19th Israeli Symposium on Jet Engines & Gas Turbines (AIJES 2022)

Gas Turbines Performance and Operation Flexibility Enhancement Enabled by Additive Manufacturing

Dr. Vladimir Navrotsky
17 November 2022, Haifa, Israel

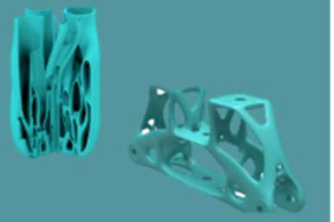
Why is Siemens Energy using Additive Manufacturing?

3D Printing enables 3D Transformation - Product Transformation + Manufacturing Transformation + Business Transformation

Product transformation
Shift from conventional design to innovative DFAM

Reimagine products

- Reduce weight, material
- Scan-to-product
- Enhance performance
- **Accelerate innovation cycles**
- Freedom of design is no longer restricted by design rules of conventional manufacturing

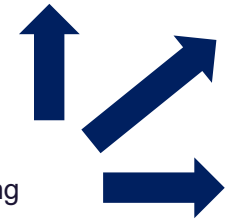


Rethink business

- Customization, personalization
- Zero inventory – on demand printing
- Design anywhere. Print anywhere.
- **Accelerate innovation**

Conventional production

- Multiple components/part
- Long lead times for design & prototyping
- Design limited by mftg process, e.g. casting

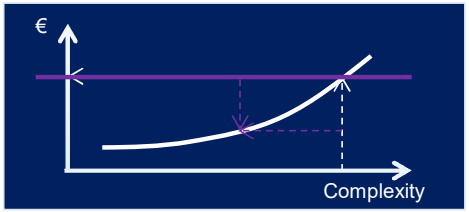


Reinvent manufacturing

- Eliminate molding/castings/tooling
- Eliminate/simplify assembly process
- Reduce supply chains
- **Affordable low volume production**

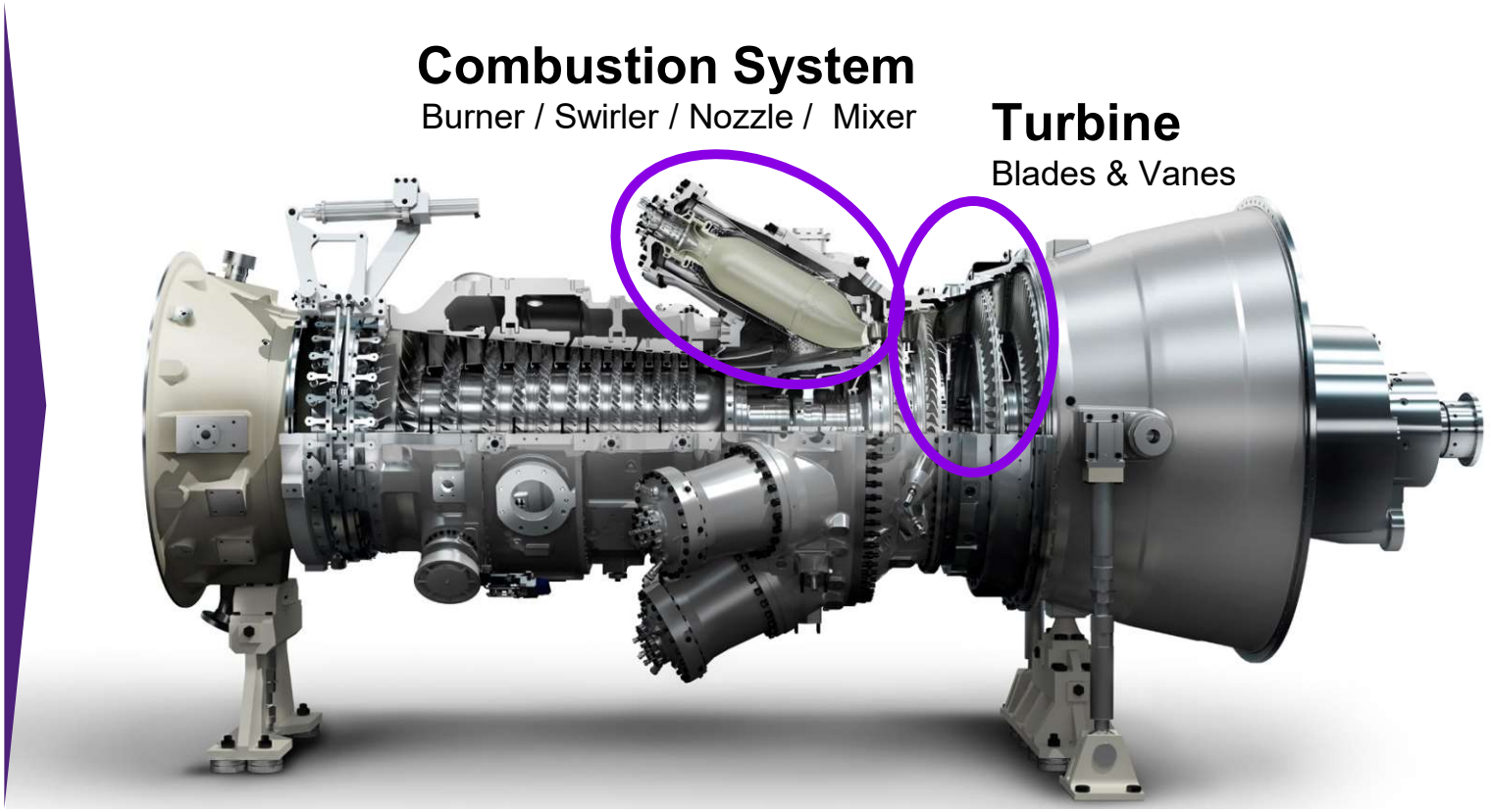
Manufacturing transformation
Shift from prototyping / experimentation to mainstream industrial production

Additive Manufacturing applicability
Gas turbine as a focal areas for Additive Manufacturing



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

efficiency, durability, life cycle improvement



AM as key driver of GT's competitiveness enhancement
Performance, Emissions, Operation and Service

Performance & emissions

Competitiveness
- *Fuel & operation flexibility*
- *Installed fleet upgrades*

Inventory Reduction
- *Lead-time reduction*
- *Digital inventory*

Cost-out
- *Part cost*
- *Life cycle cost reduction*

SGT5/6-4000F

SGT6-5000F

SGT5/6-8000H

SGT-800

SGT-400

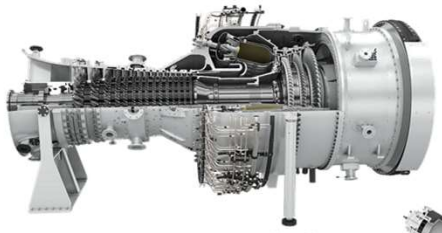
iTrent

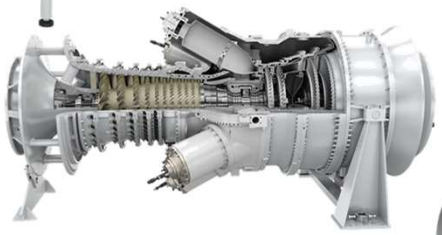
2019 2020 2021 2022 2023 2024 2025

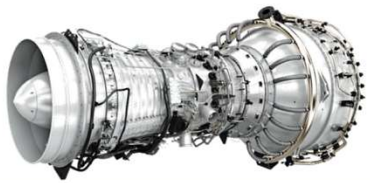
Combustion parts e.g., burners

Heat Shields,Vane 1, Vane 2

Bladetips, Blades





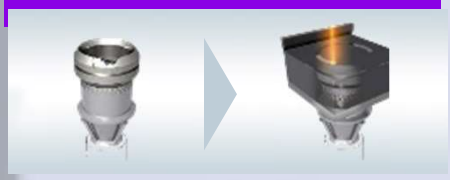


Field of use and application of AM at Siemens Energy

Rapid Prototyping

Rapid Manufacturing

Rapid Repair



Spare parts on demand
Digital Inventory

Today Siemens Energy is one of the world leaders in design and production of AM components

Worcester (UK)

Finspång (SWE)

Berlin (GER)

CLT (US)

Orlando (US)

Nuremberg (GER)

Siemens Energy experience & capability today covers more than…

>10 years
experience in AM

> 60
printers worldwide

> 100
AM components implemented

>1.500.000
operating hours on SE turbines

>200
dedicated AM engineers

>1.200
components qualified by 2025

Siemens Energy is one of the earliest adopter of AM

From R&D too serial production within 10years

Start of AM journey

2008

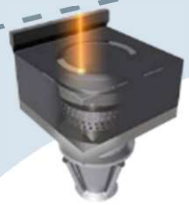
First Powder Bed Fusion demonstrators

2013

Swirlers
In serial production

2016

- Materials Solutions Acquisition
- Finspong Workshop Inauguration



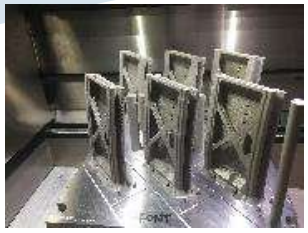
Burner Repair
In serial production

2020

Burners
in serial production

2021

Scaling-up serial production



Heat shields & Vanes ready for serial production

2025

~1.200 components qualified for serial production

Aspiration:
blades ready for serial production

Additive Manufacturing includes various technologies with different benefits for different applications

Selective Laser Melting / LPBF

LPBF in-house

- To improve product competitive position
- Not mature yet, new design for AM & AM materials under development
- > 100 components qualified for serial production by F22

LMD- Laser Metal Deposition

LMD in-house

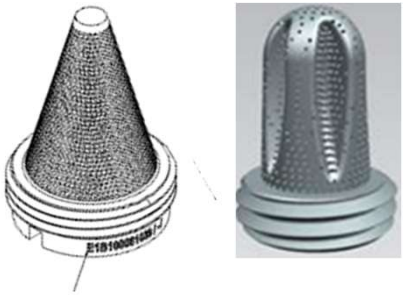
- Mature technology
- For repair and Spares on demands
- > 150 different rotor/casings repaired by FY22
- Next step - Regionalization

EBM- Electron Beam Melting

EBM with External supplier

- Due to low volume in cooperation with external suppliers
- Lead time reduction, spear part on-demands
- Few impellers qualified for serial production

Binder Jetting



BJ with External Supplier

- Due to low volume in cooperation with external suppliers
- Lead time & cost reduction (e.g. fuels strainers,70% lover cost)
- Few components qualified for serial production by F22

Additive Manufacturing at Siemens Energy

Printers and Post Processing

SIEMENS energy

One of the largest Metal AM printers fleet

Printers

EOS M400-1
EOS M400-4 &
EOS M400-4 Shared Modules
- 4 laser
- 400x400x400 mm

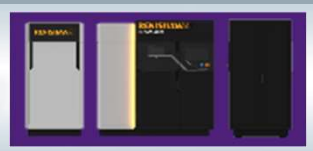
EOS M290
- 1 laser
- 250x250x325 mm

EOS M280
- 1 laser
- 250x250x325 mm

Customized for repair – printing on top of base material

EOS M270
- 1 laser
- 250x250x325 mm

RenAM 500Q



Post processing

- **Powder removal**
- **5 Axis Machining**
- **Blasting / shotpeening**
- **EDM Cutting/Bandsaw**
- **3D GOM Scanning**
- **CMM**
- **Heat treatment**
- **Brazing**
- **Flow testing**
- **Coating**

+

Siemens Supplier-base for complete production of parts

Additive Manufacturing at Siemens Energy

Materials

Materials capability

We are working with most difficult high-temperature alloys and material database building for nickel-based alloys

Qualified print process

Difficult to weld

Nickel Superalloys

- CM 247 LC
- In 738 LC
- C 1023
- MAR M002

Readily weldable

Nickel Superalloys

- Haynes 230

Aluminum

- A20X

Ferrous alloys

- SS 17-4
- SS 15-5
- SS 304
- SS 316L
- Duplex 2205
- Maraging Steel M300

Cobalt alloys

- CoCrMo
- MAR M509

Titanium alloys

- Ti6Al4V

Fully qualified with design data

Nickel Superalloys

- In 939
- Haynes 282

Nickel Superalloys

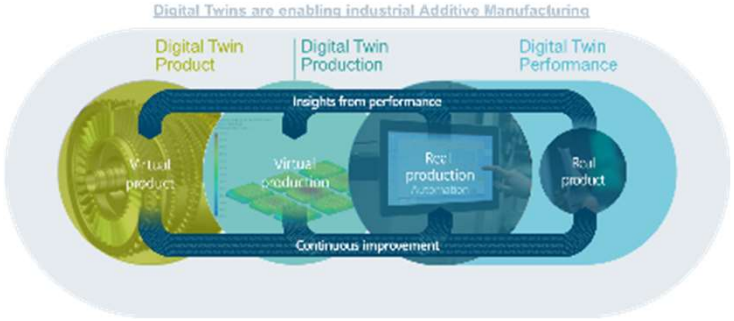
- Hastelloy X
- C 263
- In 625
- In 718

Cobalt alloys

- Merl 72

Digitalization and AM enabling Integrated Design and Sustainable Manufacturing

Vision: ”Autonomous”, Closed Loop & Self Healing Processes, Gas Turbines Order Spare Parts by themselves



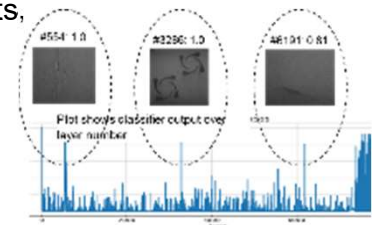
Digitalization of AM Manufacturing **is key to leverage full potential of AM** technology

2025
Autonomous Workshop

IoT for AM

Intelligent Workshop

”Intelligent Workshop” through Robots, VR/AR and AI

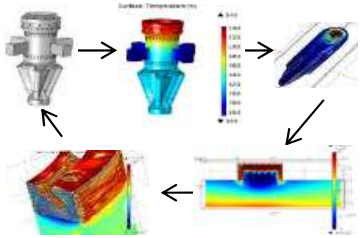


Learning Workshop

”Learning Workshop” through Big Data Analytics and Machine Learning

Connected Workshop

”Connected” through MES and Use of Build Job Simulation

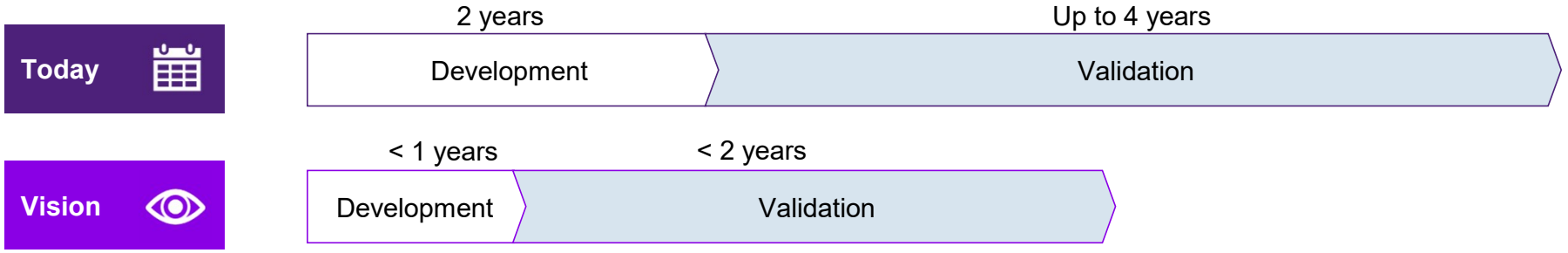


Traditional Workshop

How to accelerate AM components Implementation ?

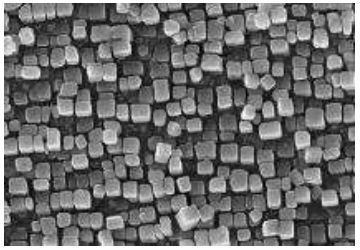
Main lead time drivers

AM GT components time to market



Acceleration Potential

Material development acceleration by cooperation with partners

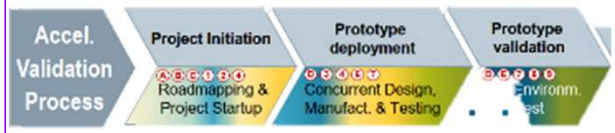


Picture: Printed and heat treated IN738 (Blade alloy)

Components test rigs & R&D test engine for faster access

Picture: SGT-800 platform

Risk release-based validation time reduction known materials and components



Picture: Variation of product development for early validation

We achieved a major … first turbine blade

- Travels over 1,000 mph
- Surrounded by gas at 1,250 ºC

BREAKTHROUGH in FY2016… was printed and tested in the engine

SIEMENS energy

Approach

- LPBF for **rapid design & prototyping** of blades
- **Rainbow test** in gas turbine for selection of best design
- **Calibration** of calculation tools and design methods
- **Full scale engine test**

Siemens awarded by ASME for 3D-printed gas turbine blades

3D PRINTING INDUSTRY
THE AUTHORITY ON 3D PRINTING

Siemens, Superalloy gas turbine blades – winner

ASME
SETTING THE STANDARD

3D-printing use case or application

- **Excellent tool** for optimization of blade cooling designs
- Substantial lead time reduction for engine upgrades - **1st blade manufactured** already **2 weeks after receipt of 3D model**
- **Minimized risk** by verification of blade temperature prior to casting

How AM can contribute to Decarbonized World and Energy Transformation ?

GT's sustainable value & flexibility generated by AM technology

Business Value Improvement

Generated value:

- Efficiency improvement to **reduce OpEx and Emissions**
- **Longer Life** of GT-components to reduce Lifecycle cost
- Operation **flexibility enhancement**
- **Increased** Power Plant **Profitability**

Lead Time Reduction

Speed:

- Rapid development, prototyping, validation and manufact.
- Spare Parts on Demand
- **Quick response** to Customer demands

Environmental Contribution

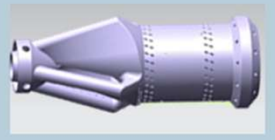
Sustainable value:

- **30% less carbon footprint** due to less waste materials and transportation
- **Fuel Flexibility** (e.g. , **biofuel, H2**, towards zero CO2)
- **Energy efficiency** enhancement (more Power for less fuel)
- **Opportunity for** AM components **re-cycling**

Fuel flexibility enabled by AM

AM burners enabling H_2

Braskem



- 2x SGT-600 DLE Sold to Braskem – Brazil
- In operation beginning of 2022
- **60% H2** content in natural gas

AM burner design and manufacturing for
fuel flexibility, emission reduction and lifetime extension

Approach

- Redesign of existing burners for SGT-600 / 700 / 800 to utilize the design freedom offered by AM
- Full scale engine test performed
- Commercial operation in 2017

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

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

Benefits

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

Göteborg Energi and Siemens Energy in cooperation for fossil-free cogeneration

Potential to demonstrate flexible grid services by operation on fossil free fuel for ultra low spinning reserve capability, zero to negative generation possible, synchronous condenser operation of GTG's & STG. Island mode operation and primary response (GT response, dP/dT 10MW/s and GT peak firing as well as secondary and tertiary response (peak firing, inlet chilling and black start < 10 min).

By 2025, all district heating in Gothenburg, Sweden, will be produced by renewable or recovered energy sources.

- **Electricity from gas turbines** has the potential to **provide carbon neutral grid balancing in a future energy** system with a high percentage of renewable energy sources such as **sun and wind**.
- A **dual fuel burner** for operation **on green fuels**, gaseous as well as liquid, **is targeted** for demonstration in Rya

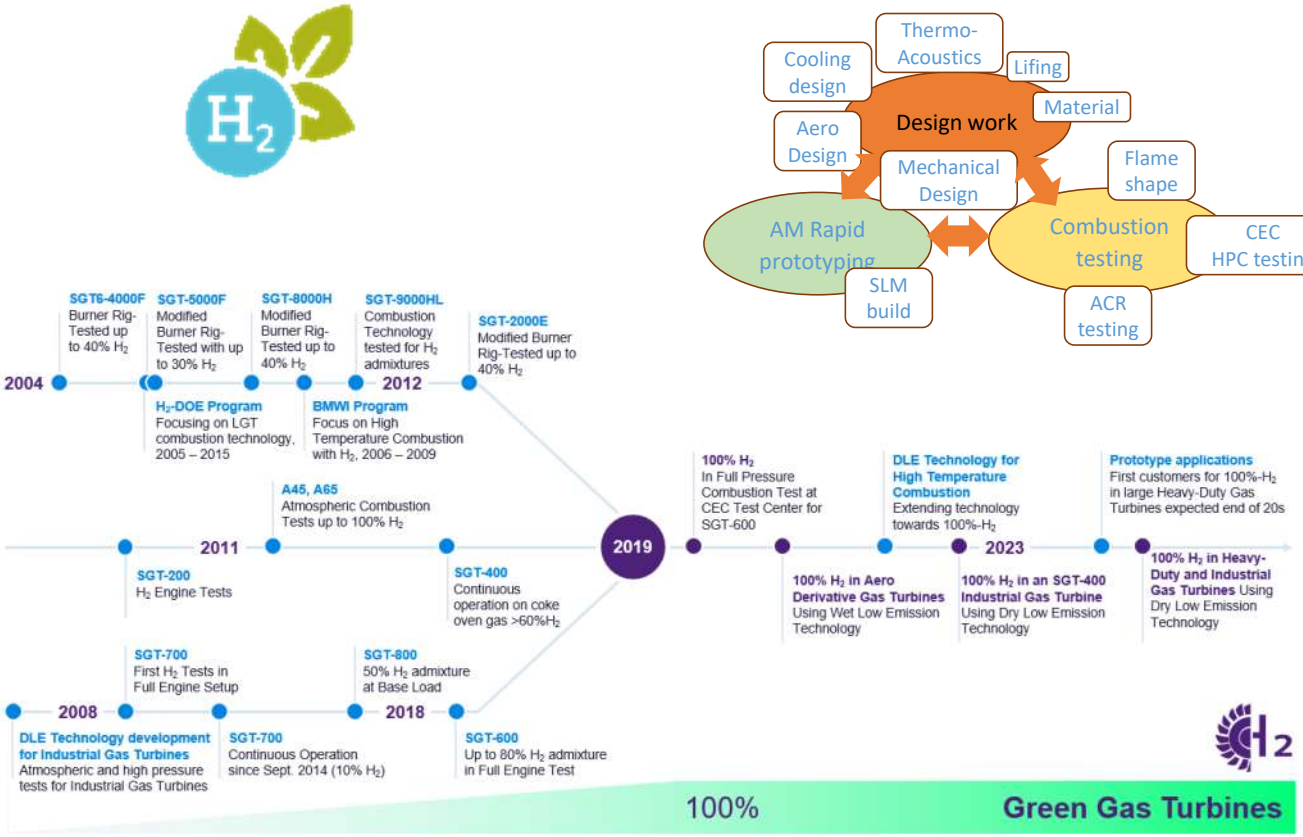
Long term collaboration on development of fossil free operation on cost effective green fuels

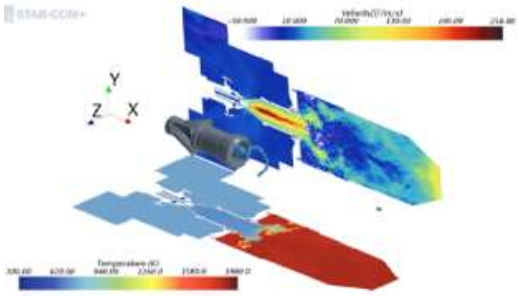
Hans Holmström (CEO Siemens Energy AB) and Alf Engqvist (CEO Göteborg Energi)

Additive manufacturing for R&D speed when developing next generation of green burners

AM contribution to Decarbonized

Acceleration of H2 development towards 100% enabled by AM



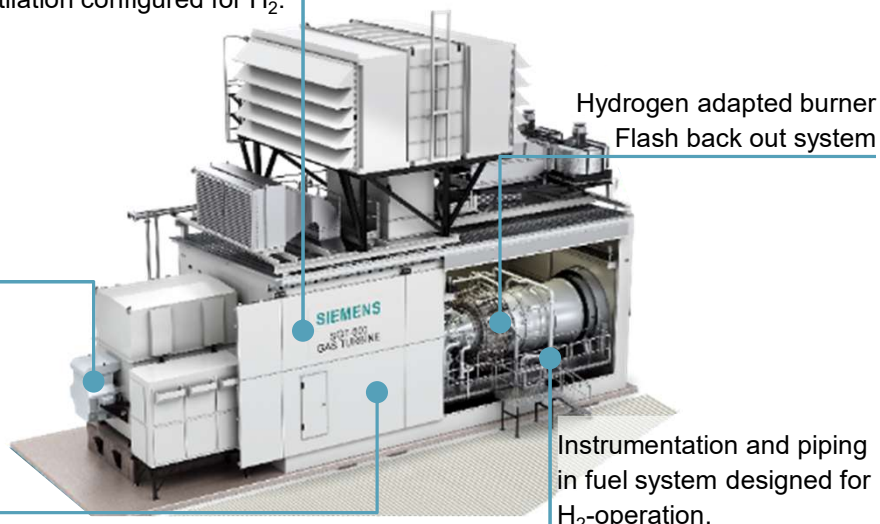


iBuMa H2 concept iterations
Theory guides but experiment decides!

Modifications for Hydrogen operation
SGT-800, SGT-700 & SGT-600 3rd generation DLE

SIEMENS energy

Installation adaptations to consider



- Currently released hydrogen capabilities:
  - SGT-600 → **75 vol-%** H_2 @ **≤25** ppm NOx
  - SGT-700 → **75 vol-%** H_2 @ **≤25** ppm NOx
  - SGT-800 → **75 vol-%** H_2 @ **≤25** ppm NOx
- **Higher H_2 content** can be evaluated on a project-by-project basis

Conditions that need to be considered for tailored adaptation:

- Fuel composition
- Emission regulations
- Estimated operating profile
- Existing installed auxiliary equipment and control system
- Currently installed version of combustion chamber and burners

---

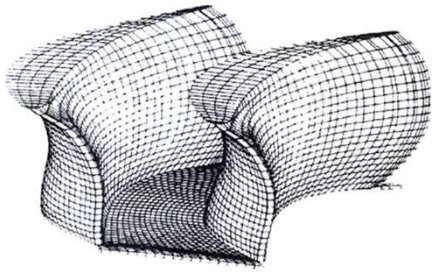
- Package Modification **optimized to customer installation to required level of H_2**, based on OEM knowledge
  - Step-wise scope increase with H_2-level 15, 30 and 75 vol-%
- **Quick installation** meaning minimal disruption to operation, especially if performed together with a major inspection
- **No or minor additions** to the maintenance programme required

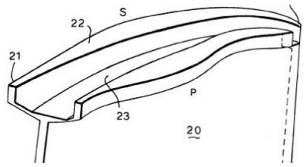
Additive Manufacturing as a Key Enabler

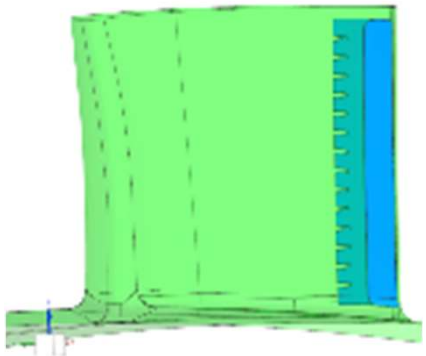
GT efficiency enhancement by Additive Manufacturing

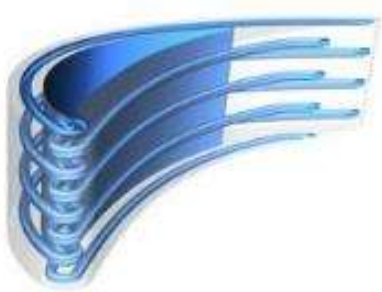
Key approaches for GT efficiency improvement:

- **Turbine blades and vanes aerodynamic enhancement**
  - 3D airfoils profiling w/o any geometry limitation (compared to casting)
  - Thin trailing edge
  - Cooled light-weight shrouds / winglets
- **Blades & Vanes Cooling air saving**
  - Less cooling air for blades and vanes to improve turbine efficiency



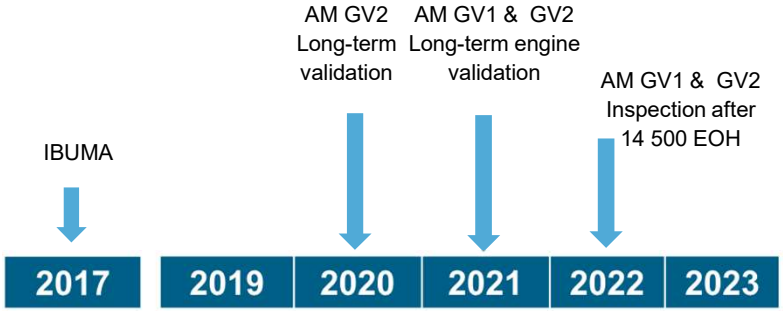




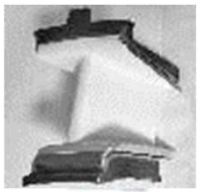


SGT-700 – Additive manufacturing for higher efficiency and fuel flexibility towards deep decarbonization

AM Component field Validation



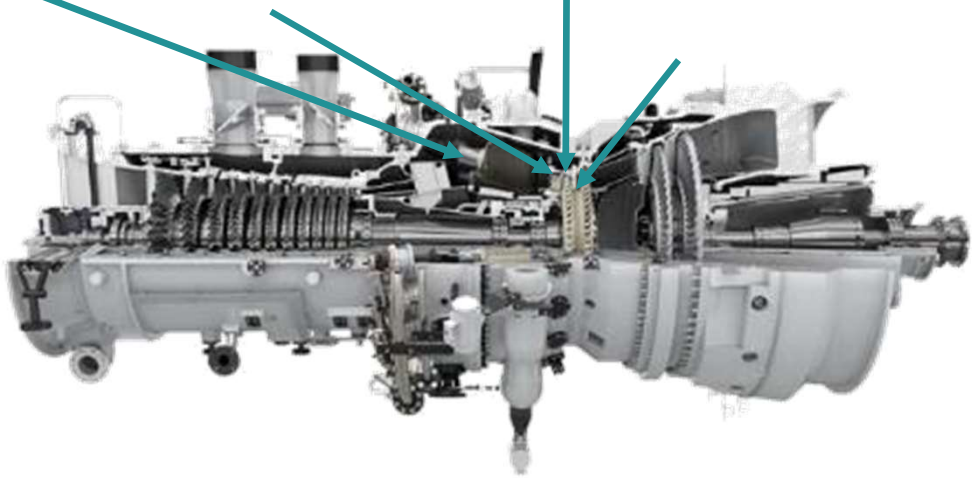
IBUMA:
- H2 capability



GV1:
- Performance improvement or life extension

HS1:
- Performance improvement or life extension
- Reduced perform. degradation

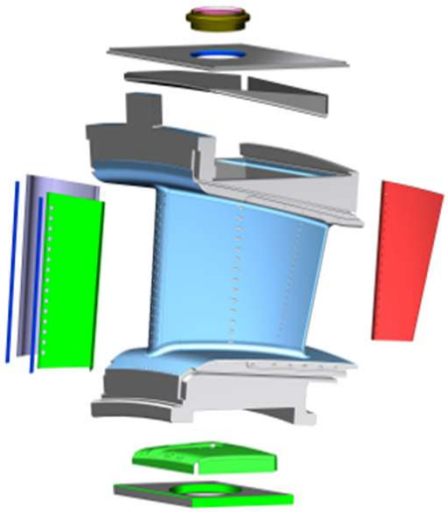
GV2:
- Performance improvement or life extension



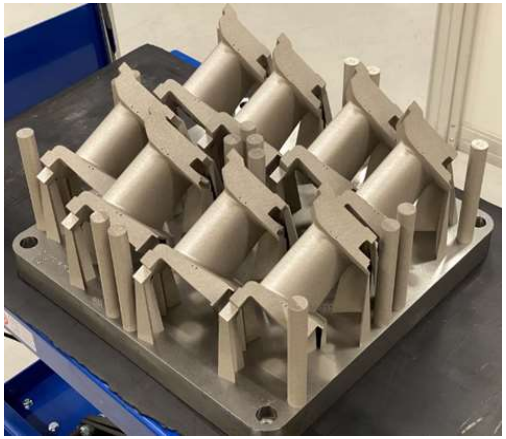
GV1 AM Design and Manufacturing

SIEMENS energy

Conventional casted vane



8x Vanes printed



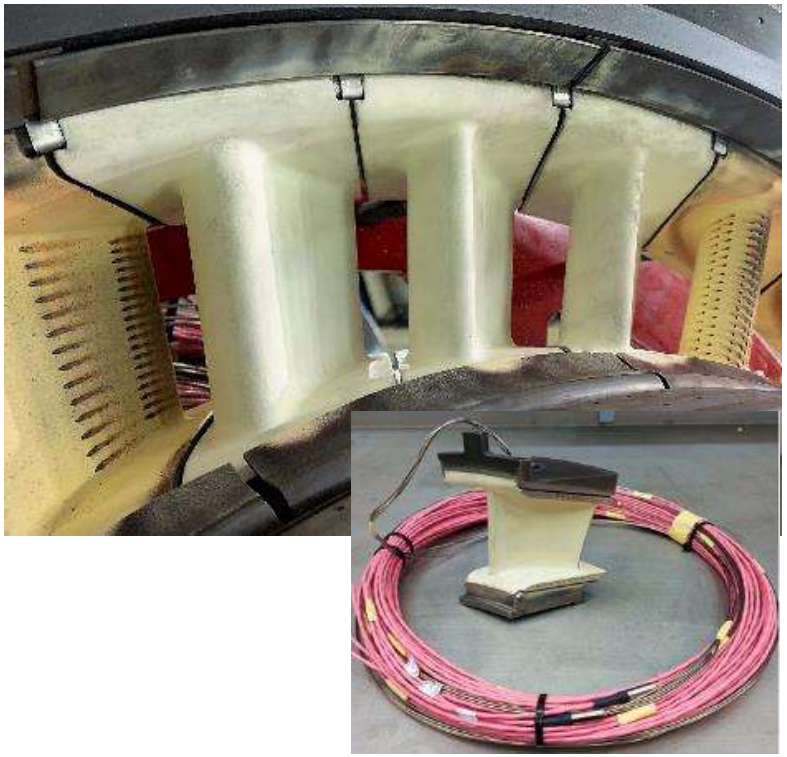
Printed vane machined

Printed vane coated

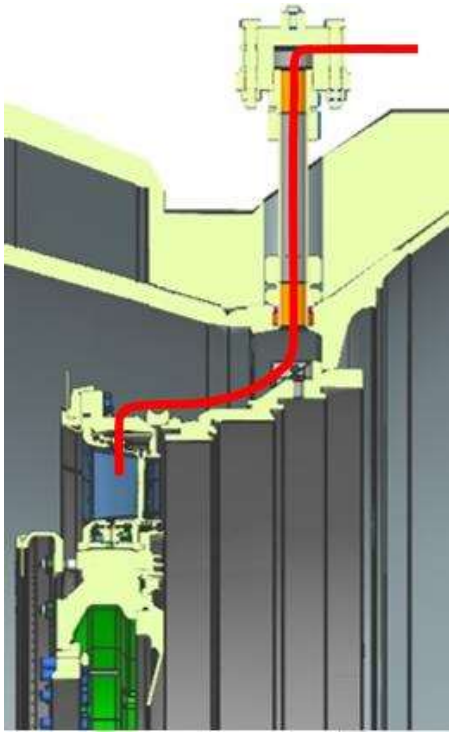
- 12 -> 1 Part
- Reduced cooling -30%
- Leadtime - 6 months
- Performance improvement

SGT-700 GV1 Validation

Instrumented AM GV before and after engine assembly



AM GV Thermocouples lead out Instrumentation on the Customer Engine

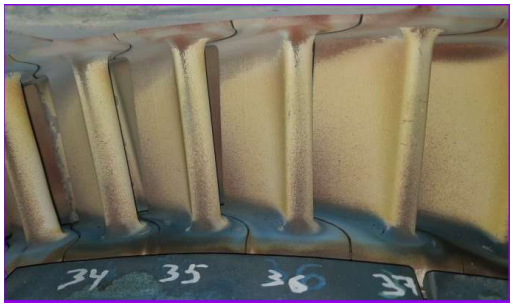


AM Components Test & Validation

Materials and design long-term validation in real engine condition

- **AM Materials long-term Validation:**
  - SGT-1000 (V64.3) engine (68MW) Conventional robust turbine vanes 1 design, but additively manufactured from In939 (with similar coatings) were installed in customer engine for long-term material validation:
    - Inspection after 24 000 EOH shows that vanes are in a good condition
- **AM Vanes design long-term validation**:
- SGT-700 GV1 and GV2 Long-term validation Design for AM of in a customer engine
  - GV2 accumulated ~14 500 EOH;
  - GV1 accumulated ~11 500 EOH

SGT-1000 AM GV1 after 24 000 EOH



SGT-700 AM GV1 and GV2

GV1
11 500 EOH

GV2
14 500 EOH

Additive Manufacturing as a Key Enabler

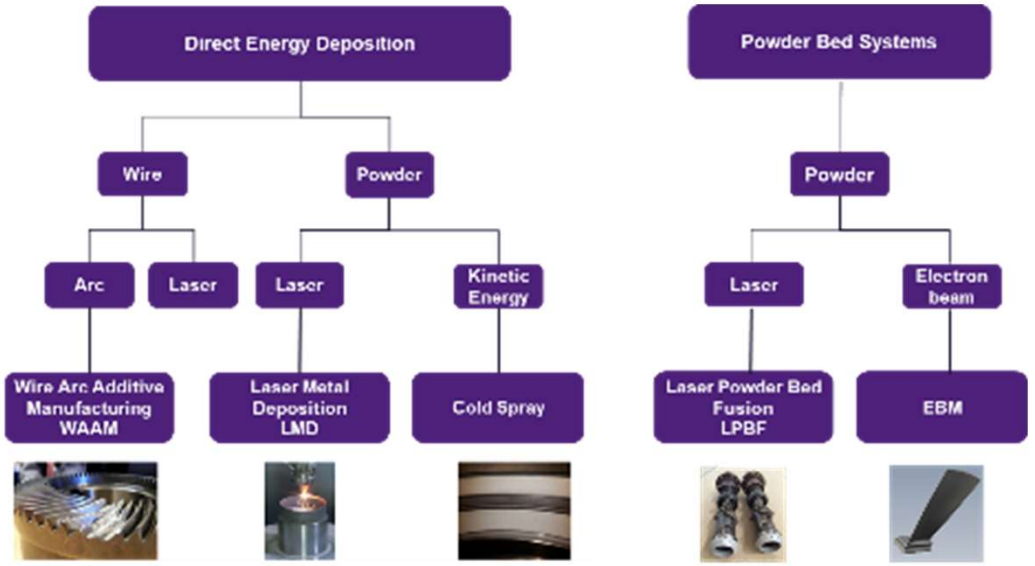
AM enables not only life cycle cost reduction, but generates sustainable value

Target:

Development and application of repair technology to reduce cost / outage time

Flexible refurbishment options

Factory in the field



Additive manufacturing bringes Repair of the Gas Turbine Burners to the next level

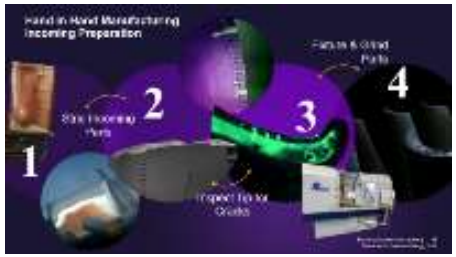
Our First Additive Manufacturing technologies application was started from SGT-700/800 burners repair in FY2013

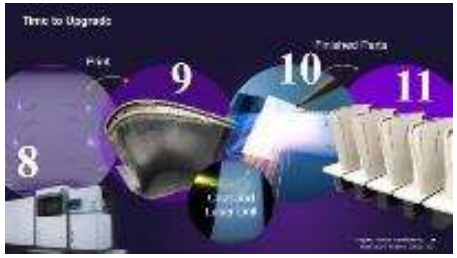
Rapid Repair- 90 % lead time reduction

- **Product**: SGT-700/800
- **Component/scope**: Burner tip
- **Benefits**:
  - Quick burners upgrade to latest design
  - Life extension
  - Lifecycle cost reduction
  - Decarbonization
- **Status**:
  - In commercial application since 2013
  - **> 1 500 000 hours** accumulated operating field experience

Additive Manufacturing as a Key Enabler

AM enables not only life extension, but also GT performance enhancement





Blade tip repair

- Laser Powder Bed Fusion qualified since 2020
- > 24 000 EOH field experience
- Life extension + performance enhancement
- Significant reduction of blade tip temperature (>100 ºC) by improved cooling of blade's tip
- Turbine performance degradation rate slows down

Siemens Energy is one of the world leaders in operating field experience > 1.500.000 hours

SIEMENS energy

Repair

- 90% lead time reduction
- **2013:** Commercial Operation
- **30,000 EOH fleet leader experience**

Lifetime extension

Design for AM

- Longer life
- Higher reliability
- **2017:** Commercial Operation
- **> 20,000 EOH fleet leader experience**

Emissions reduction

Design for AM

- Swirler can only be made via SLM
- **2013:** Commercial Operation
- **> 36,000 EOH fleet leader experience**

Performance enhancement

Design for AM

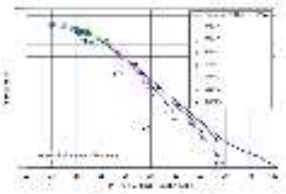
- New Vane cooling system
- Less cooling air & Emission
- 2020: field validation,
  - AM Material validation **24 000** EOH (V64.3)
  - First ever design for AM Vanes in SGT-700 **14 500** EOH

Performance enhancement, or Lifetime extension

Additive Manufacturing
Challenges and Focus Areas

AM challenges to be managed

- Availability of qualified materials
  - Materials data base
  - Design New Materials
- Predictable, stable & repeatable processes
- Quality Management
- Horizontal & vertical machine integration
- Digital Twin & Simulation
- New design criteria implementation
- Accelerated testing and validation
- Implementation of AM standards and regulations
- Productivity / cost



Contacts

Dr. Vladimir Navrotsky

AM Chief Technology Officer,
Senior Principle Key Expert,
Siemens Energy, Gas Service

Slottsvaegen 1
612 83 Finspong, Sweden

Phone: +46 122 82610
Mobile: +46 70 202 43 09

E-mail:
vladimir.navrotsky@siemens-energy.com

Disclaimer

This document contains statements related to our future business and financial performance and future events or developments involving Siemens Energy that may constitute forward-looking statements. These statements may be identified by words such as “expect,” “look forward to,” “anticipate” “intend,” “plan,” “believe,” “seek,” “estimate,” “will,” “project” or words of similar meaning. We may also make forward-looking statements in other reports, in presentations, in material delivered to shareholders and in press releases. In addition, our representatives may from time to time make oral forward-looking statements. Such statements are based on the current expectations and certain assumptions of Siemens’ management, of which many are beyond Siemens Energy’ control. These are subject to a number of risks, uncertainties and factors, including, but not limited to those described in disclosures, in particular in the chapter Risks in Siemens Energy’ Annual Report. Should one or more of these risks or uncertainties materialize, or should underlying expectations not occur or assumptions prove incorrect, actual results, performance or achievements of Siemens Energy may (negatively or positively) vary materially from those described explicitly or implicitly in the relevant forward-looking statement. Siemens Energy intends, nor assumes any obligation, to update or revise these forward-looking statements in light of developments which differ from those anticipated.

Trademarks mentioned in this document are the property of Siemens Energy, its affiliates or their respective owners.