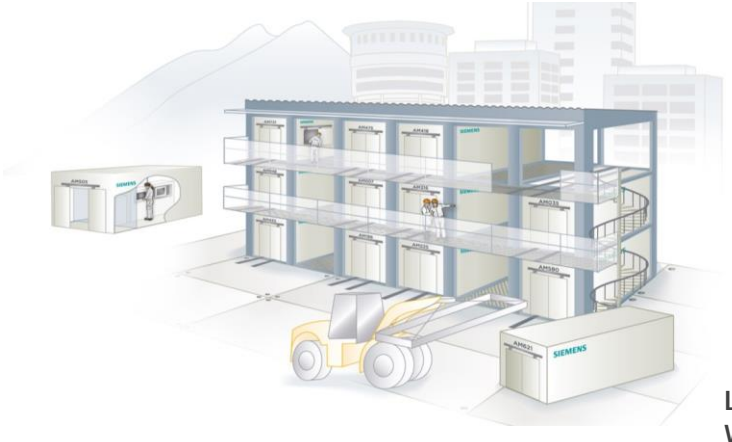
Step 3: Become ”Intelligent Workshop” Through Robots, VR/AR and Artificial Intelligence

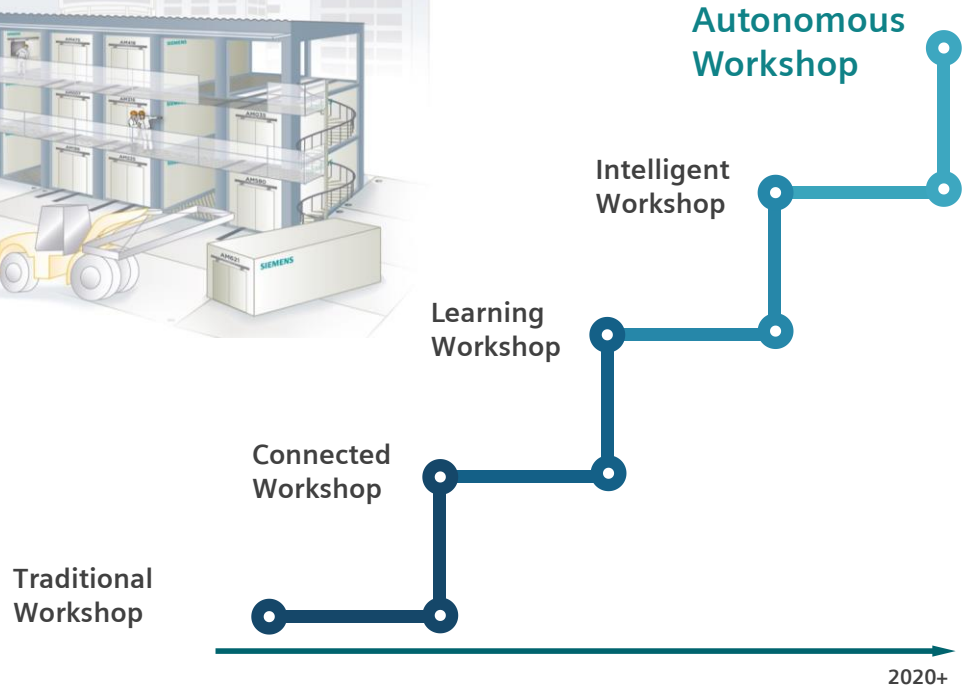
Traditional Workshop



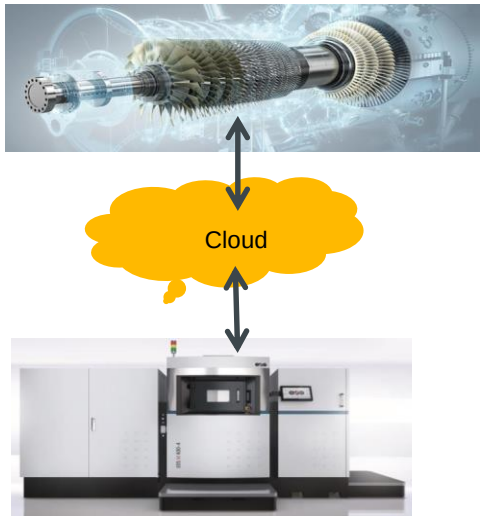


Step 4: Become ”Autonomous”, closed loop and self healing processes; gas turbines order spare parts by themselves

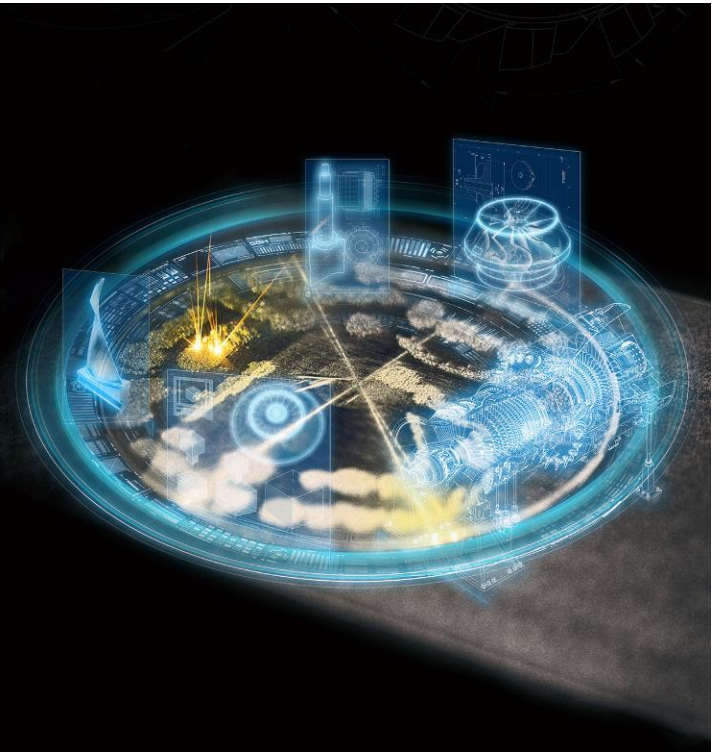




IoT for AM



Contact Us



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