Ghenadie Bulat - Group Leader Combustion Aero

70 years of combustion development for industrial gas turbines in Lincoln

Outline

- Introduction
- Lincoln heritage
- Combustion development:
  - Past
  - Present
  - Future trends
- Towards digital factory
- Summary and Conclusions

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169 years of history – Milestones

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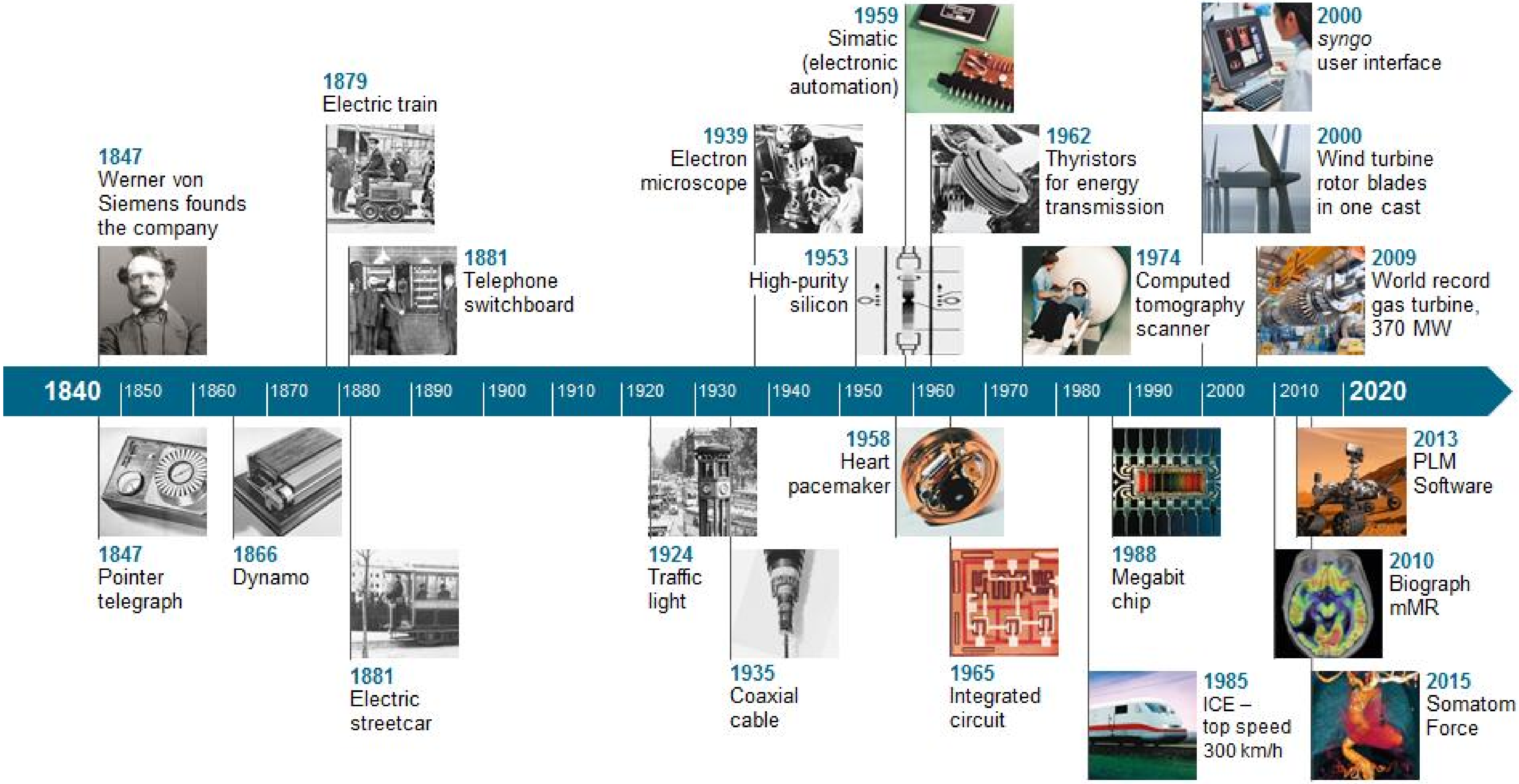

Megatrends –
Challenges that transform our world

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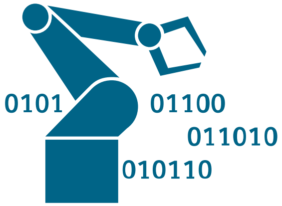
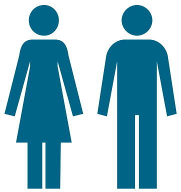


Digitalization

By 2020, the digital universe will reach 44 zettabytes – a 10-fold increase from 2013.

Urbanization

By 2050, 70 percent of the world’s population will live in cities. (2009: 50 percent)



Demographic change

The earth’s population will increase from 7.3 billion people today to 9.6 billion in 2050. Average life expectancy will then be 82 years.

Globalization

Since 2000, the volume of world trade has nearly doubled.

Climate change

In 2013, scientists measured the highest CO_2 concentration in the atmosphere in 800,000 years.

Digitalization –
The great paradigm shifter

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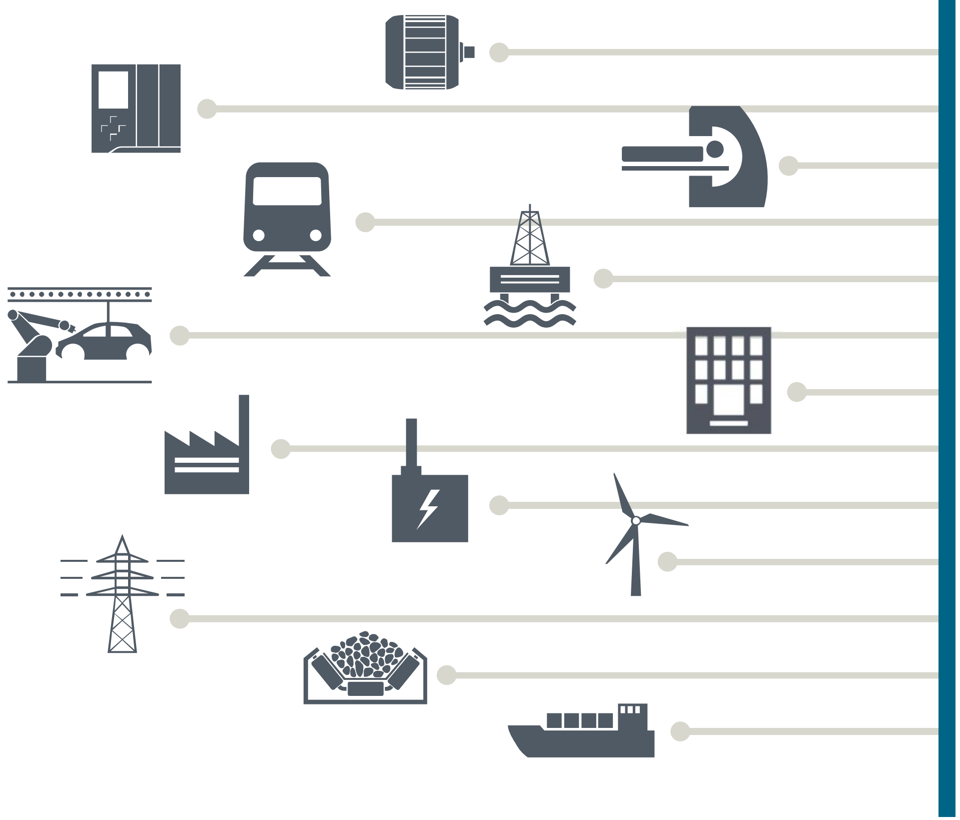
Physical world

Siemens installed base –
280k connected devices



Virtual world

Insights from 16TB+
operations data per month

CAx
Autonomous fault recovery
Traffic management
MES
Analytics
Imaging software
Fleet management
Smart grids
e-Tolling
Digital Factory
Image-guided therapy
Meter Data Management
Collaboration in the cloud
PLM
Embedded software
Efficient buildings
Decision support
Neural networks

Digitalization– Technologies for growth

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- Mobile and collaboration
- Connectivity and Internet of Things
- Cloud technologies
- Big data and analytics

Digitalization

	Vertical software	Digital services
Revenue FY 2014	€2.4bn	€0.5bn
Profitability	++	+++
Market growth	+9%	+15%

Automation

	Enhanced automation	Classic services
Revenue FY 2014	€19bn	€14bn
Profitability	++	+++
Market growth	+6%	+3%

Electrification

Enhanced electrification

~€37bn

Vision 2020 –
A customer-oriented setup

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Power and Gas

Dresser-Rand
Former RR

Wind Power and Renewables

Power Generation Services

Energy Management

Building Technologies

Mobility

Digital Factory

Process Industries and Drives

Healthcare (separately managed)

Financial Services

Power Generation

Power Transmission and Distribution

Efficient Energy Application

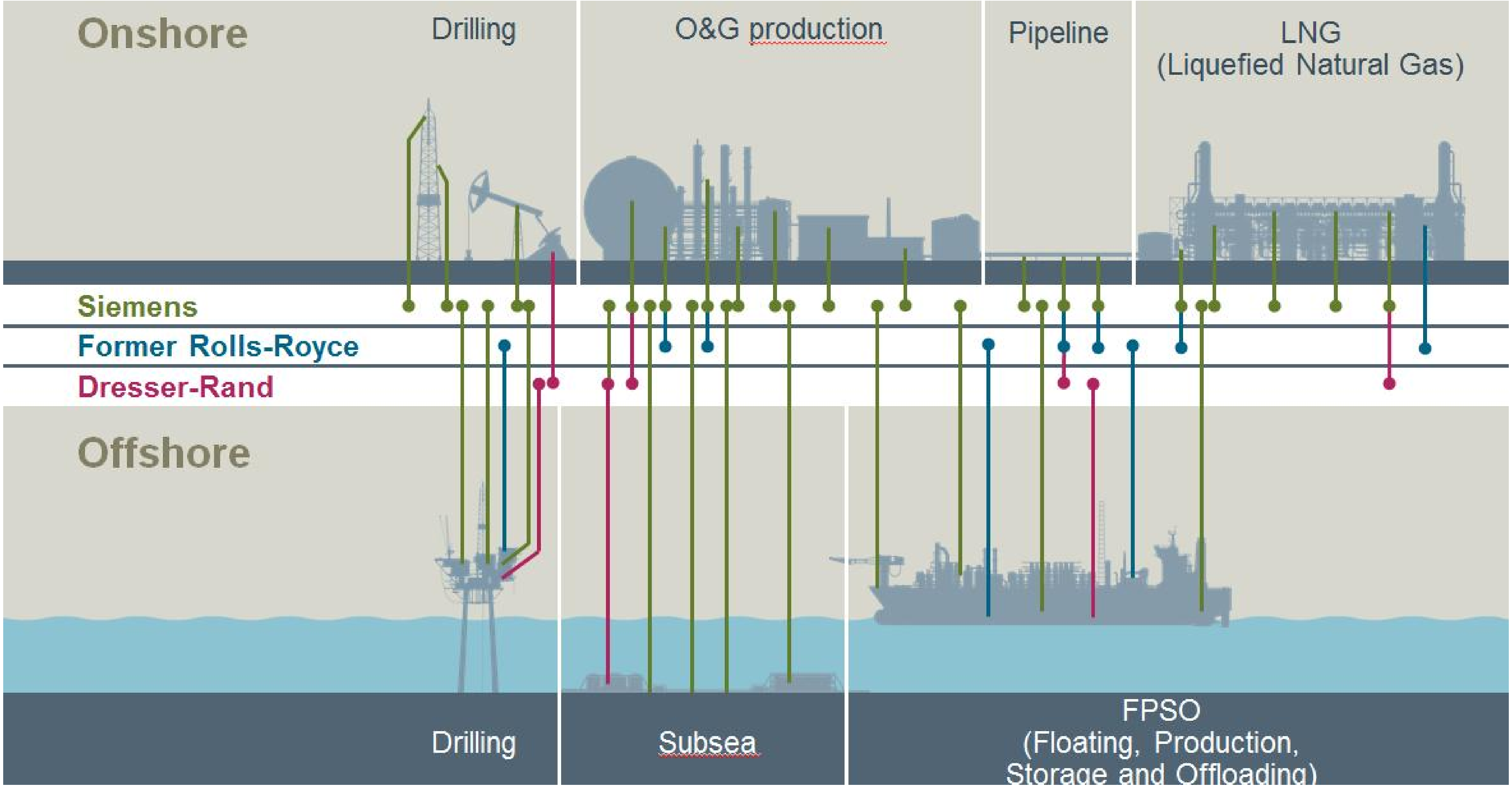
Imaging & In-vitro Diagnostics

Corporate Core

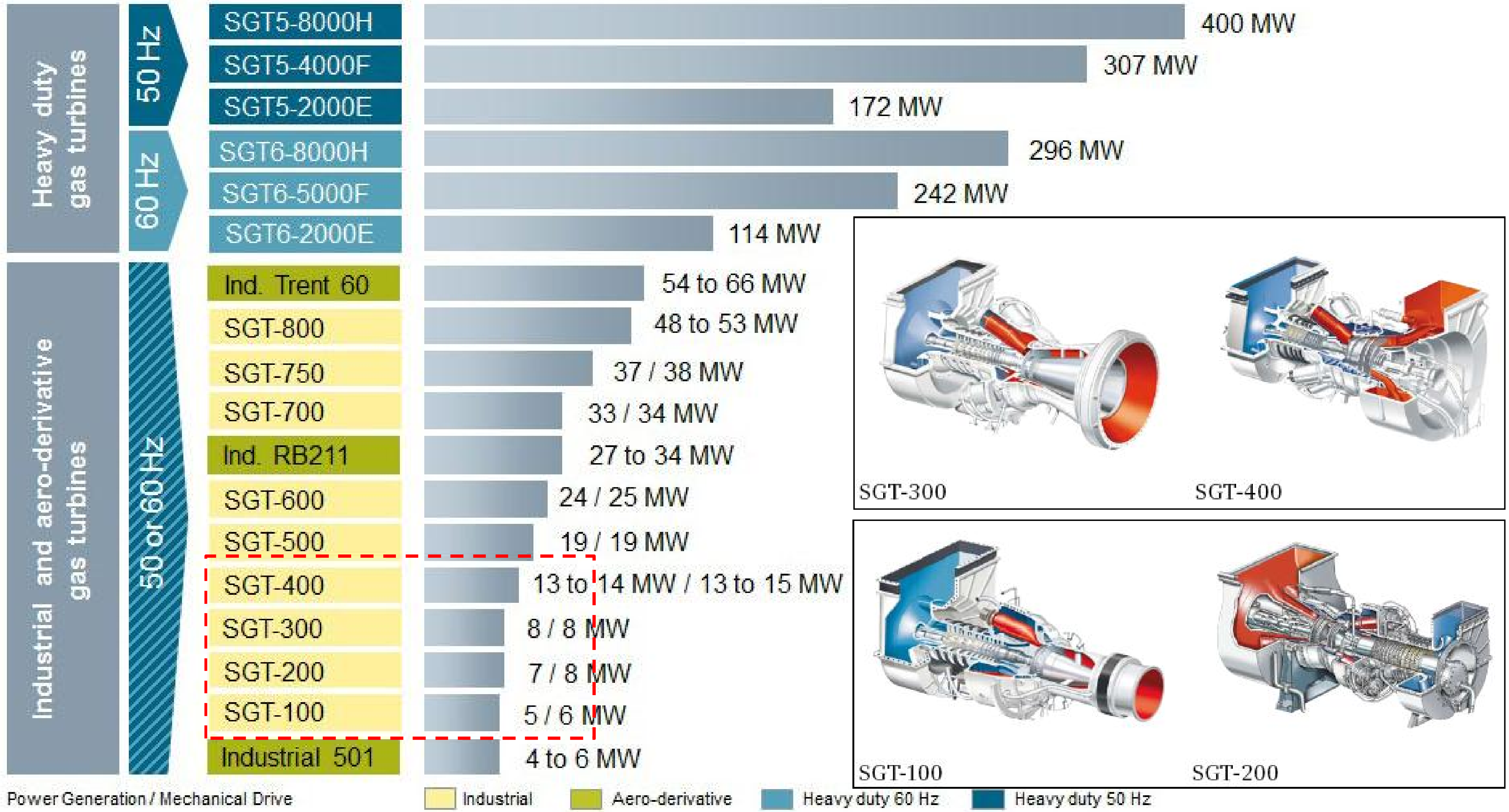
Corporate Services

30 Lead Countries

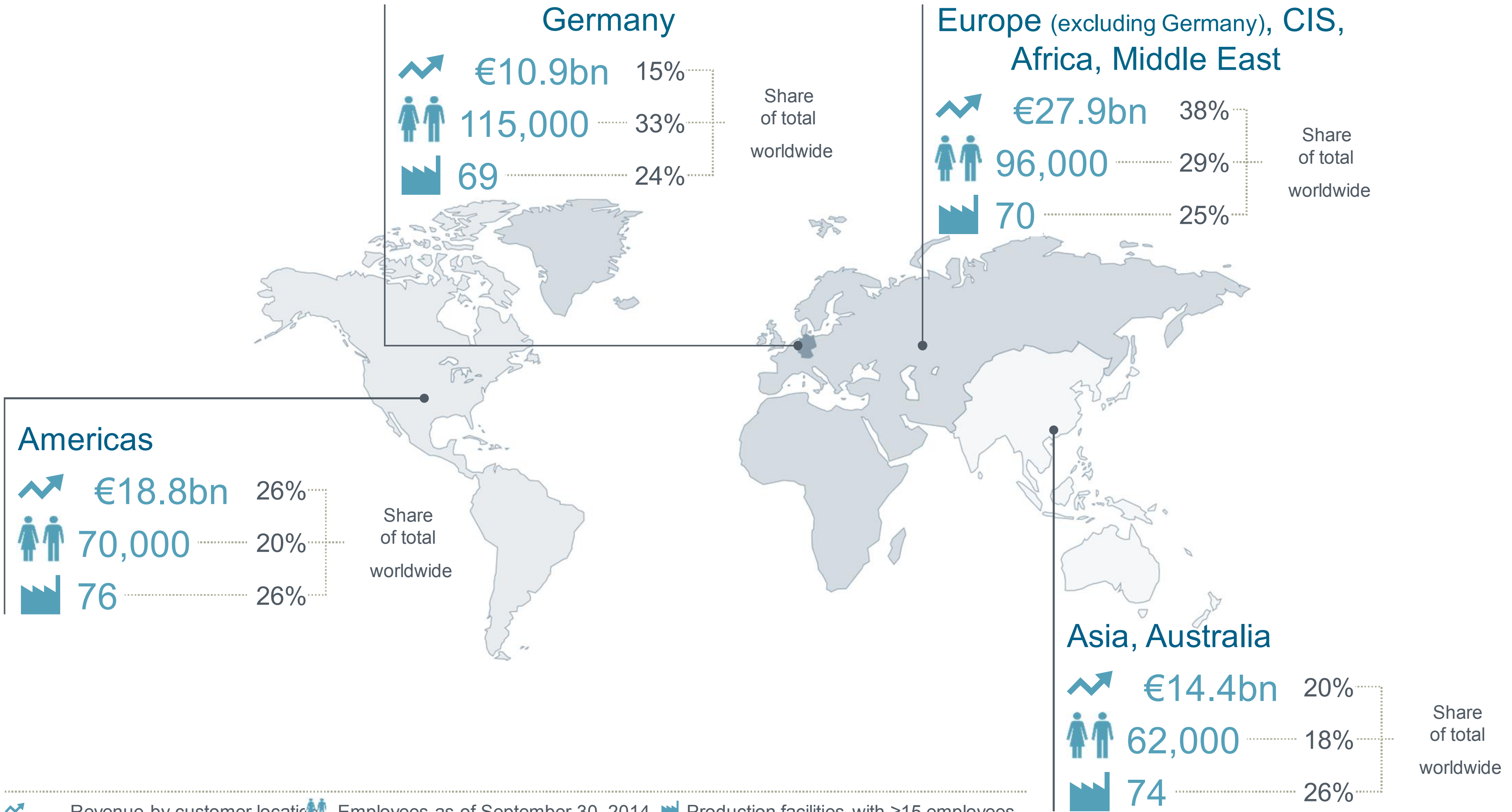
Acquisitions strengthen Oil & Gas business – Portfolio across entire value creation chain



Our Products
Gas Turbines



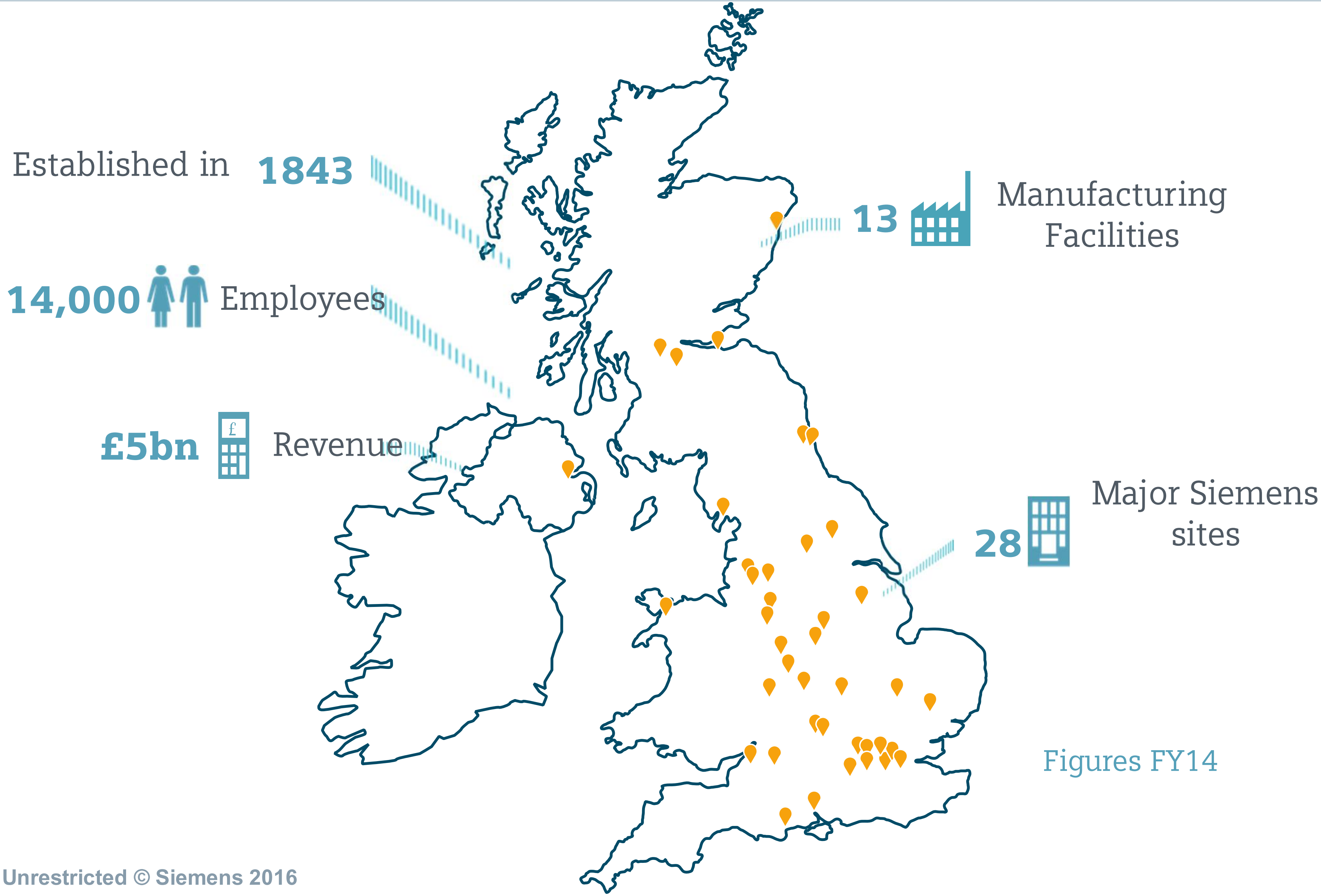
Global presence –
Close to customers all over the world



Revenue by customer location | Employees as of September 30, 2014 | Production facilities with ≥15 employees

All figures refer to continuing operations. CIS: Commonwealth of Independent States.

Siemens in the UK



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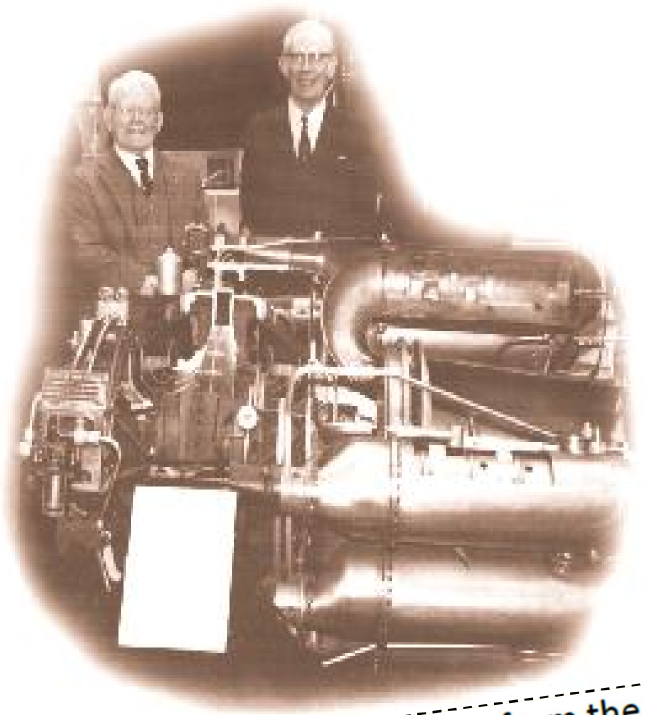
Our heritage



In 1946, a team of Sir Frank Whittle's engineers, led by Bob Feilden, came to Lincoln to develop the first industrial gas turbine, using Frank Whittle's jet engine technology.

- Developments have continued ever since …

In 1946 following on from the work of Frank Whittle on jet engines and gas turbines, Ruston set up a small specialist team, known as the Internal Combustion Development Group, to investigate the feasibility of designing a gas turbine. It was shortly after Power Jets completed their work that G.B. R. "Bob" Feilden was invited to take charge of Ruston work in the gas turbine field. A team of young enthusiastic engineers was then created to design the first Ruston industrial gas turbine. It is recorded that it was no exaggeration to say that every single component of the original 3CT engine and the subsequent TA turbine was stressed out individually. Subsequently the output of the TA engine has been increased by some 50% mainly by using materials and technology more recently available.

Ref: IDGTE 582, The History of the Industrial Gas Turbine, 2011

Our heritage

1946 – Ruston & Hornsby developed prototype gas turbine

1952 – Ruston & Hornsby delivered first production gas turbine to Kuwait

1968 – Ruston & Hornsby acquired by GEC

1969 – Ruston Gas Turbines Ltd formed

1989 – GEC ALSTHOM formed

1990 – European Gas Turbines created by GEC ALSTHOM and GE (USA)

1998 – ALSTOM Gas Turbines formed as part of ALSTOM

1999 – ABB ALSTOM POWER formed (GE agreement terminated)

2000 – ALSTOM acquired ABB’s 50% to form ALSTOM Power

2003 – New ownership – Siemens

Siemens Industrial Turbomachinery Ltd.

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- Over 60 years global experience in Gas Turbine design, manufacture & support
- Main markets:
  - Oil and Gas
  - Industrial Power Generation
  - Gas Turbine Service
- 1,500 in the UK
- 3,500 units sold in over 90 countries
- 1,700 of these are in operation
- Global purchasing network

Ruston Works

Gas Turbine Manufacturing

Feilden House, Teal Park

Service Centre

Freeman Road

Parts Warehouse

Firth Road

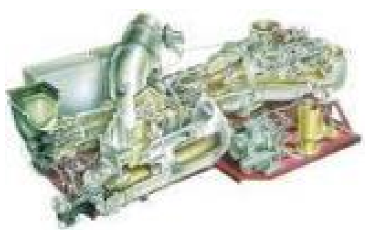
Research & Development Test

Industrial Small Gas Turbines Range < 15 MW
Current Lincoln gas turbine portfolio

SIEMENS
Ingenuity for life

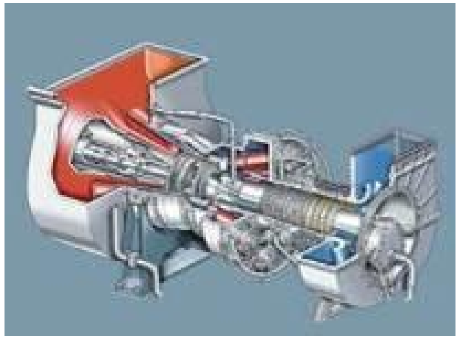
SGT-400	15 MW
SGT-300	8 MW
SGT-200	7 MW
SGT-100	5 MW
TB	3.7 MW
TA	1.3 MW

TA / 1.3 MW



TB / 3.7 MW

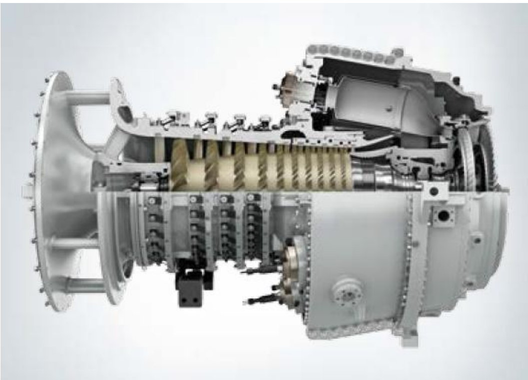
SGT-200 / 7 MW, 31.5%



Portfolio upgrades/ New Products

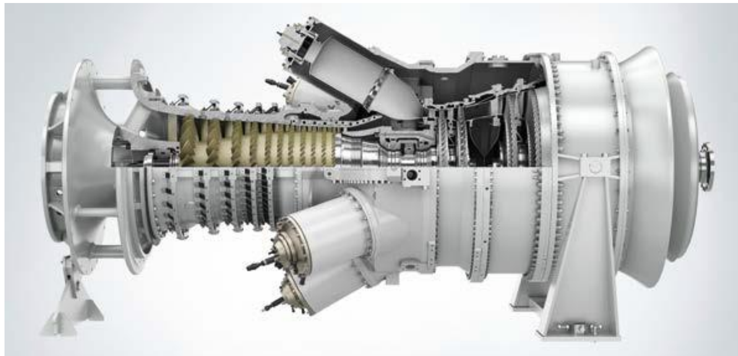
SGT-400	15 MW	2011
SGT-300 MD	8 MW	2012
SGT-100 (N)	5 MW	2012

SGT-100 / 5 MW, 32.9%

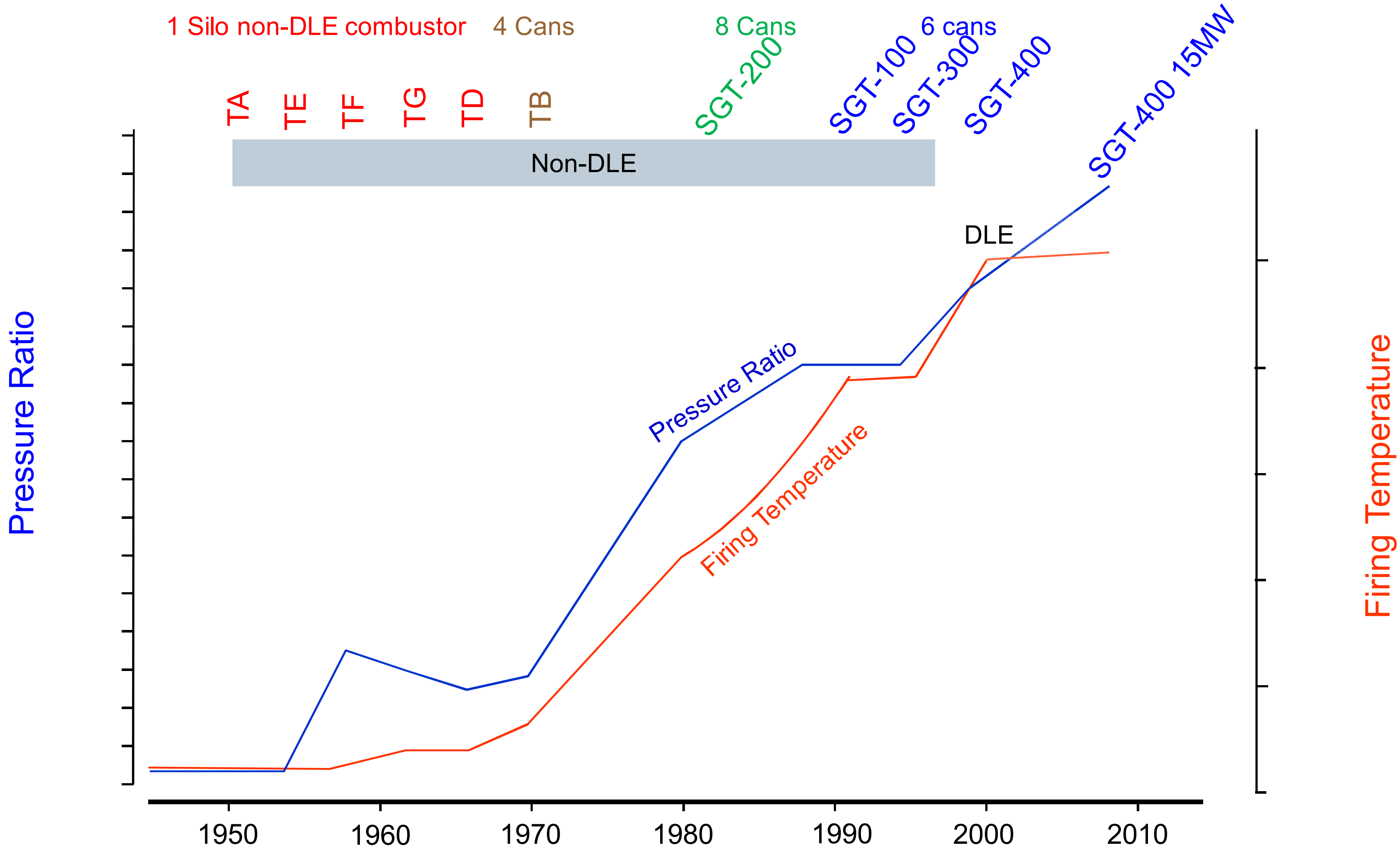


SGT-300 / 8 MW, 34.6%

SGT-400 / 15 MW, 36.8%



Gas Turbine Engine Trends



TA
Combustion system, 1952

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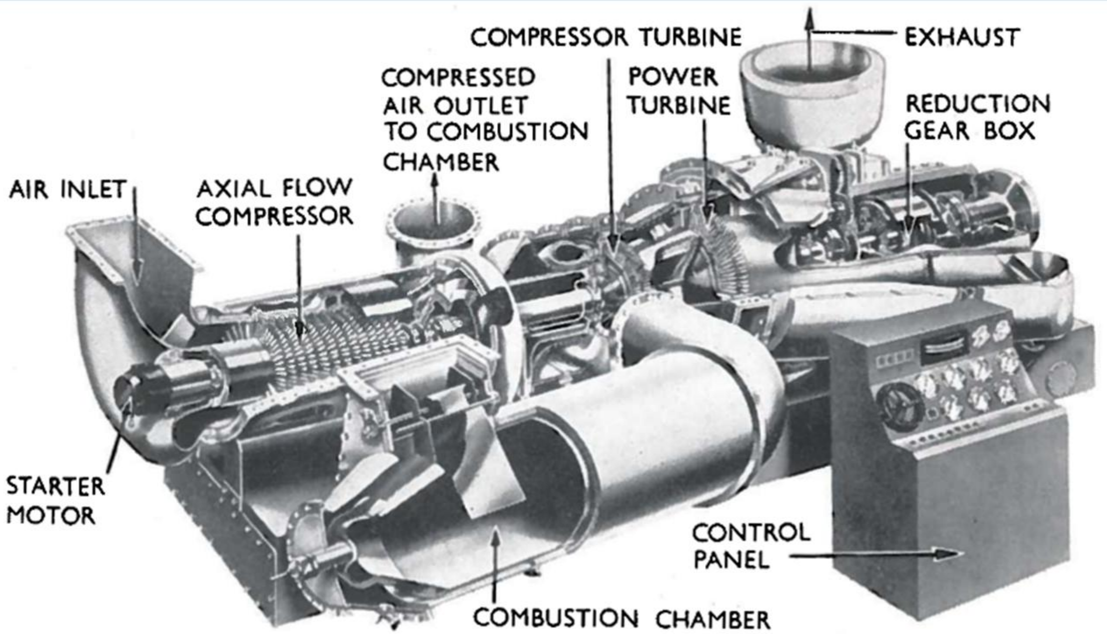
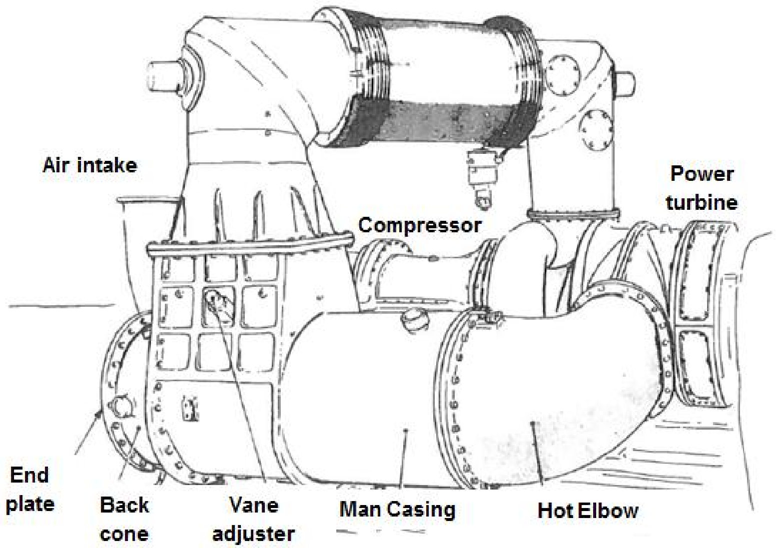
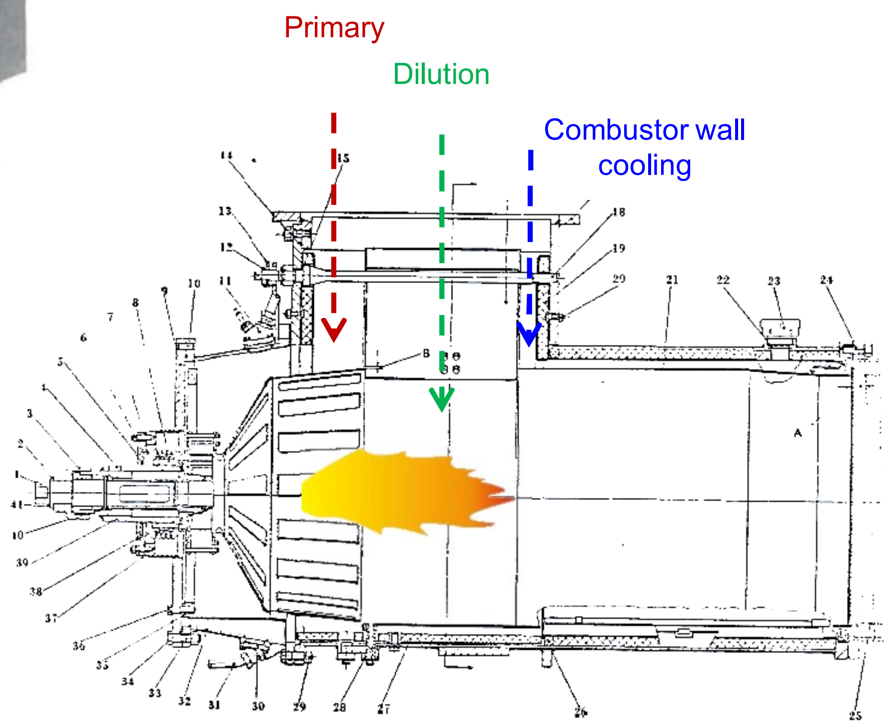
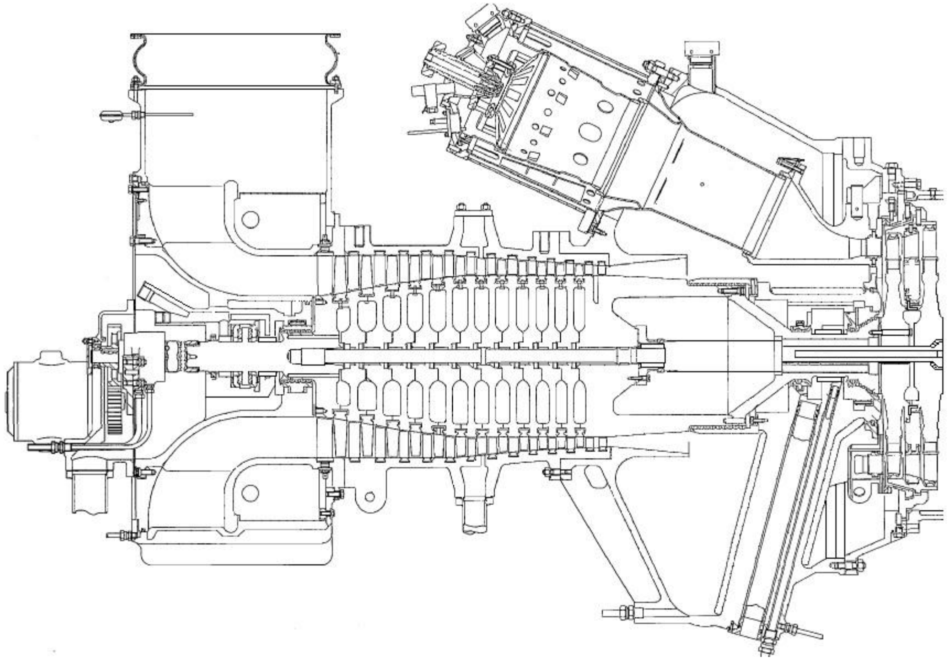




Combustion Air Split

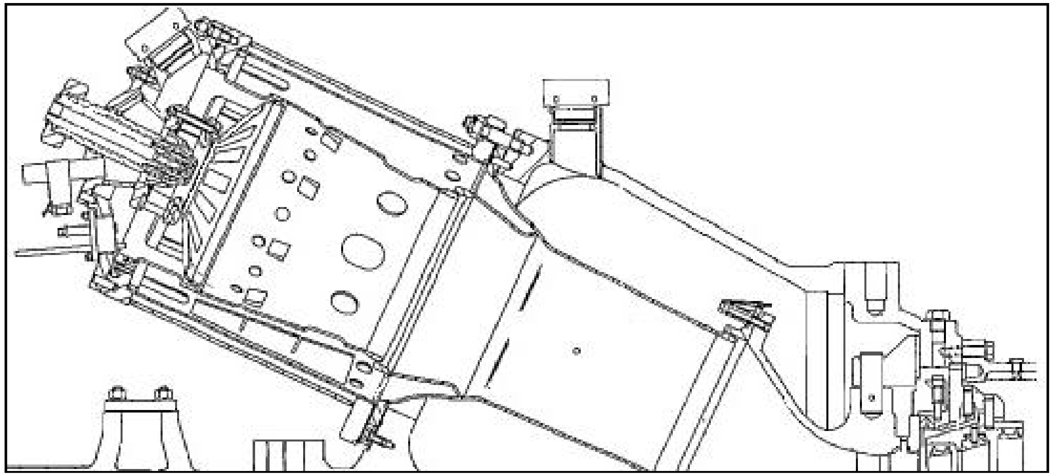


TB
Combustion system, 1970



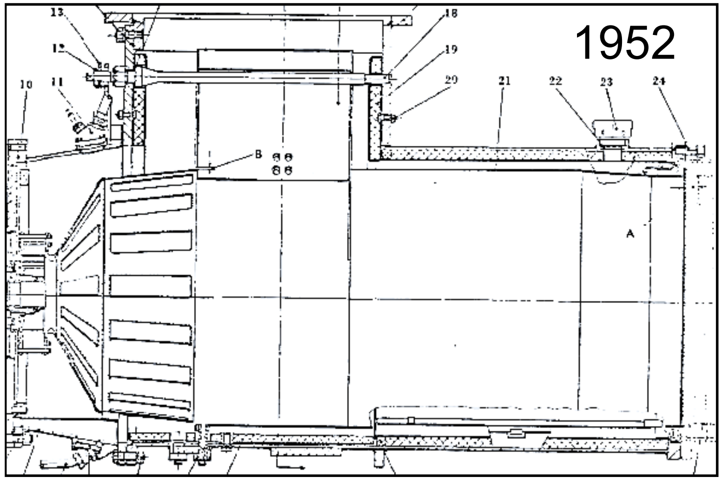
- ✓ Reverse flow combustion system
- ✓ Easy and quick installation
- ✓ Increased component life

➢ **Visual flame monitoring!**



Evolution of Combustion Systems
From diffusion to premixed flame

SIEMENS
Ingenuity for life



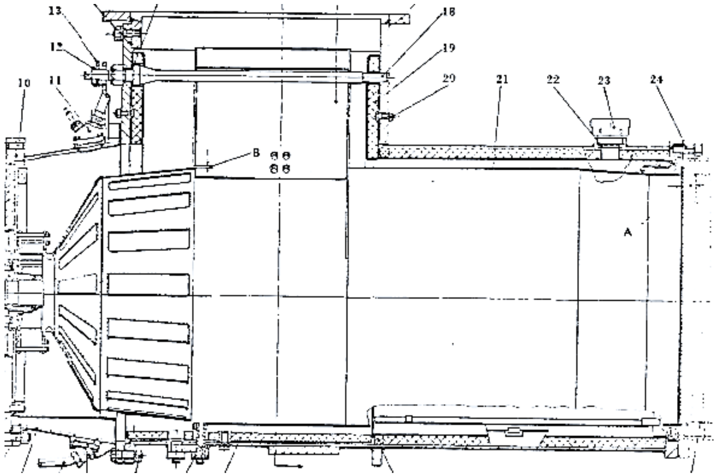
- Robust design
- Large footprint

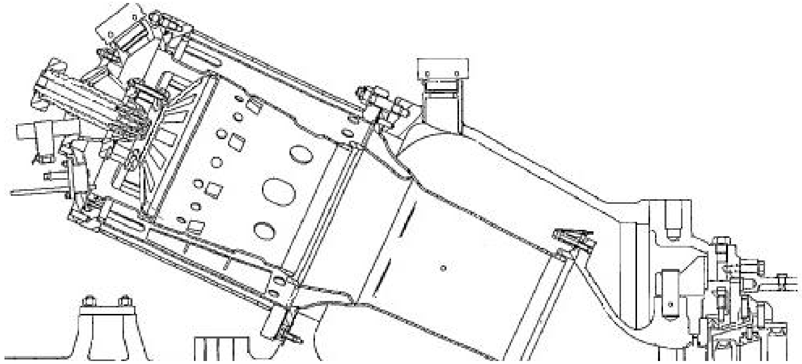
- Increased efficiency
- Small footprint
- Increased component life

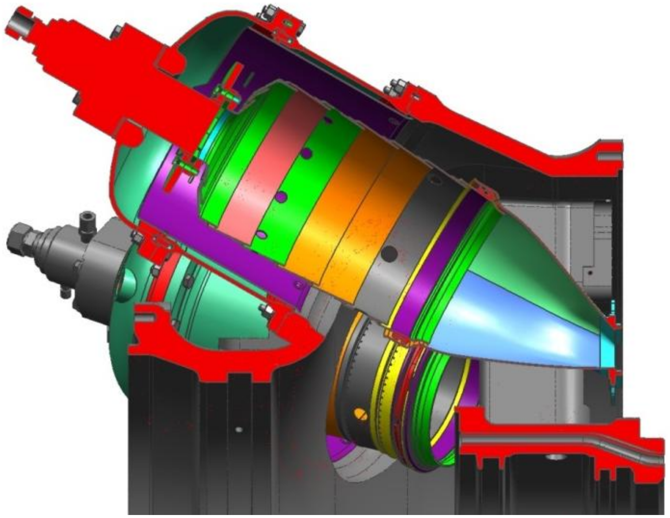
- Increased efficiency
- Increased thermal loading
- Low emissions

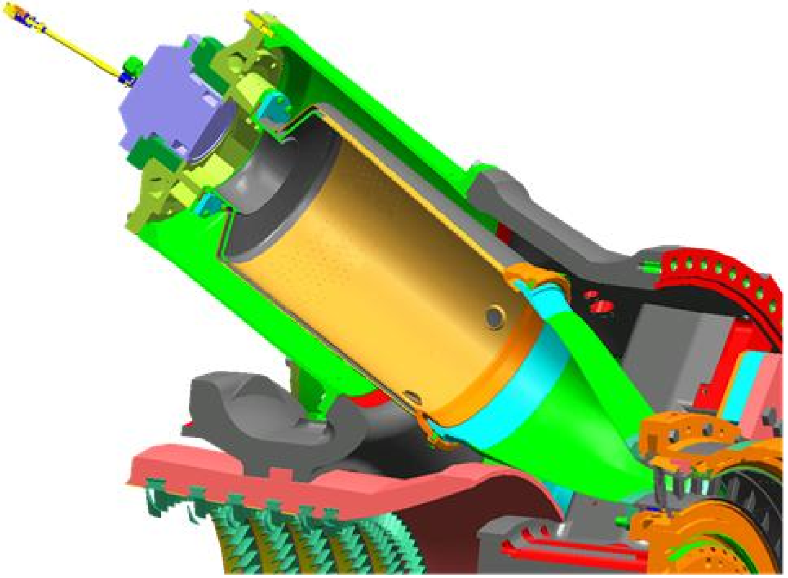
Evolution of Combustion Systems
From diffusion to premixed flame

SIEMENS
Ingenuity for life



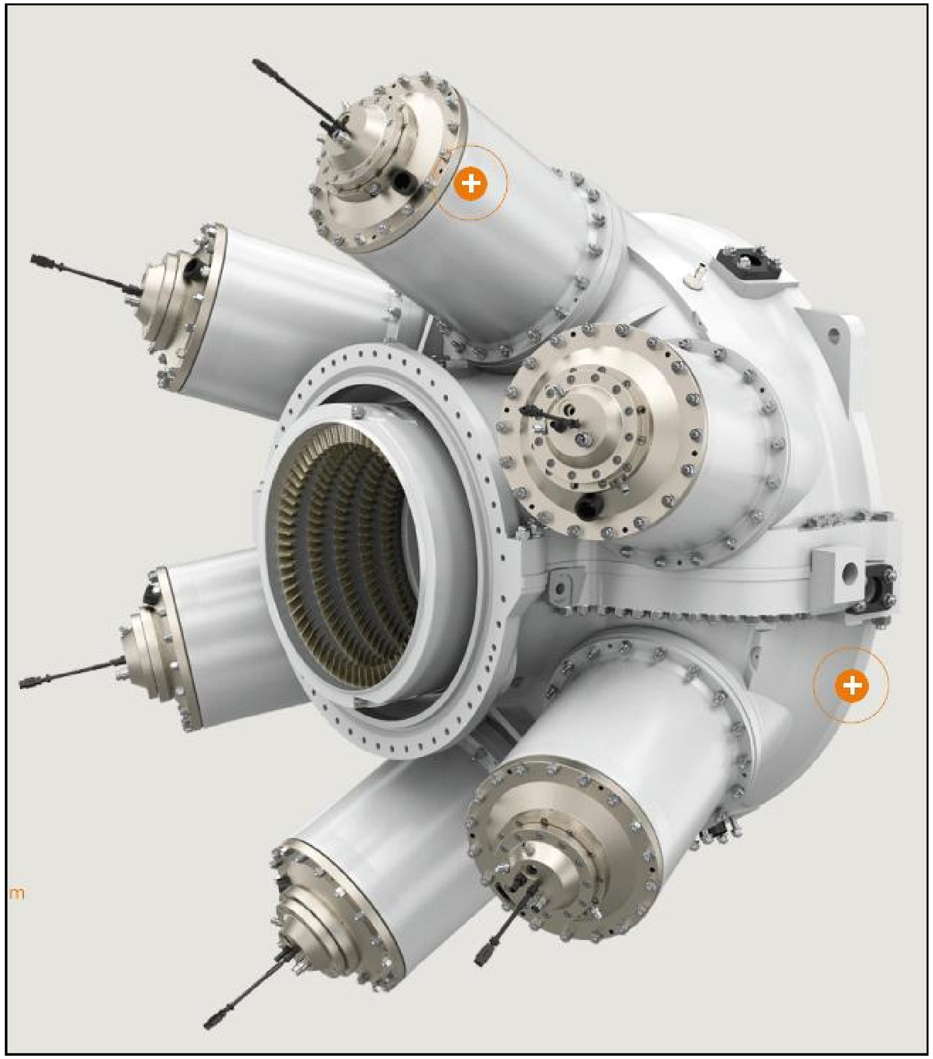


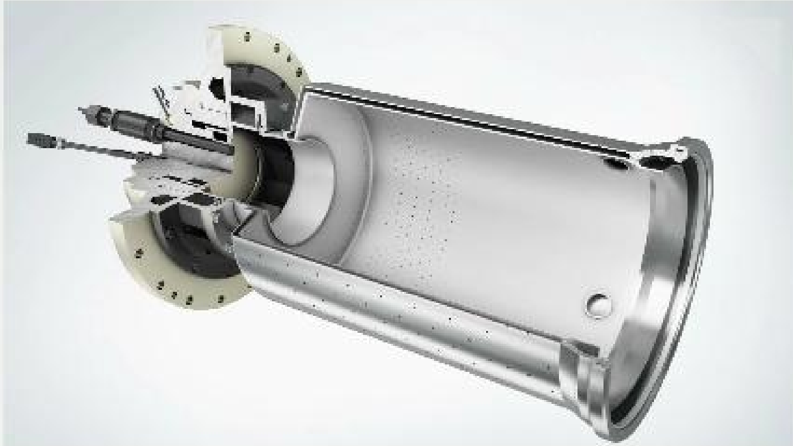




Trend: Reduction in air consumption for combustion can cooling, leaner flames & more uniform temperature profiles

DLE Combustion System





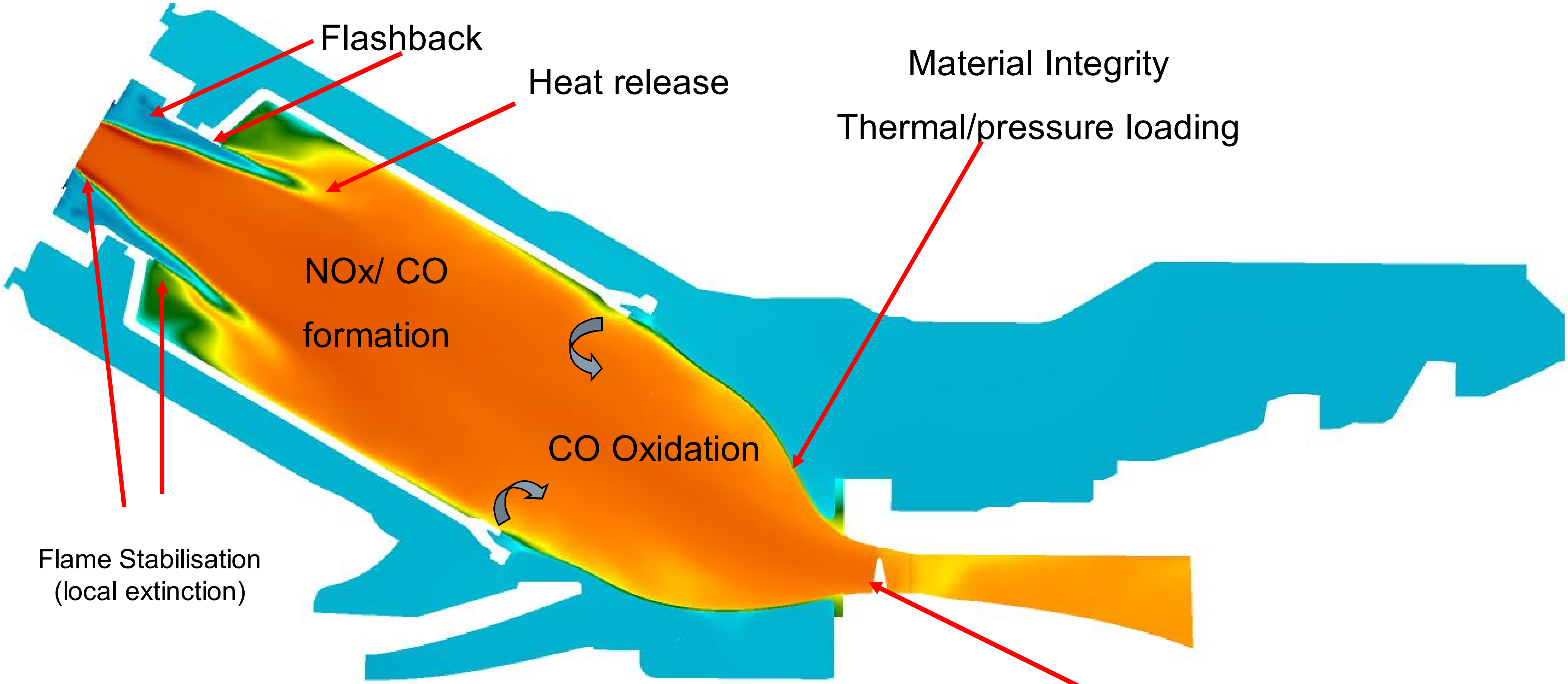
DLE Combustion System

The well-proven and reliable Dry Low Emission (DLE) combustor offers clean combustion with low emissions over a wide operating range.

The combustor also has the capability to burn a great variety of fuels.

- Six reverse flow tubular chambers
- Simple robust construction
- High energy igniter in each combustor
- NO_x emissions: ≤ 15 ppmV (corrected to 15 % O_2 dry)

Typical CFD of a DLE combustor



20 ºC error in temperature prediction
halves the component creep life

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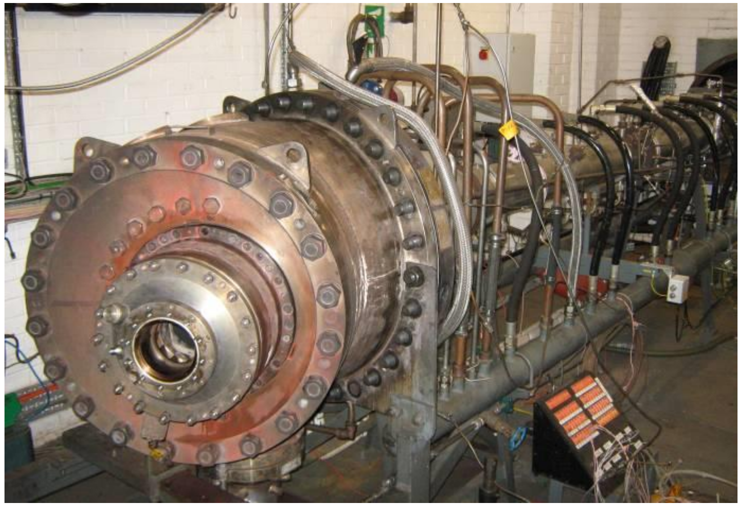
Combustion Development Approach
Component Test Facilities

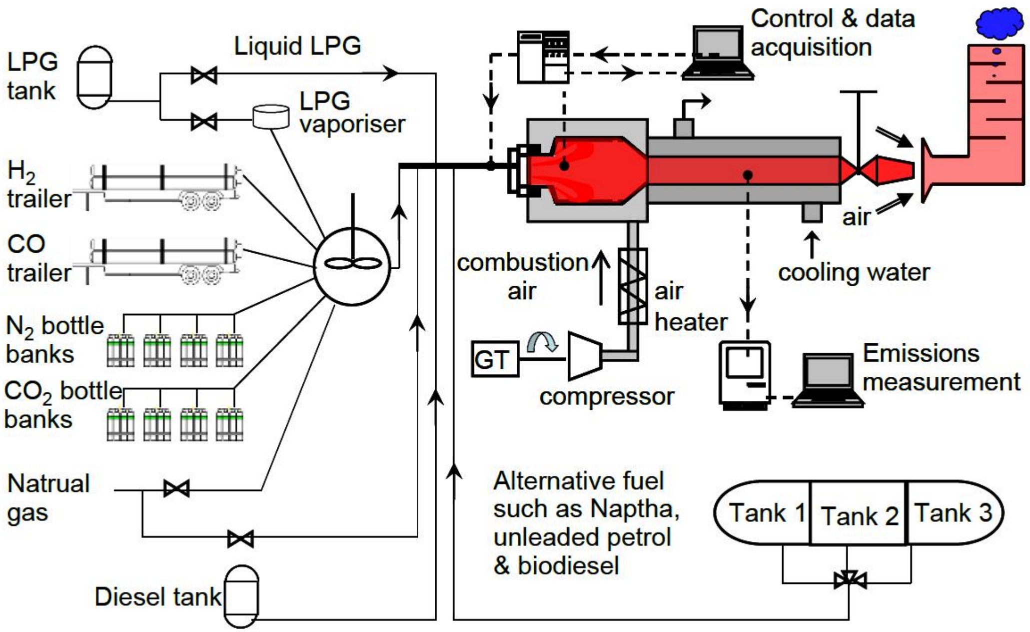
High Pressure Combustion Rigs

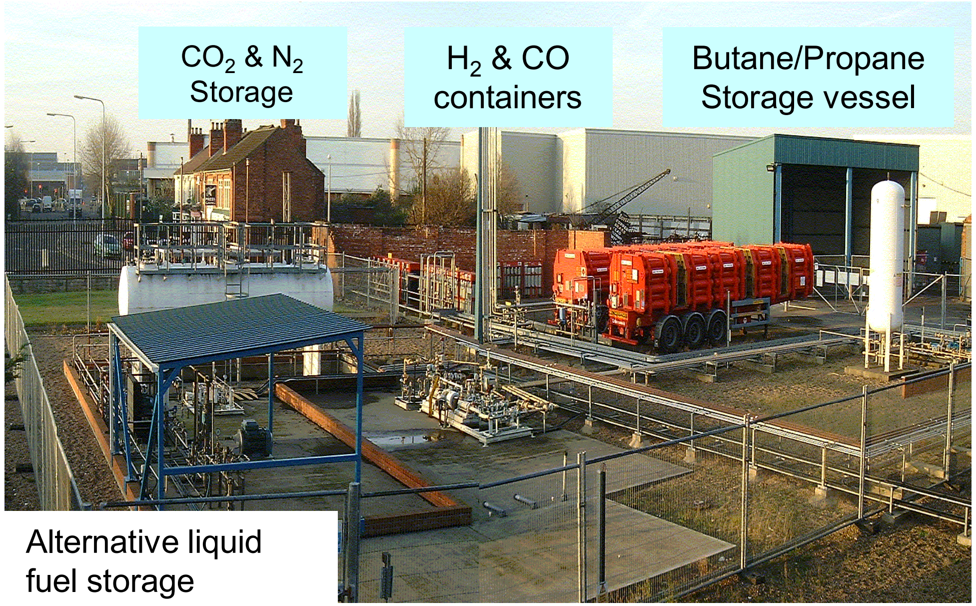
- ❑ Allows combustion testing at full engine temperature and pressure
- ❑ Facility to cover all current product range

Gas Fuel Mixing Facility

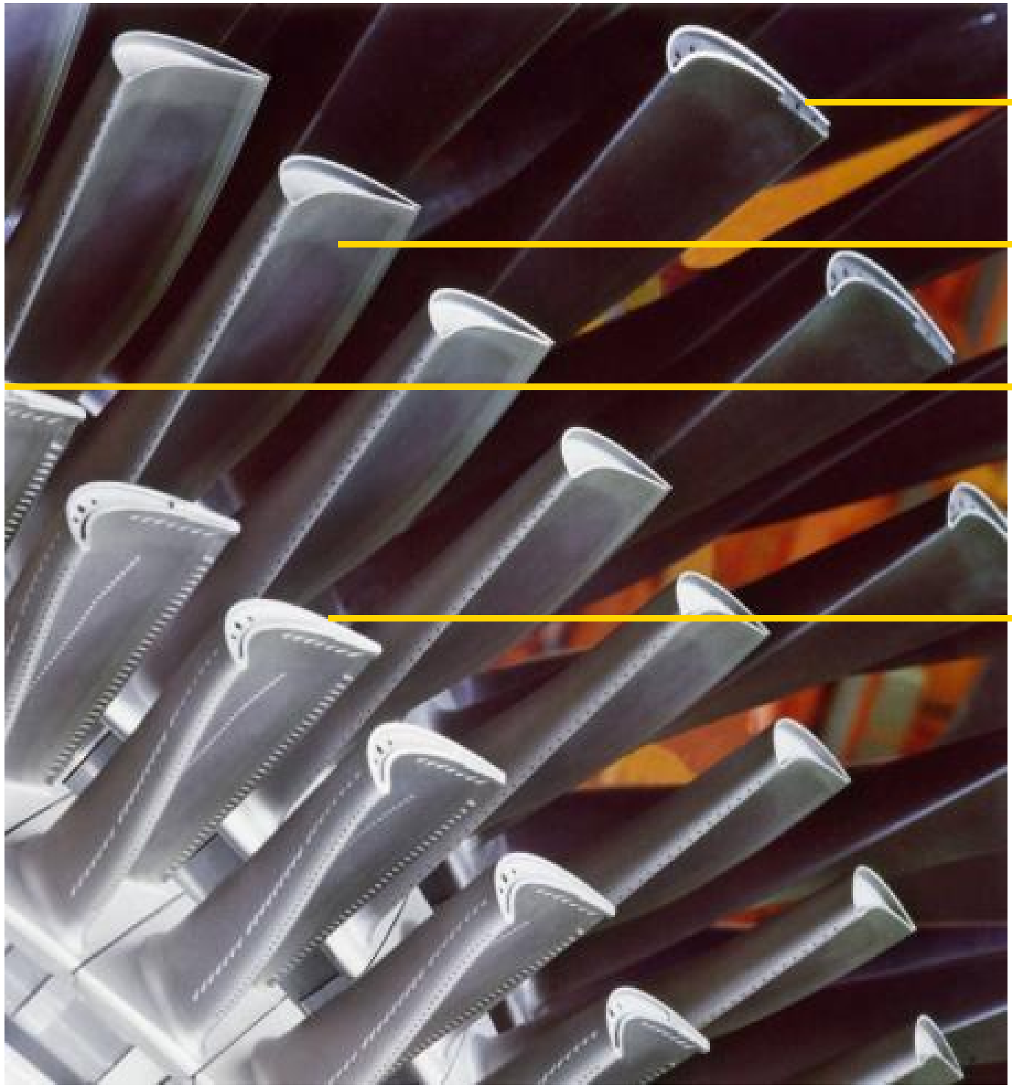
- ❑ Ability to mix fuels to meet full WI range
- ❑ Covers range 15 – 65+MJ/m^3 WI







Combustion Development Approach
Lessons learned - Past



- Single component testing
- Expensive development cost
- Long development time
- Designs based on empirical correlation and 1D calculations

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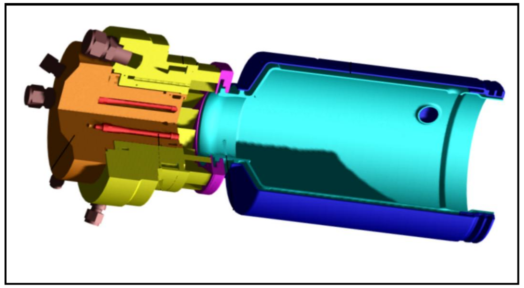
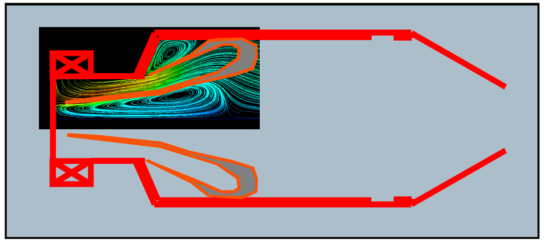
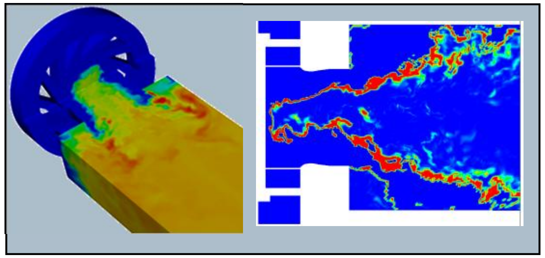
Integrated Combustion Development Process



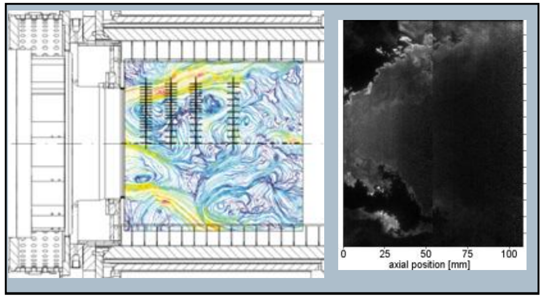
- **Design modelling**
  - 3d solid modelling
  - Integrated design systems



- Fundamental understanding
  - Combustion, chemical kinectics, aerodynamics, heat transfer, lifing and integrity, acoustics

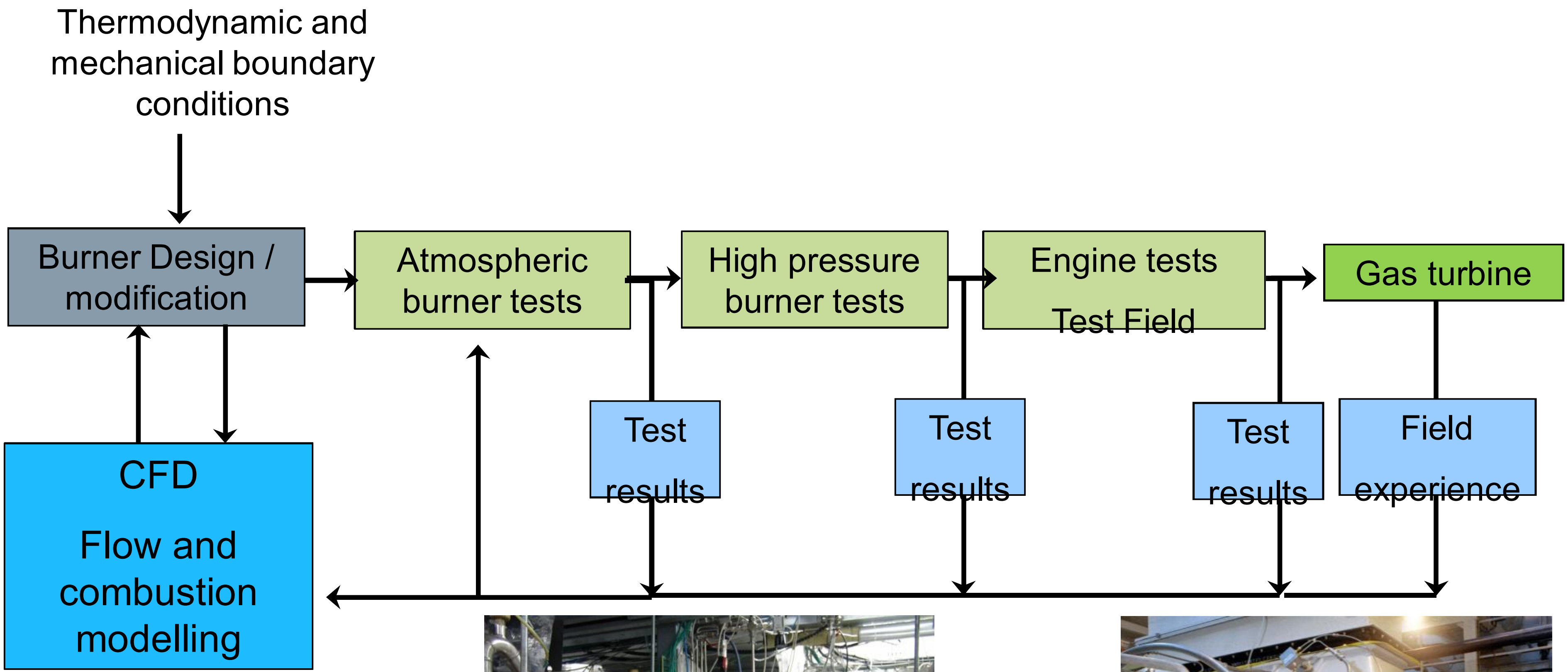


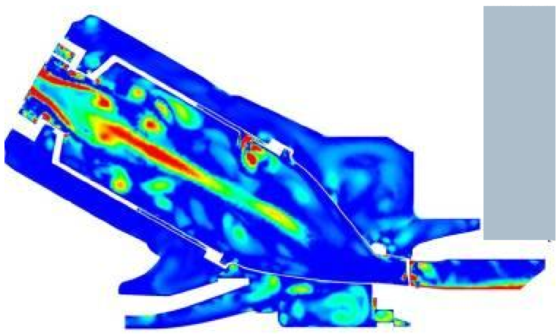
- Advanced modelling methods
  - CFD (RANS, URANS, LES): combustion, heat transfer, …
  - FEA: Creep, LCF, HCF, acoustics

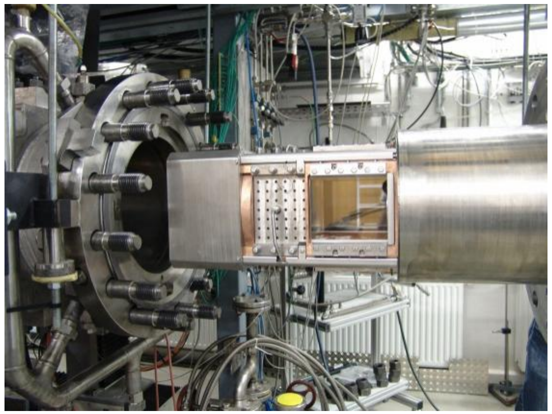


- Advanced experimental methods
  - Low and high pressure rig facilities and engine testing
  - PIV, LIF, chemiluminescence, Raman, emissions, thermal paints…

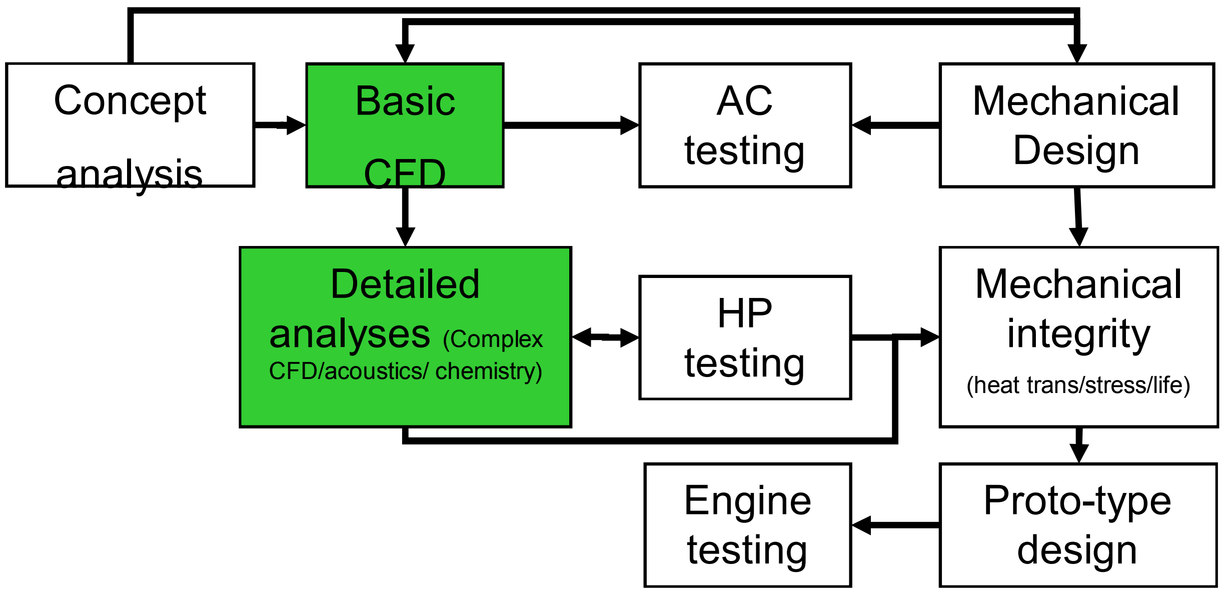
Typical Development Process
Combustor Design or Enhancement







Design Process and Requirements from CFD



Current industrial expectation

- Mixing calculations
- Trend predictions for temperatures
- Flame location
- Transient aerodynamics

Technology targets

- Emissions predictions
- Accurate temperature predictions
- Combustion instabilities
- Liquid fuel combustion

Combustion development
Lessons learned - Current

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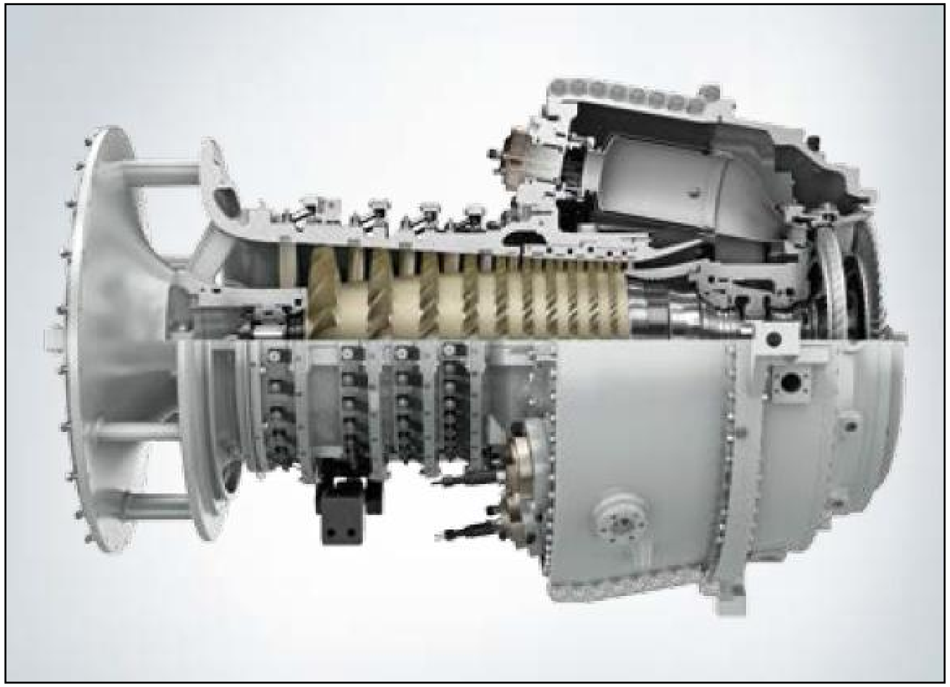
Ingenuity for life



CFD part of the development process

-> need to increase accuracy

Integrated development approach

-> reduced time to market

Optimized design concepts

-> increased efficiency & reduced component costs

Reduced number of development tests (as a result of using more CFD)

-> reduced cost and increased production capacity

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Combustion development
Future trends

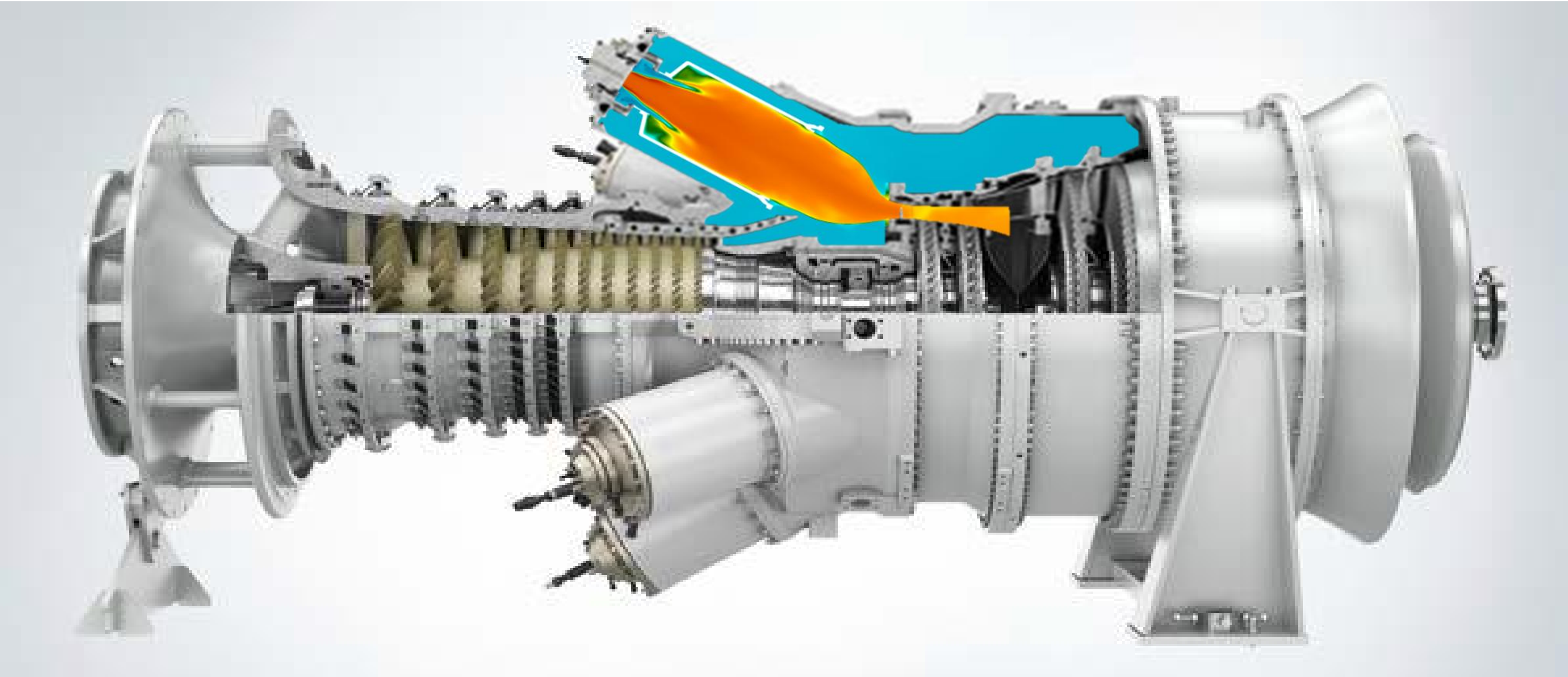
Multi-physics & multi-component design concepts

-> increased product efficiency

Novel design concepts -> increased flexibility, reduced cost

CAD to CAE & digital factory -> rapid prototyping & reduced time to market

Novel manufacturing techniques -> product competitiveness



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Digitalization –
Big data in Lincoln

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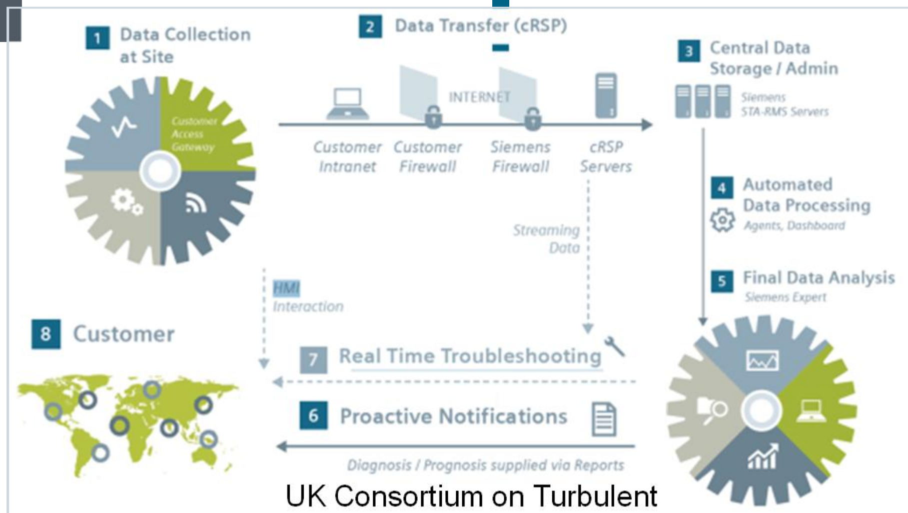
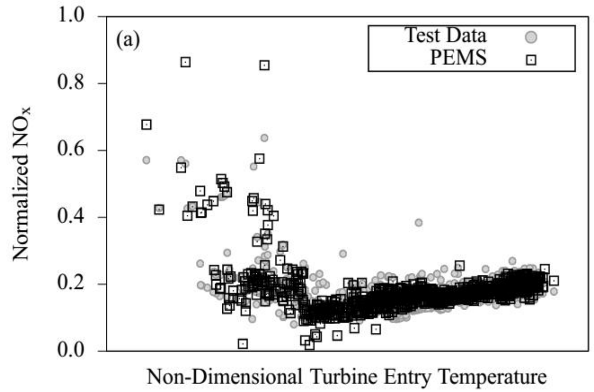
Physical world

- ✓ Data collection from each factory tested engine
- ✓ Additional development datasets from whole engine development tests
- ✓ High quality full package test datasets
- ✓ Remote monitoring and data collection of field engines



Virtual world

- ✓ Condition based maintenance recommendations
- ✓ Outage optimization and reduction of unscheduled rectification costs through trend and root cause analysis
- ✓ Prediction emissions capability (PEMs instead of CEMs)



Ref: GT2016-57656

Test data from 90 engines

Computational combustion
Increasing prediction accuracy

SIEMENS
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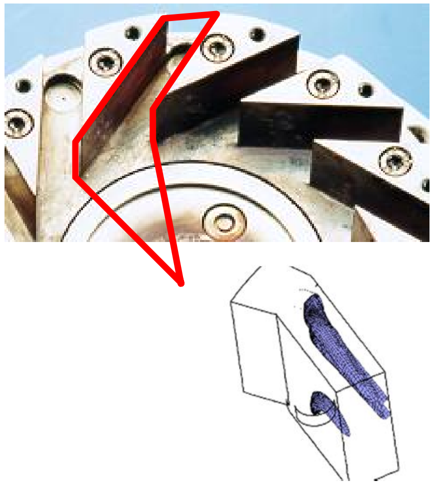
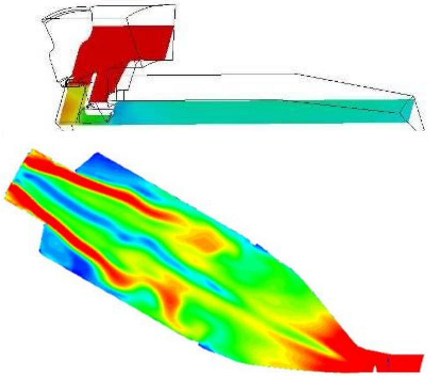
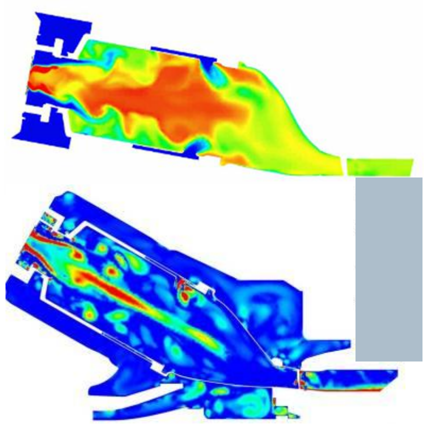
1990's



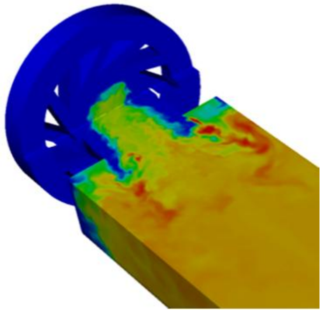
2000's



Current design process



Future technology



2 equation

URANS

URANS/LES

LES

TURBULENCE MODELLING

Improved computational capacity allow model development and increase geometry and its resolution

Mixing only → Eddy-dissipation type → Flamelet type → Stochastic field /transported pdf

COMBUSTION MODELLING

Pushing boundaries of CFD to deliver requirements

Computational requirements

- **Always limited by computational resource!**
  - Traditional concerns over run times for CFD still valid
    - Better models/more detailed geometries
    - Parallel efficiencies, CPU & GPU
  - Modern methods (CFD and experimental) produce so much data that new analyses techniques are required

- **Model development**
  - The potential of new methods (LES) is being demonstrated at industrial scale
  - Comparatively still very computationally expensive to run and analyze
    - Need for an model recommendation as an industry standard

- **Learning and model development from high end modelling/experiments**
  - DNS understanding to support combustion models
  - Detailed understanding of combustion and aerodynamics at industrial conditions
    - Need of good quality experimental datasets

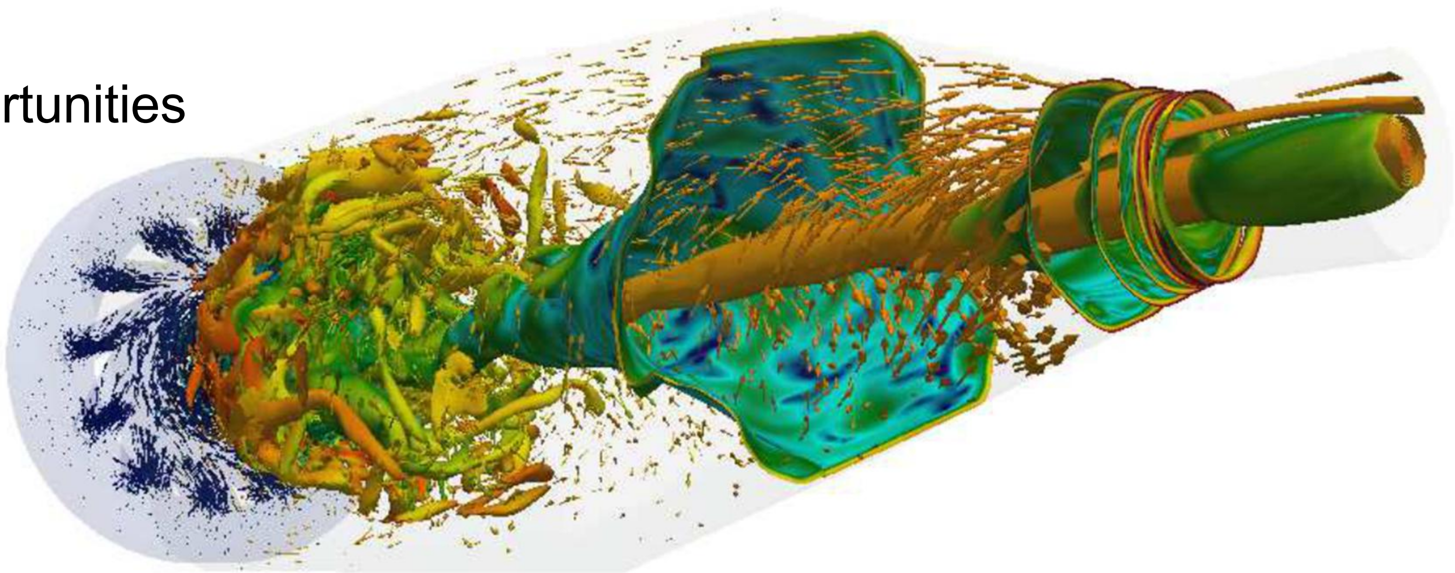
Understanding and exploiting the ever increasing computational capacity is critical to industry adopting future applications of combustion models

- Well demonstrated in the CFD development over the decades

Academic industrial interaction

UKTRFC benefits:

- ✓The forum provides through meetings and workshops an excellent single point for knowledge transfer
- ✓Visibility of current work
- ✓Visibility of new researchers in field
- ✓Networking opportunities



- Introduction
- Lincoln heritage
- Combustion development:
  - Past
  - Present
  - Future trends
- Towards digital factory
- Summary and Conclusions

Summary

- Combustion is an attractive and evolving field of engineering development

- Significant product enhancements have been achieved due to combustion R&D over last 70 years of gas turbine development

- DLE technology mature and well accepted in the field
  - ✓Lower emissions
  - ✓Increased fuel flexibility
  - ✓Increased reliability and operability

- Computational requirements for combustion is still high
  - Need for increase of model accuracy
  - Need for multi-component/ multi-physics experimental datasets

- Additive manufacturing techniques and digital factory approach will promote the applicability of combustion engineering

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Thank you!

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Questions?