Flexibility Upgrades for Future Energy

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Ansaldo Thomassen

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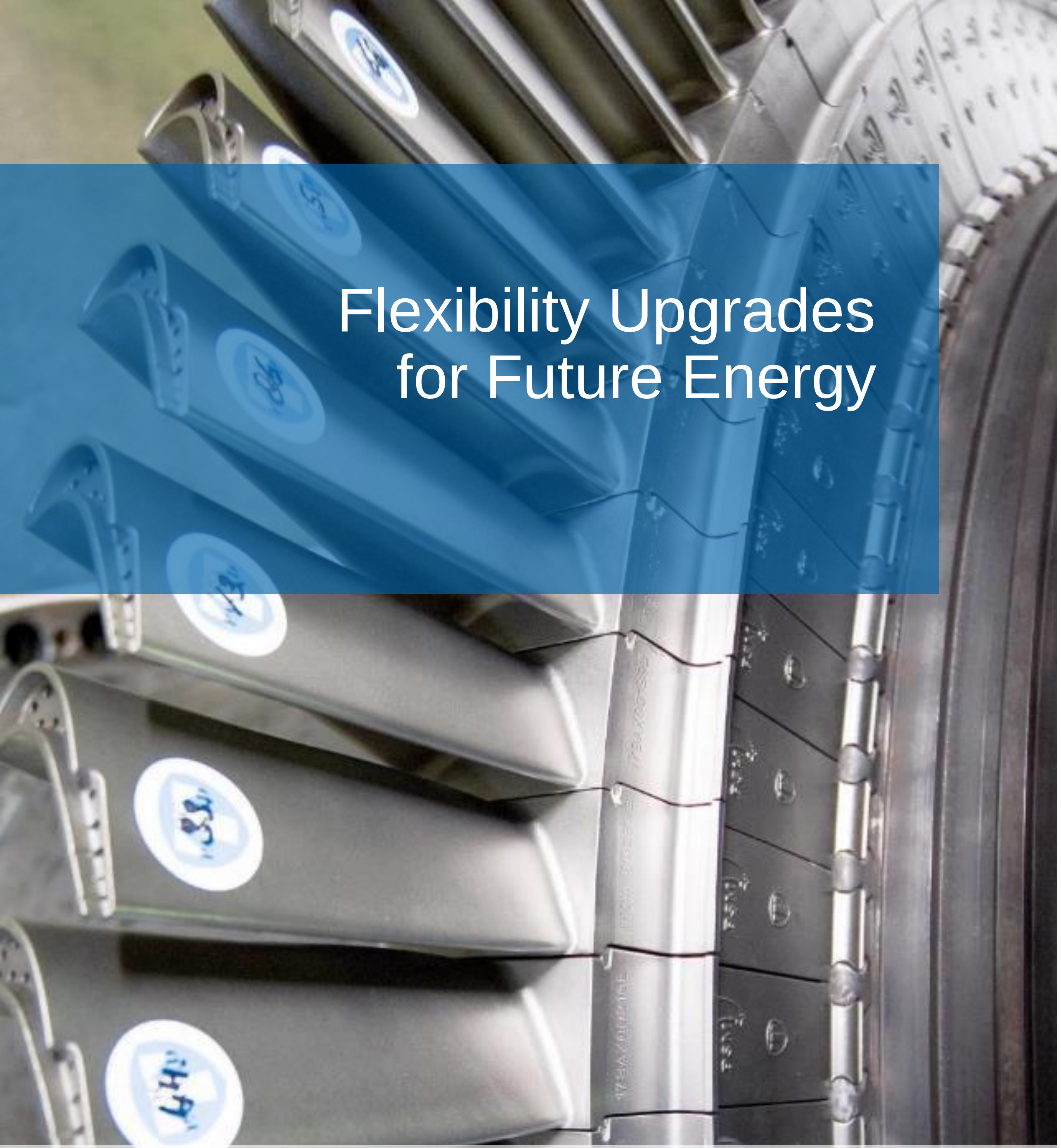
4 Oktober 2019 – Middelburg
Project 6-25: innovatie en samenwerking in de industrie voor minder CO2-uitstoot en meer efficiency



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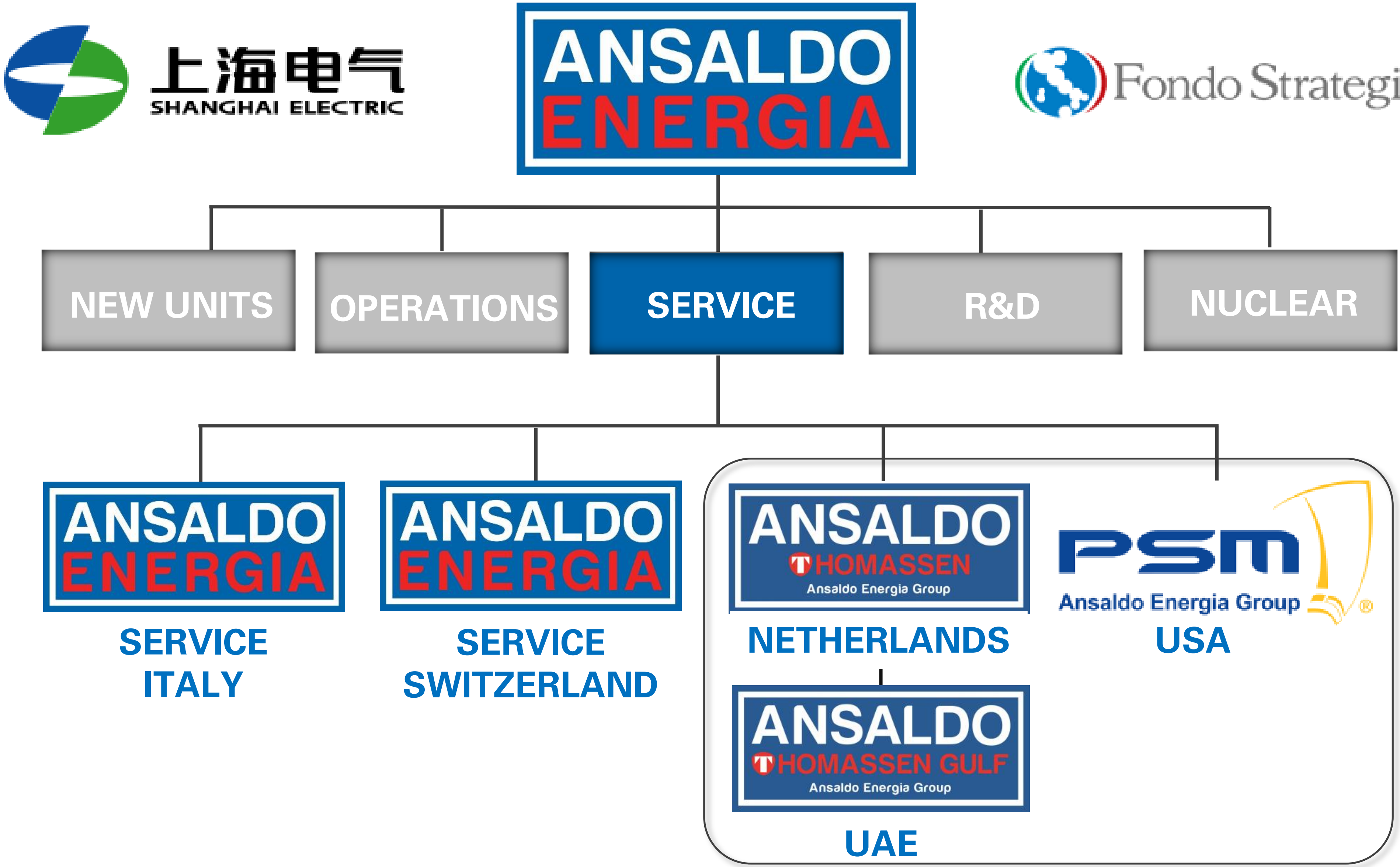
- Waar vind de technologie haar toepassing?
- 1-2 voorbeeld cases bij eindgebruikers

Our Vision and Mission

Innovation and Service for a world with **Clean Power**

Partnering and Supporting Customer Needs by providing a Flexible, Reliable & Multi-Platform Portfolio to improve life cycle costs

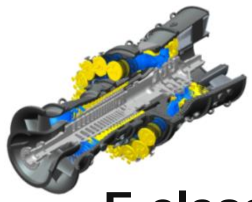
Ansaldo Energia Group Focus on Service



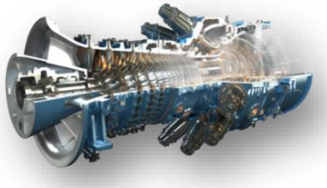
4.086
Employees

1.200 €
2018
Revenue

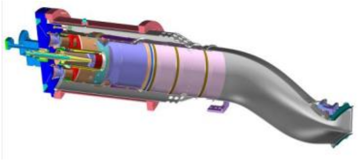
Multi-OEM GT Products and Services



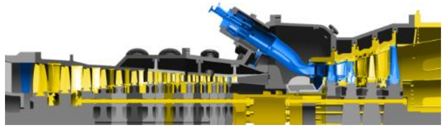
F-class



Advanced Frame

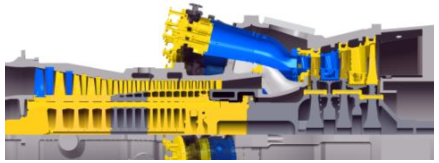


B/E Fleet



Siemens Westinghouse and Mitsubishi

General Electric



3 Engine Classes

13 OEM Frames

Total Lifetime Support

Full Service & Maintenance

Rotors & LTE

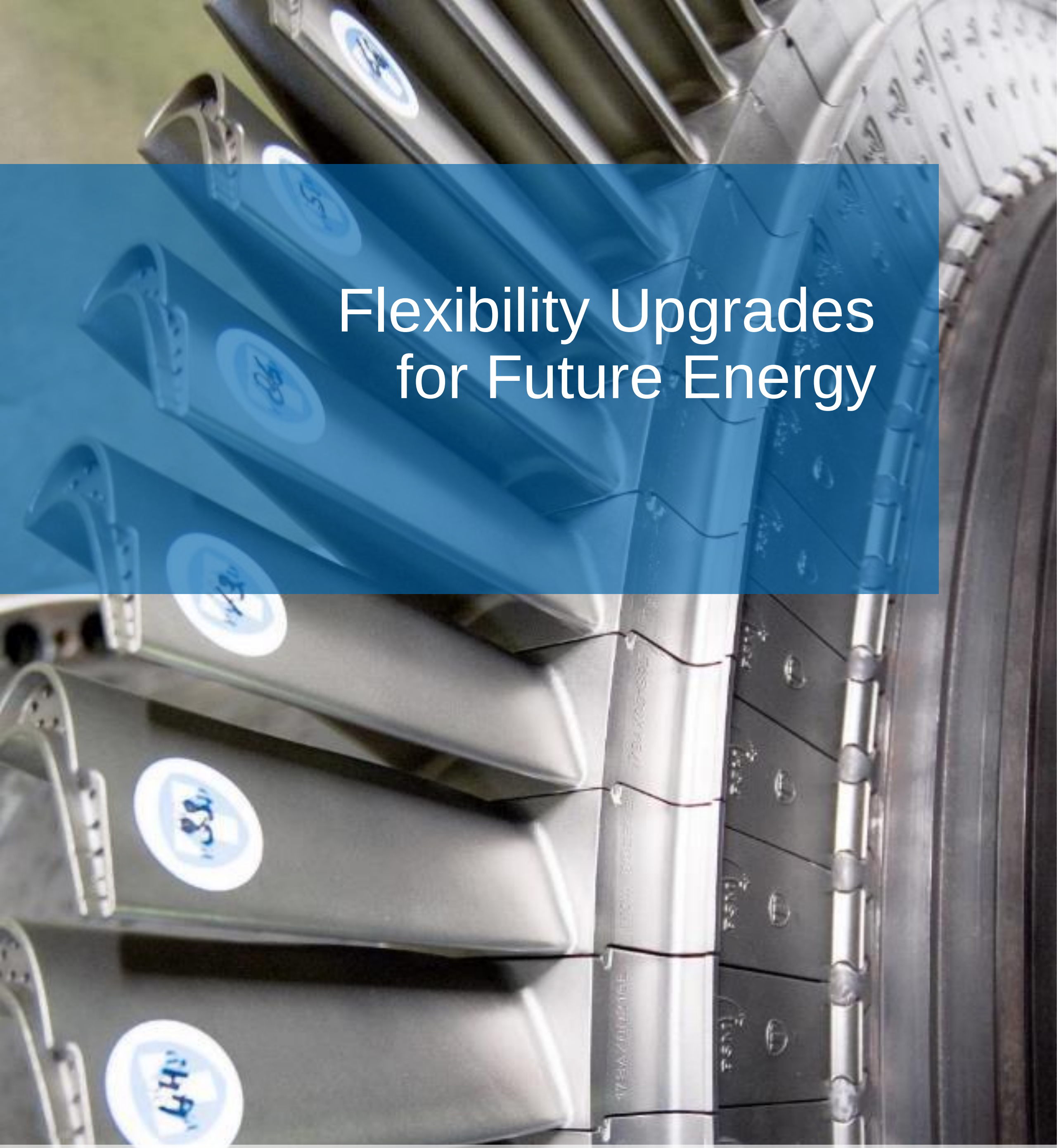
Cases

M&D

Reconditioning

Field Service

Includes Full Product Line for GE, Siemens and Mitsubishi platforms



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GTOP – Gas Turbine Optimization Package

By combining design innovations, advanced materials, and proven empirical-based AutoTune control software, the advanced design enables E-class fleet customers to benefit from:

- Output and efficiency improvements
- Synchronized and extended maintenance intervals and increase in parts life up to 96k
- Maintaining low emissions

Maintenance Mode
1970-2055F
32k FFH / 1200FFS

Performance Mode
2055-2084+F
24k FFH/900 FFS

Combustion Hardware | HGP Hardware | Unit / Rotor Upgrades | LTE Rotor | Engineering Assessment








Provides Flexibility to Optimize Plant Performance & Maintenance

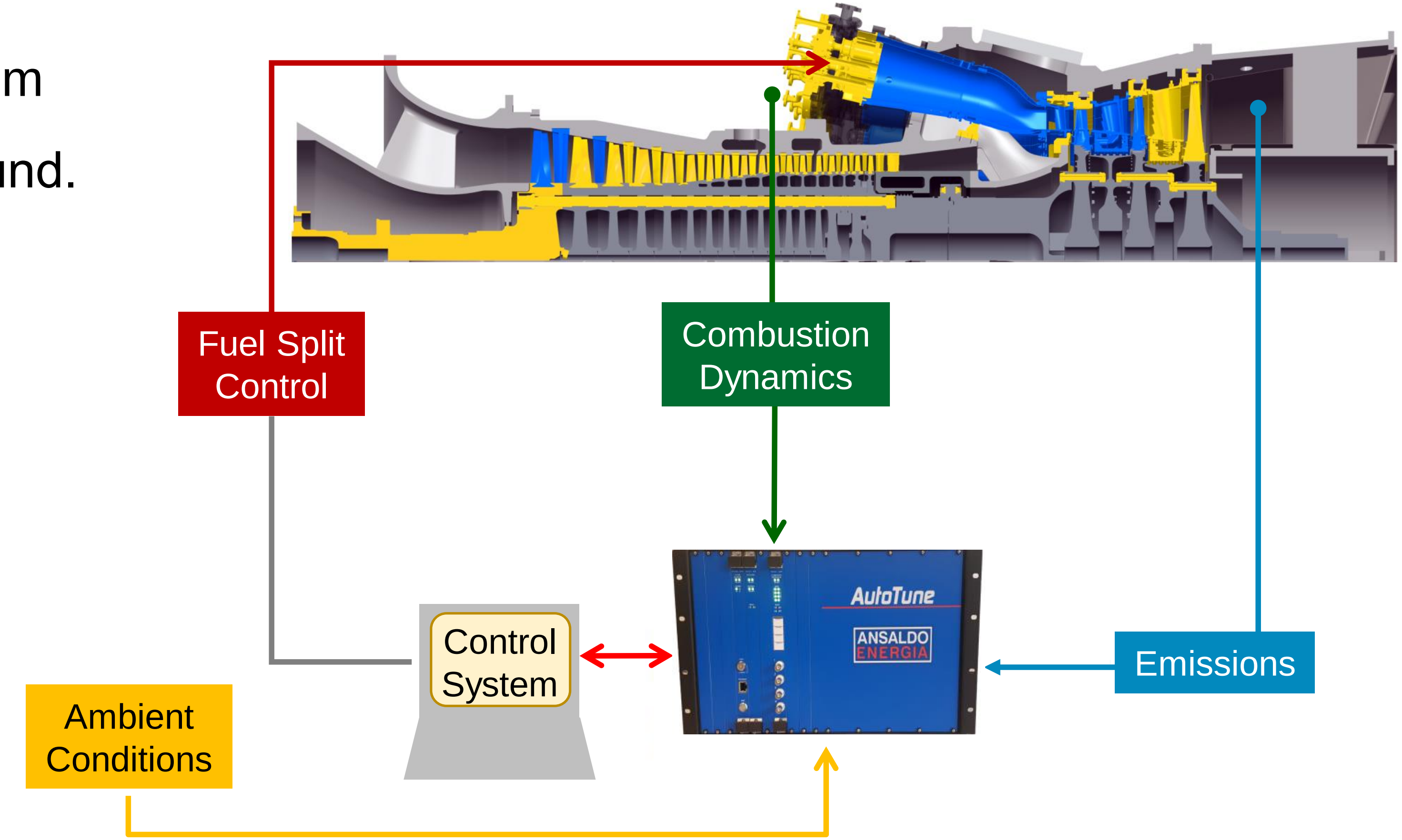
AutoTune

Auto Tune will ensure the combustion system will controlled in it “sweet spot” all year around.

Auto Tune will control based upon:

- Ambient temperature
- Firing temperature
- Fuel composition

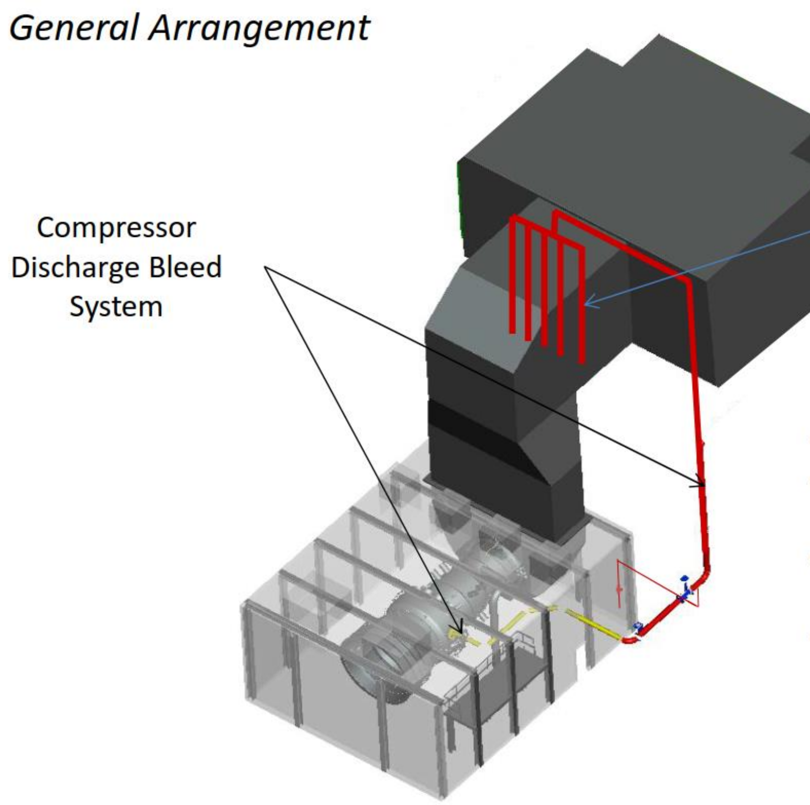
If any value exceeds it limits Auto Tune will tune to find new solution and store it in his combustion mapping



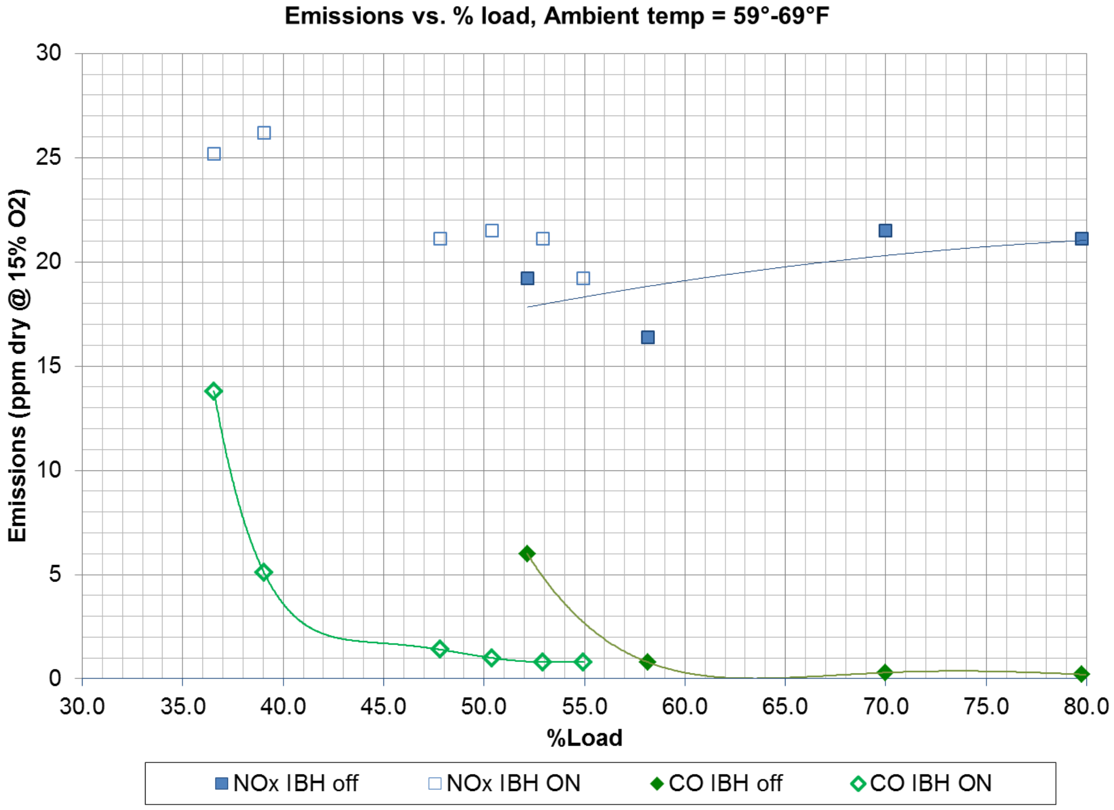
AutoTune Able to Minimize Emissions and Provide Cost Savings

Inlet Bleed Heat

Inlet Bleed Heat system (mechanical, controls and instrumentation) effectively reduces compressor flow at turndown, allowing reduction of CO emission level



- Simpler mechanical execution
- No Filter House modifications required
- Simple modification to Inlet Duct to install the IBH Manifold
- Less interconnect piping



System Results – 2017 Installation on a 501F (701F applicable)

Inlet Bleed Heat allows for remaining low CO levels at low load

Partnership Objective with FlameSheet^{TM} Platform

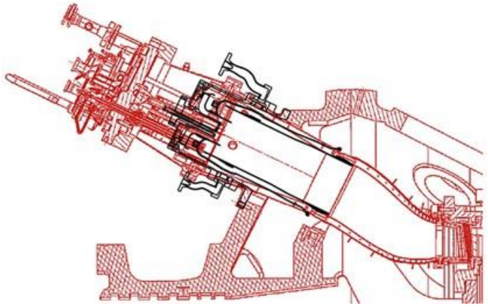
Objective:

Develop a low emission gas turbine combustor retrofit for fuel flexible operation from 100% Natural Gas to 100% Hydrogen and any mixture thereof

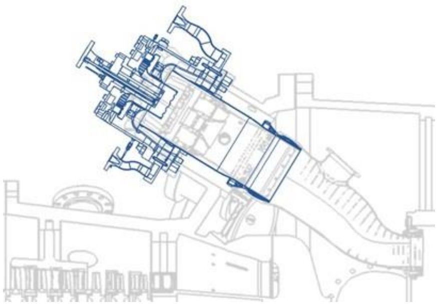
Additional key objectives can be summarized as follows:

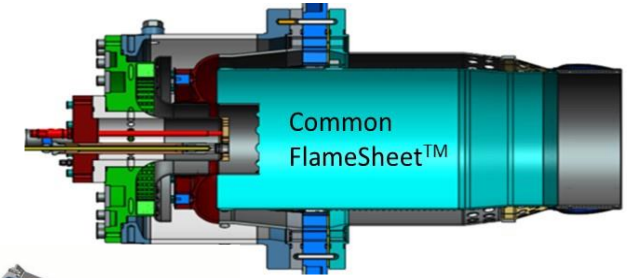
- Cost effective, payback within 2-3 years.
- Sub 9ppm NOx emissions with no diluent
- Wide operational flexibility starting/ramping
- Maintenance inspection intervals of at least 32000 hours or 1200 starts

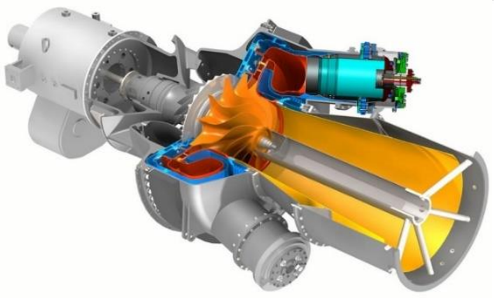
GE 7FA / 9FA



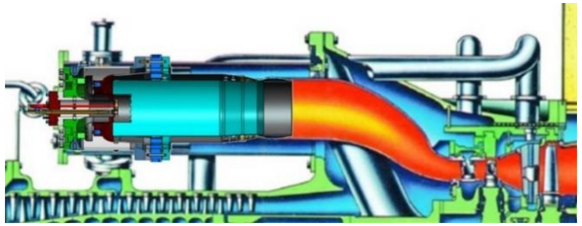
MHI 501F / 701F







OPRA OP16



GE Fr5, 6B, 7E, 9E

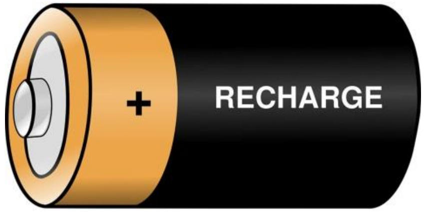
1MW to 300MW with 0% to 100% Hydrogen with 1 Combustion System

Why a Partnership?

- Shared vision for path to carbon free power production
- Leverage strengths of each entity to contribute
  - Academia – TU Delft
    - Developing fundamental tools to assist design development
  - Manufacturers – OPRA and Ansaldo Thomassen
    - Applying practical development experience and advanced technology for state-of-the-art real World solutions
  - Users – Vattenfall, Emmtec and Nouryon
    - Ensuring commercial generating needs are met and providing infrastructure to support demonstrations

TUDelft ANSALDO THOMASSEN OPRA TURBINES Nouryon EMMTEC services VATTENFALL

H_2 =



Cost Effective Approach Leveraging Broad Range of Resources

PartnerShip Goals

- Using ***advanced analytical techniques*** to demonstrate 100% hydrogen capability
- Initiate atmospheric rig tests to show ***further improvement*** from the already demonstrated 80% hydrogen to achieve the 100% hydrogen goal, ***with no diluent***
- Complete high pressure (full-scale conditions) to verify robust 100% hydrogen operation
- Perform engine demonstrator, with combustor retrofit on existing E- or F-class machine, with <u>fuel-switching from 100% natural gas to 100% hydrogen</u>

TUDelft

ANSALDO THOMASSEN Ansaldo Energia Group

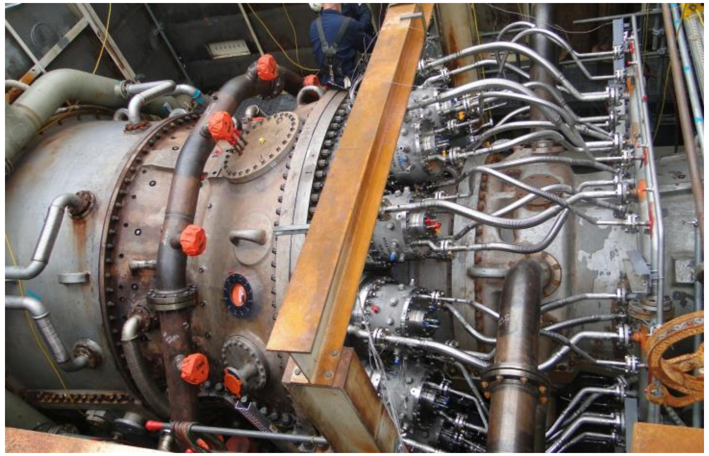
OPRA TURBINES

H_2

Nouryon

EMMTEC services

VATTENFALL

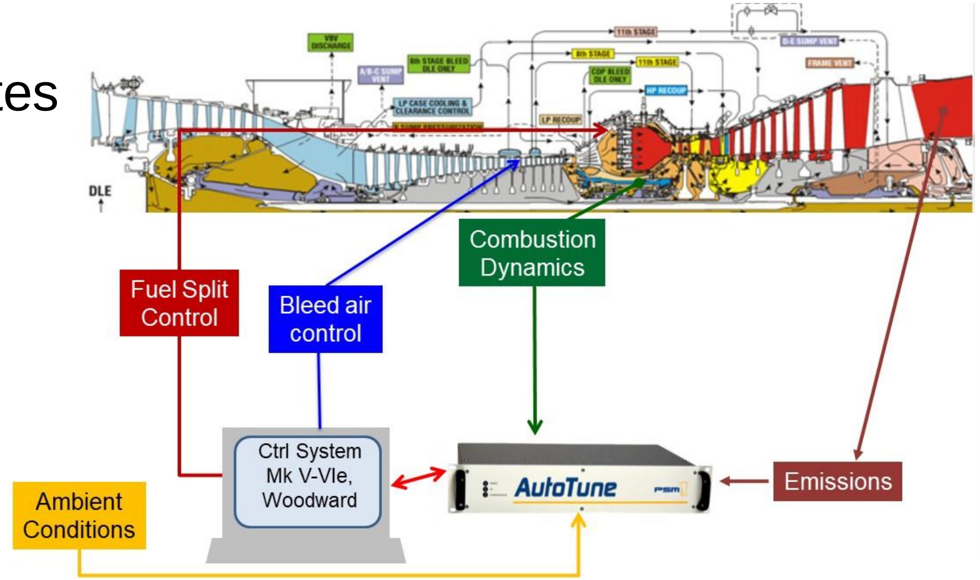


Development Toward 100% Hydrogen Flexibility

The Three steps to Hydrogen use in Gas Turbines

1. **Fuel systems** rated for hydrogen containment
   - Sealing & detection
   - Sizing for flexibility
   - Blending and substitution

2. **Controls & AutoTune**
   - Flexibility in burning hydrogen in with high rates (1 second) of change
   - Modern control system supplemented with **AutoTune** for instantaneous combustor zone temperature management

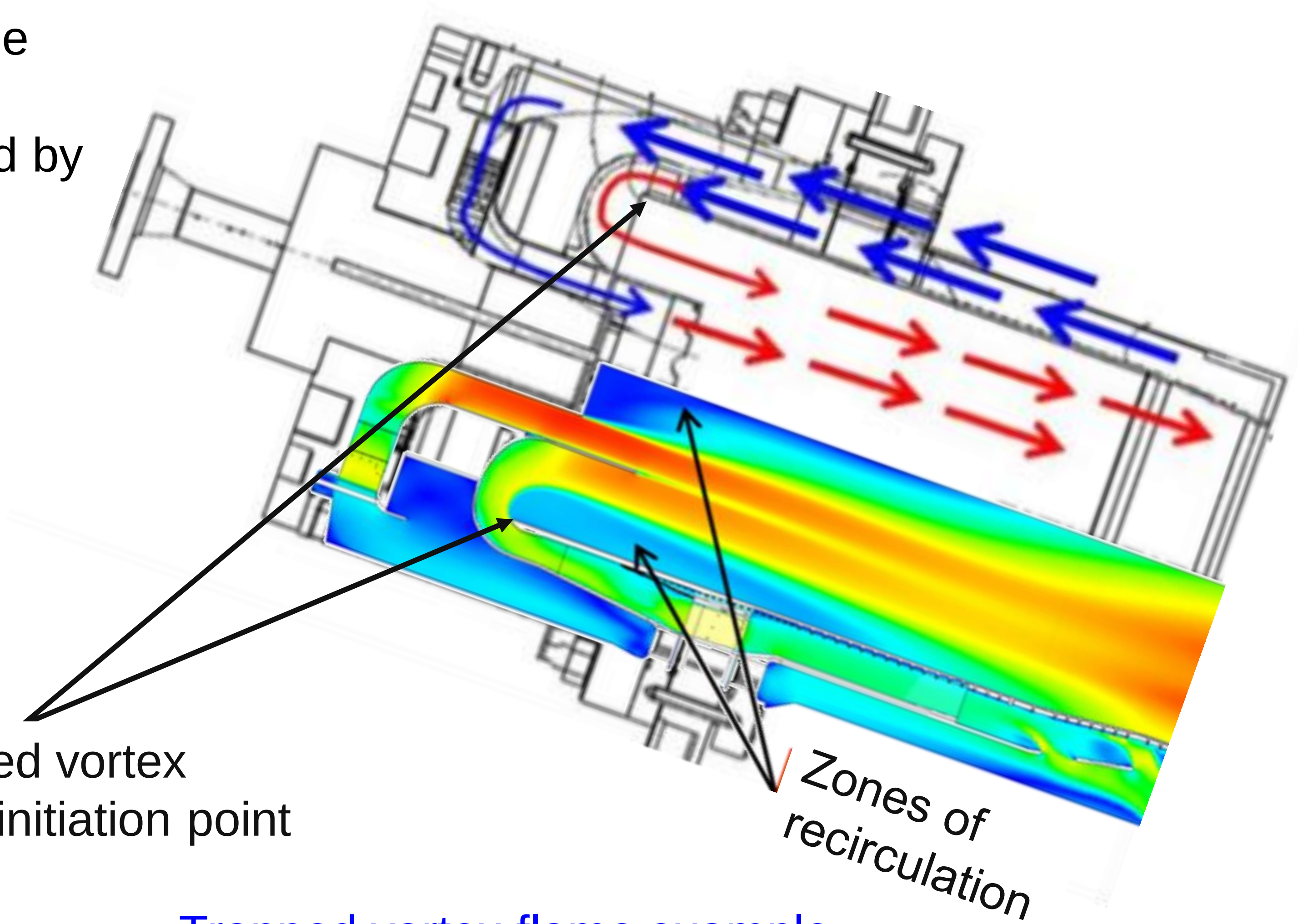


3. **Combustion hardware**

Fuel Skids & Controls Flexible Hydrogen Operation with Instantaneous Response

Combustion Hardware Development

- Trapped vortex flames less sensitive to flame shifting position
- Flame anchored at point of vortex as defined by geometry and less dependent on fuel constituents
- FlameSheet primary flame stabilization by aerodynamic trapped vortex

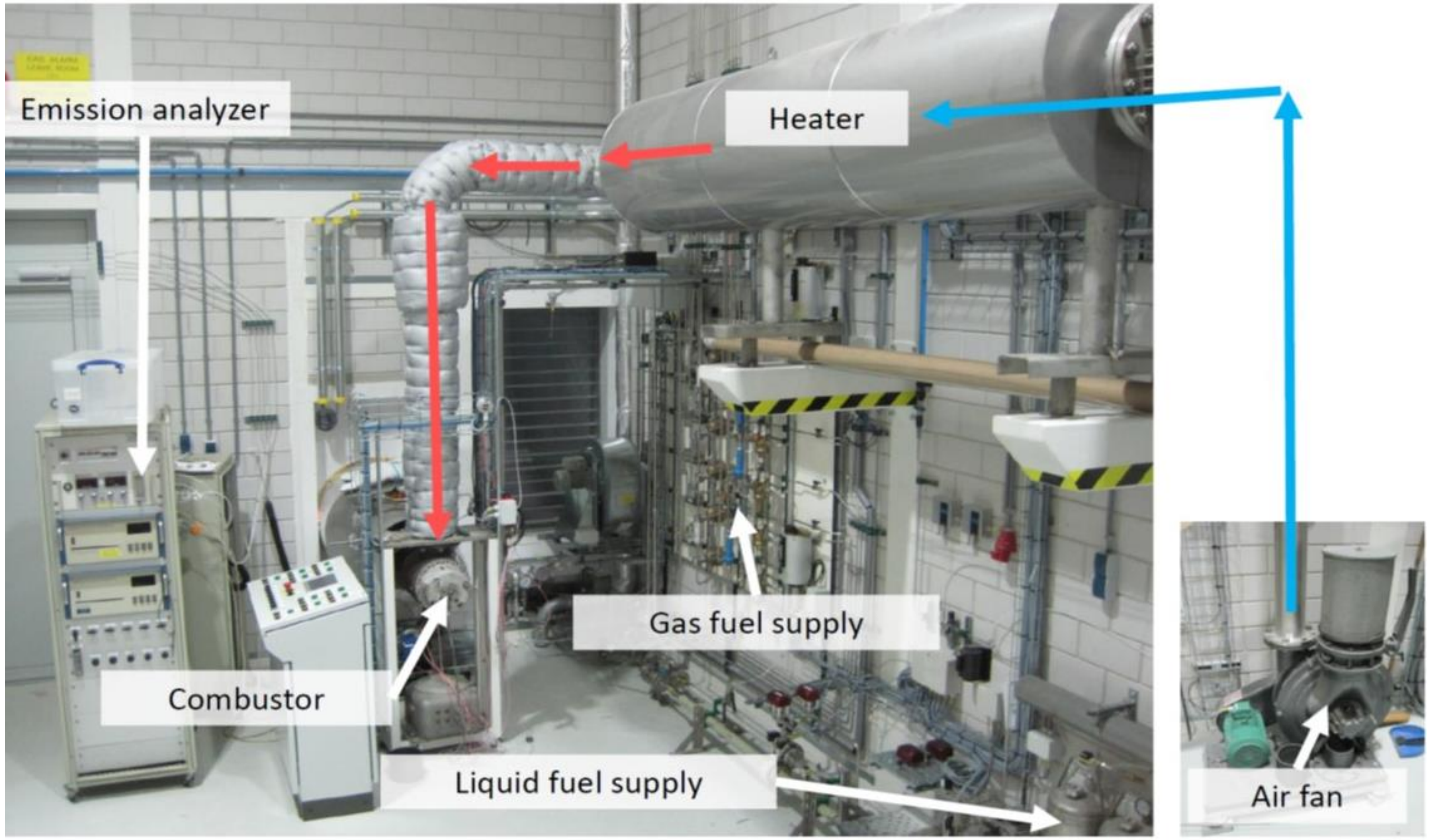


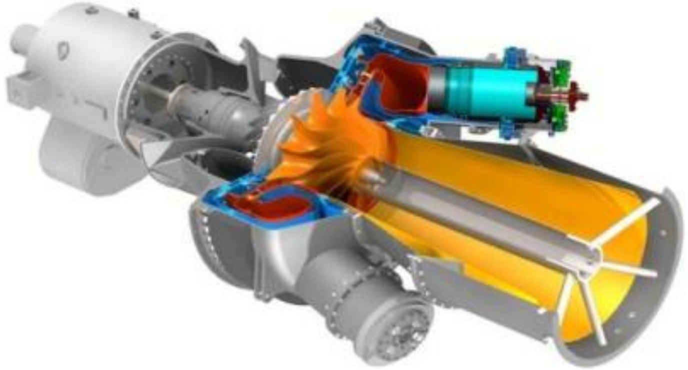
Trapped vortex flame example

Trapped Vortex Technology Offers New Path for Hydrogen Consumption

Atmospheric demo OP16

Preparations in progress for testing to start Q4 2019 with up to 100% hydrogen





OP16 with Advanced Premix High Hydrogen FlameSheet™

High Hydrogen Prototype Defined and Test Rig Identified

Hydrogen Partnership Development Roadmap

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Major Milestones	Date	
Initiated Project – Dutch Government Subsidy Awarded (50/50 match)	April 2019	**Phase 1** Atmospheric
Design, Develop and Procure Prototypes	2019	
Atmospheric Combustion Rig Testing	2019/2020	
Develop High Pressure Hardware	2020	**Phase 2** High Pressure Small Engine Demo
Perform Full Pressure Combustion Rig Tests – Initial Phase	2020/2021	
Demonstrate Full System Capability on OPRA 1.6MW Machine 0% - 100% Premixed Hydrogen	2021/2022	
Finalize Combustion System and Support Systems for Frame Machine	2021	**Phase 3** High Pressure Large Engine Demo
Perform Full Pressure Combustion Rig Tests – Final Phase	2022	
Demonstrate Full System Capability on 20 – 40 MW Frame Machine 0% - 100% Premixed Hydrogen	2023	
Demonstrate Full System Capability on 200+ MW Frame Machine 0% - 100% Premixed Hydrogen	2024	

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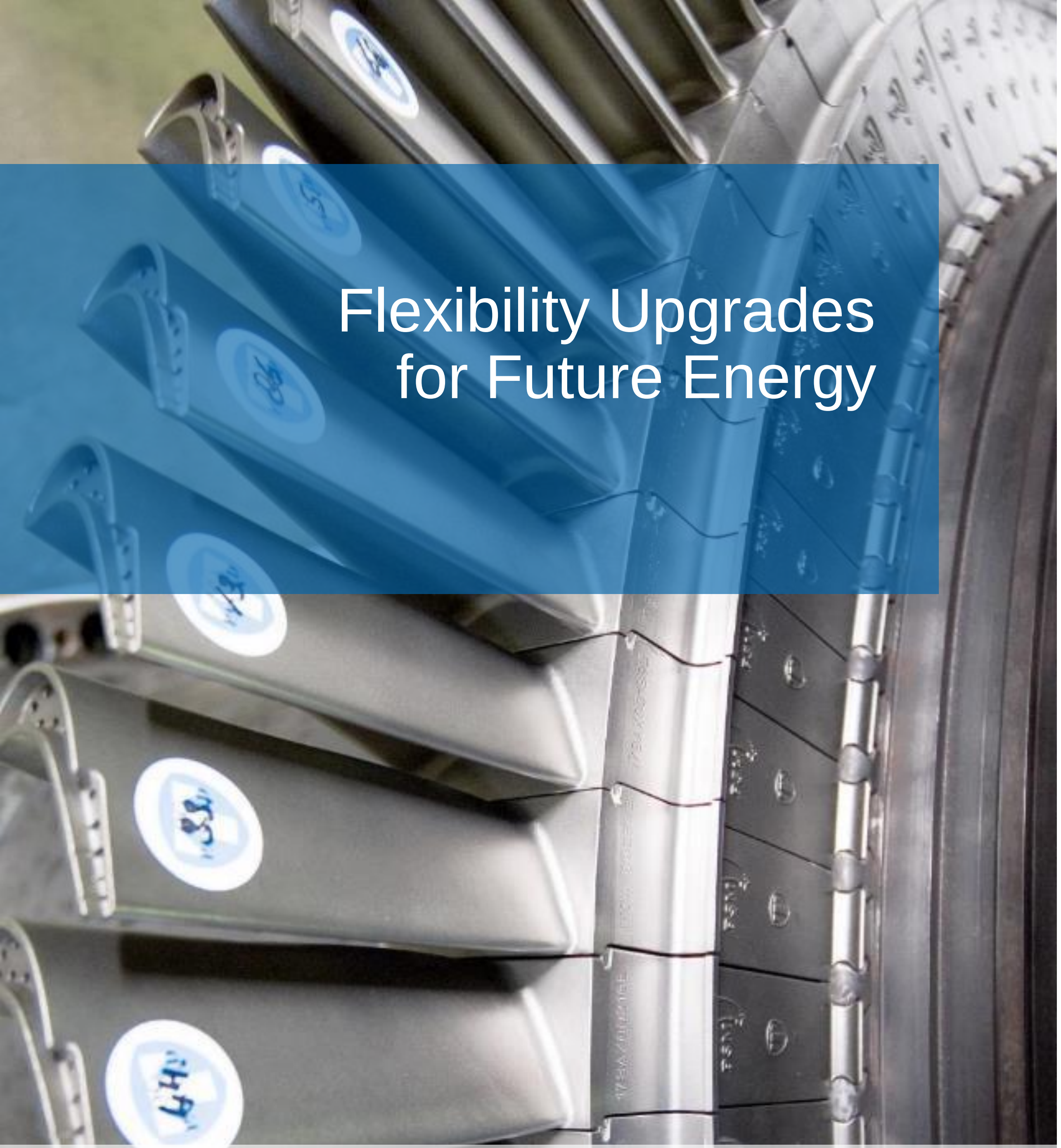

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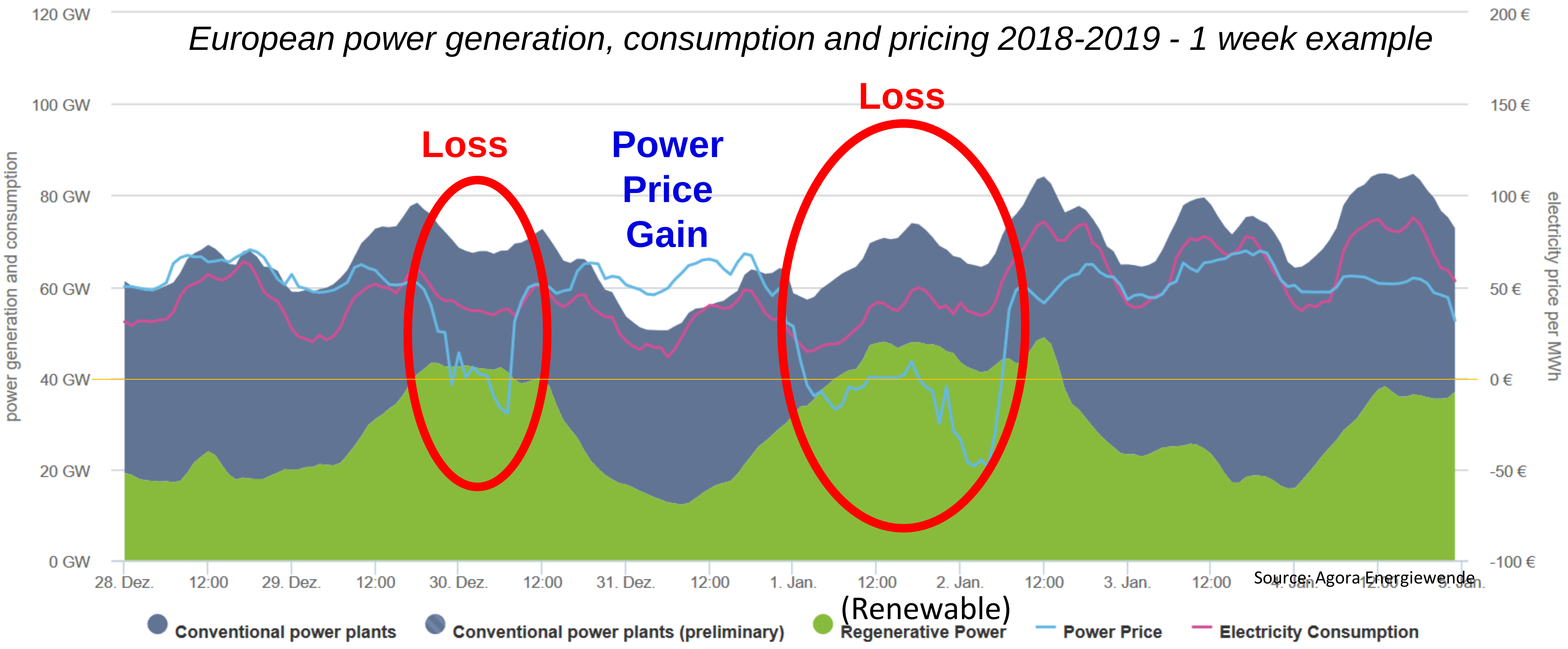
What about When Renewables Penetrate?

- 2018-2019 European Example



More Renewables = Bigger Fluctuations

The Renewable Gap

Recognizing the Opportunity

- Renewables are clean but they depend on the weather
- The weather is unpredictable
- More renewables = more unpredictable power supply

- What is needed? (The Opportunity)

- *Massive* energy *interconnect* to balance regionally
- *Energy storage* to release energy when it is needed
- *Flexible and fast* source of energy generation to help us get there

Renewables Define the Market … an Opportunity to Fill in the Gaps

Filling The Renewable Gap with Existing Equipment

Region	GE 5-1/5-2	GE 6001	GE 9001	GE 6000F	GE 9000F	MHI 701F	Others*)	Total
Netherlands	21	10	6	1	4	3	0	**45**
Rest of Europe	54	129	54	60	132	22	0	**451**
Rest of the world	1827	1038	724	143	232	142	2724	**6830**
Total	**1902**	**1177**	**784**	**204**	**368**	**167**	**2724**	**7326**

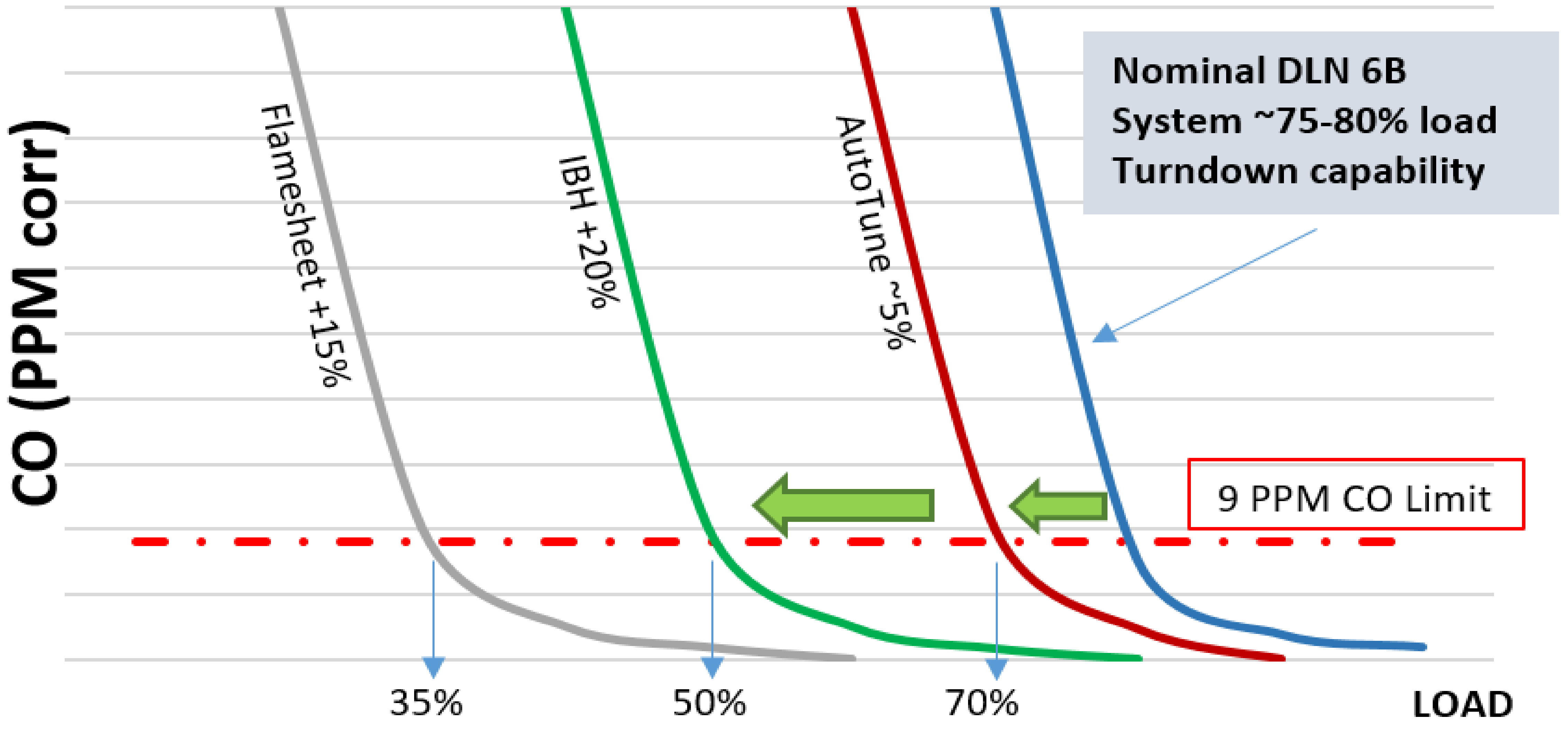
Table: Operational Gas Turbine Units Europe (incl UK), known to Ansaldo Thomassen

**) Others are 7E, 7F, M501G, M701G, SW501F/G, W501B/D not located in Europe.*

- Over 7,000 frame machines available
- Flexible retrofits offer a path forward for existing installed base

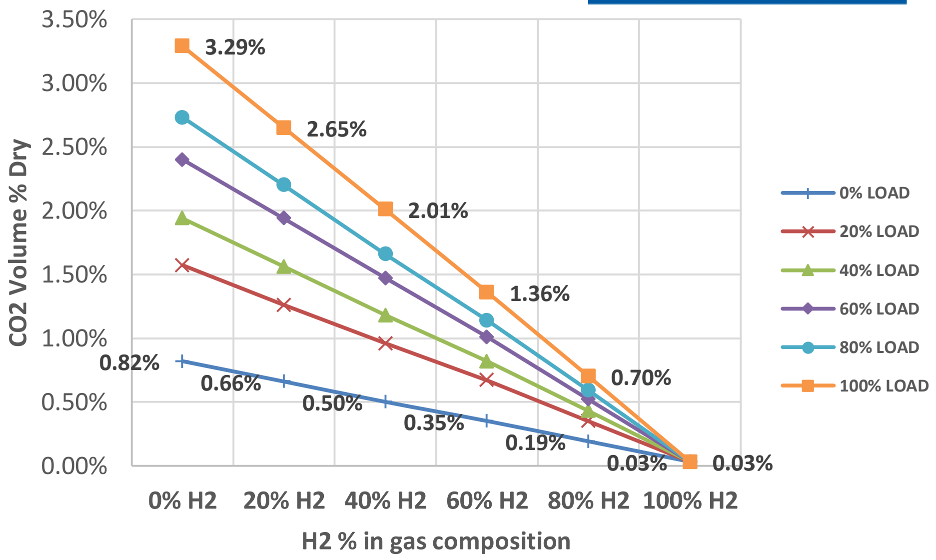
Gas Turbines Reconfigured to be Part of the Energy Solution

Existing path for low load operation and low CO emissions

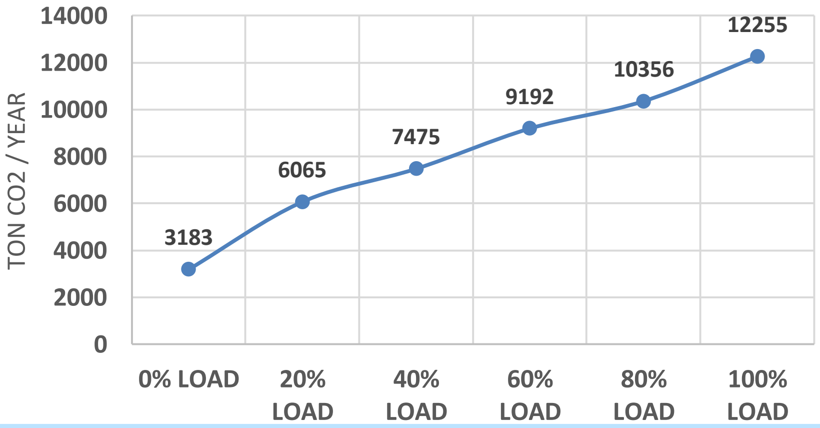


Path forward is CO_2 reduction using Hydrogen in Retrofitted Gas Turbine

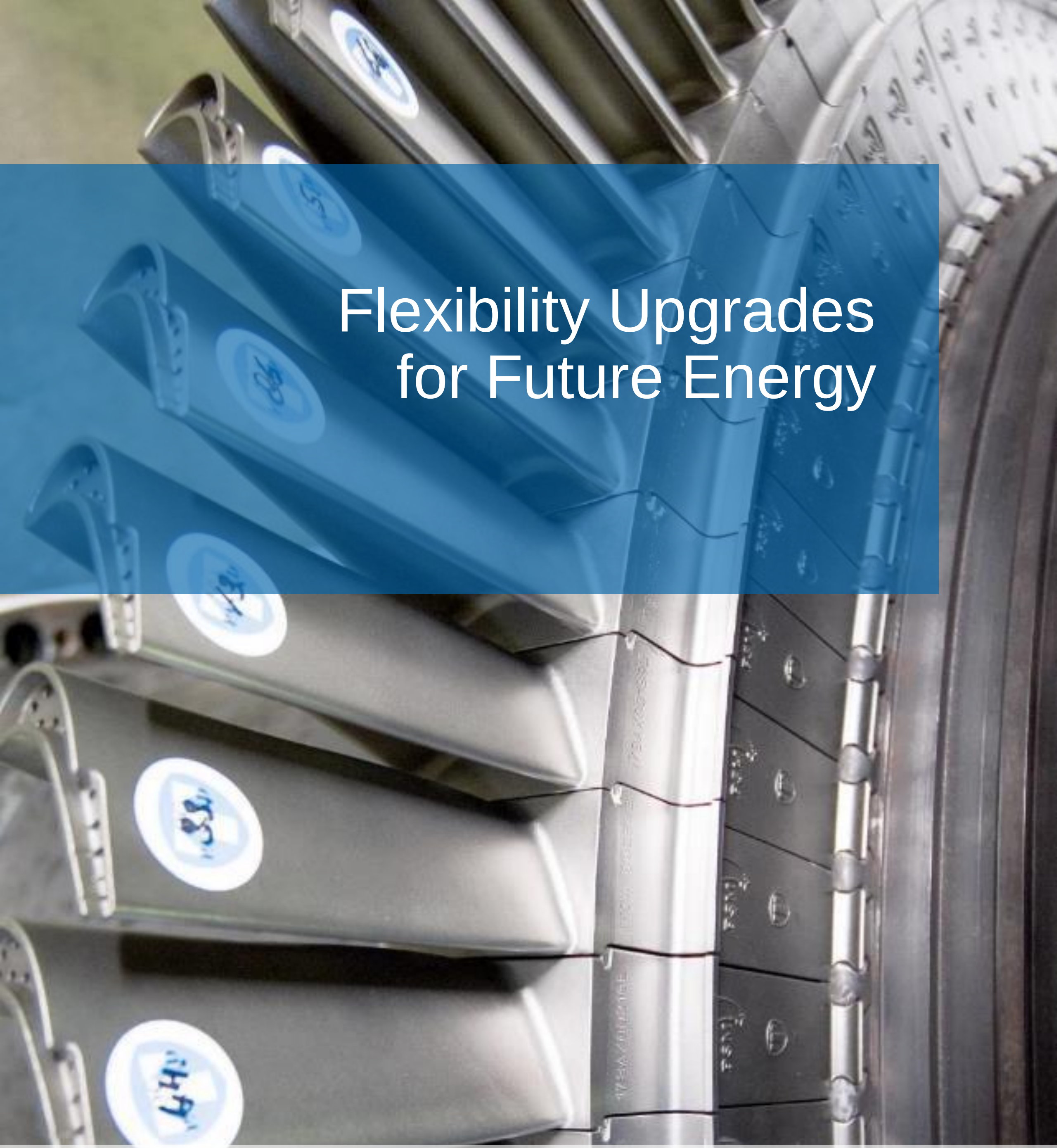
- Using **Hydrogen** reduces CO_2 emission 1:1 (H_2 vs <u>C</u>H_4)
- Small OP16 Engine has an emission of 12.255 ton CO_2/year using natural gas (<u>C</u>H_4)*(100% load 8000hr/yr)*
- Large scale MS5, MS6 & MS9 GT's go up to resp. 150.000, 180.000 & 540.000 tonnes CO_2/year*(100% load 8000hr/yr)*
- The total power generation by natural gas is 58 milliard kWh. Assuming conventional gas power plants the contribution is 396 gCO_2/kWh, meaning natural gas power generation is emitting **22.968.000 tonnes CO_2 in 1 year**.
- On the Dutch operational fleet of MS5, MS6 & MS9 the total reduction of CO_2 could potentially be **around 37%** of this. This is **8.190.000 tonnes CO_2** per year !



<u>CO2 OP16 on natural gas - 0% H_2</u>



Gas Turbines Retrofit will provide a significant CO_2 emission reduction



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FlameSheet^{TM} Commercial Machine Experience

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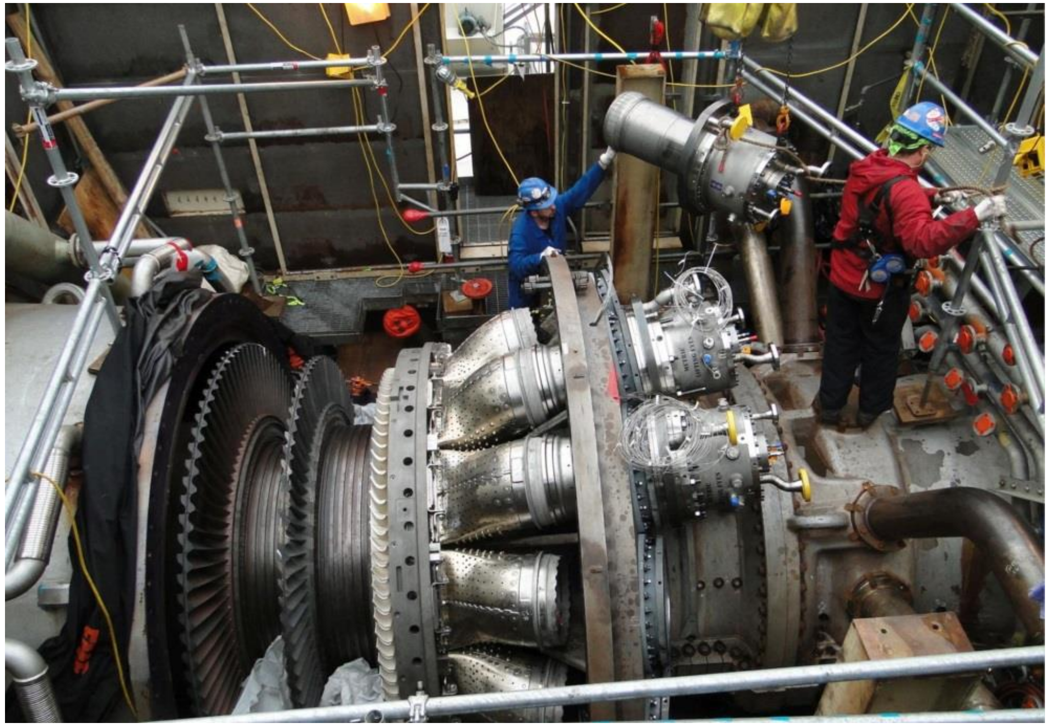
- ***7*** FlameSheet™ machines in operation
- Key attributes - ***20% additional load turndown*** and ***fuel flexibility***, with ***sub 9ppm Nox***
- Hardware in excellent conditions after 28,000 hours and 400 starts



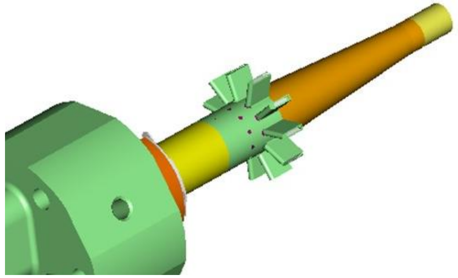
FlameSheet™ Retrofit Enhances Operational and Fuel Flexibility

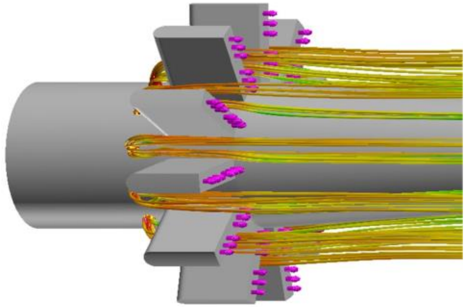
Elements of consideration – 3 Hydrogen steps implemented

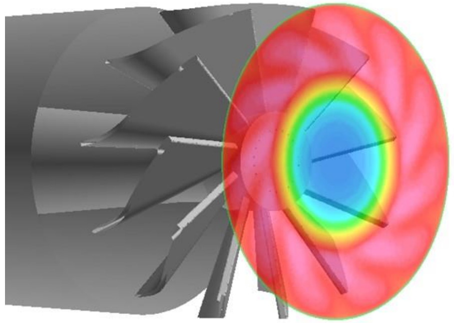
1. Fuel skid

2. Control System / AutoTune

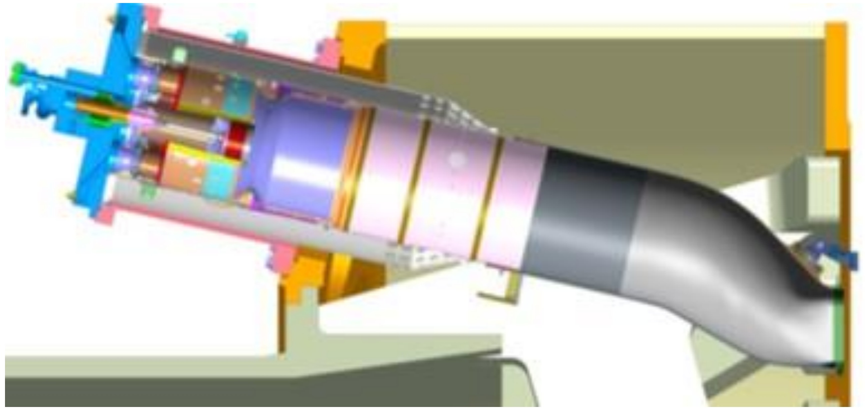
3. Combustion system (more than 100 natural gas E-class installations, 3 with H_2)



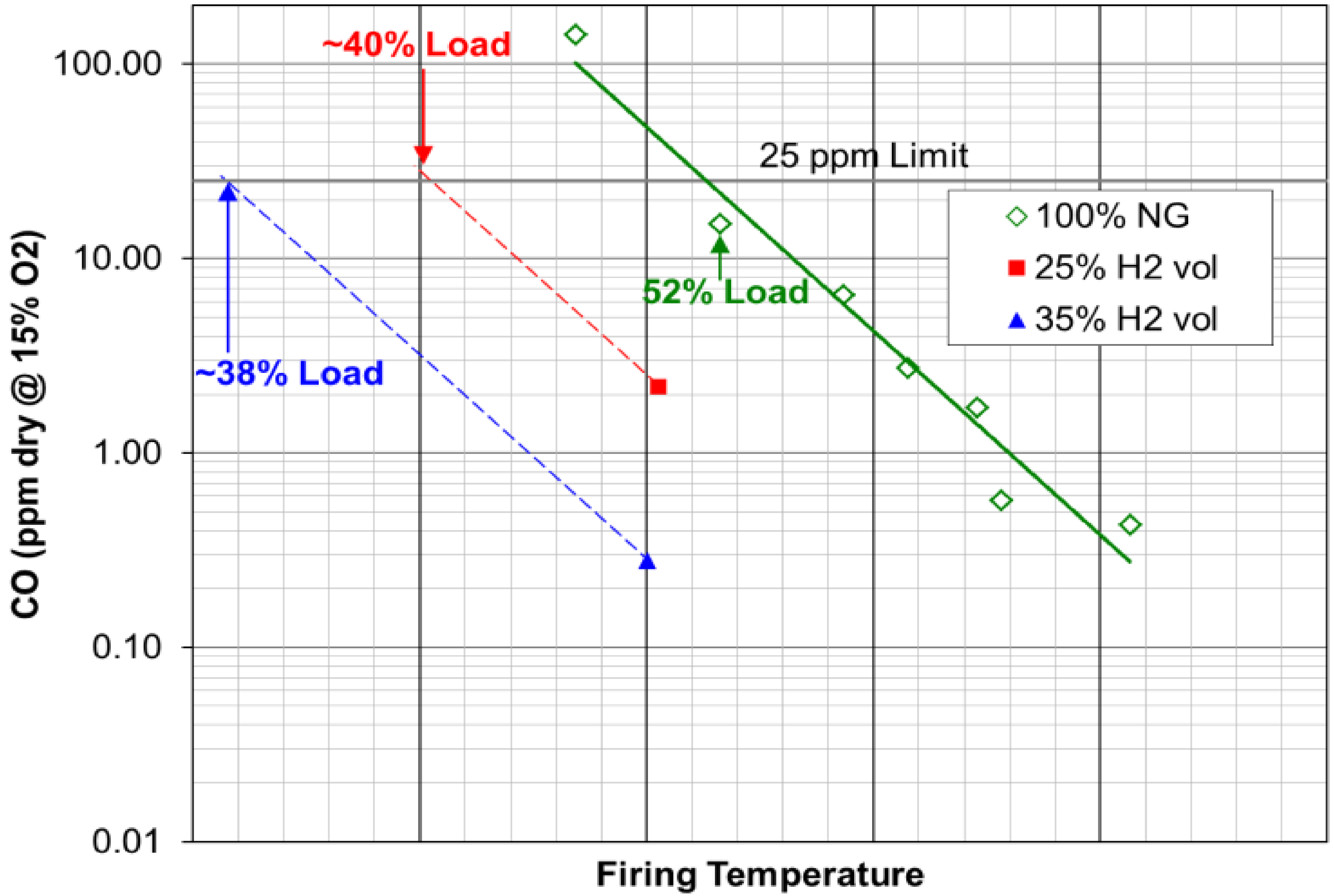


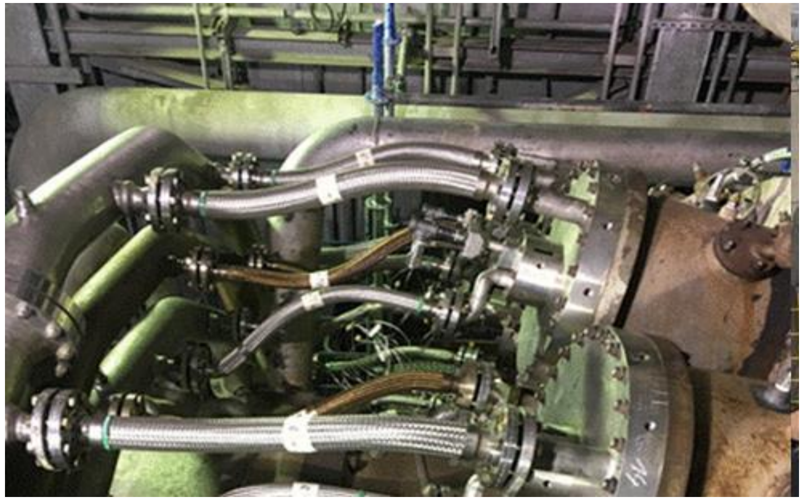


High hydrogen Secondary fuel nozzle upgrade



Enhanced Turndown with Flexible Hydrogen Operation





Advantage for Extended Low Load Operating Limit with the Addition of Hydrogen

Gas Turbine World

May - June 2019

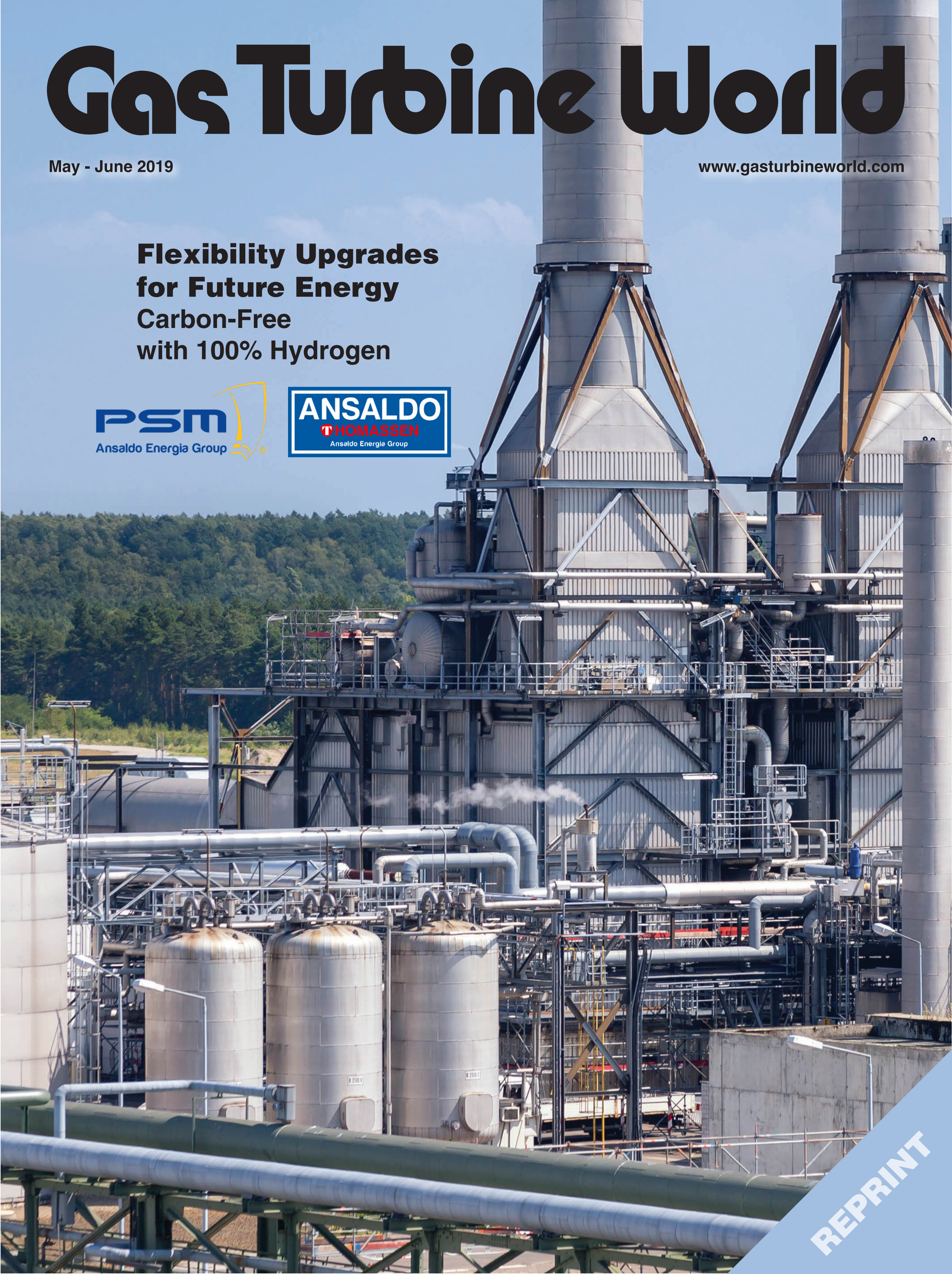
www.gasturbineworld.com

Flexibility Upgrades for Future Energy

Carbon-Free with 100% Hydrogen

PSM Ansaldo Energia Group

ANSALDO THOMASSEN Ansaldo Energia Group



REPRINT

Hitting 100% hydrogen

By David Appleyard

The idea of using hydrogen as a medium for storing excess renewable energy is gathering momentum but to deliver, a number of technological advances are required. Now, a new technology partnership aims to do just that.

Considered a clean alternative to natural gas combustion, hydrogen is attracting growing interest as a medium for storing excess renewable energy capacity. As Peter Stuttaford, CEO of Ansaldo Thomassen, and formerly the Director of Engineering at PSM, explains: “It's clear that renewable energy is here to stay. The footprint of that renewable energy is only going to increase and we are seeing the next phase, where there's so much of it that it starts to impact the stability of the grid. We're looking beyond renewables to energy storage. That's really the next game changer.

“We think storing energy in synthetic fuel is a very effective large scale way to approach this. Hydrogen for example is a synthetic fuel. You can store large quantities of it and then release it in a way which takes advantage of existing assets.”

However, for this idea to generate commercial traction resulting in a significant power industry sector, new developments in gas turbine designs are needed and almost all of the major OEMs are already exploring this area.

One of the latest developments is set to emerge from the Ansaldo Energia subsidiary, which is working in partnership with a number of other players to develop 100% hydrogen-fired turbines. The group is set to explore development of a gas turbine demonstrator that will be able to use hydrogen fuel flexibly as well as being efficient and generate low emissions.

In April this year, the consortium comprising of six partners – Ansaldo Thomassen, Delft University of Technology, OPRA Turbines, Vattenfall, Nouryon (formerly Akzo Nobel) and EMMTEC – was awarded a Dutch government grant to explore the idea.

The ‘High Hydrogen Gas Turbine Retrofit to Eliminate Carbon Emissions’ engineering development project is being funded to the tune of €500,000 by the Dutch Ministry of Economic Affairs and Climate Policy.

The technology is aimed at the owners of existing power facilities that are currently being priced out of the power market by burgeoning renewable capacity and limited requirement for peaking capacity.

Europe is awash with stranded gas turbine assets as some owners are not running enough hours to meet their conventional business model. Combined heat and power (CHP) assets have an advantage in that they are producing electricity and heat. In fact a key advantage of the gas turbine power cycle is the production of heat, which is of high value to industrial processes as well as residential needs.

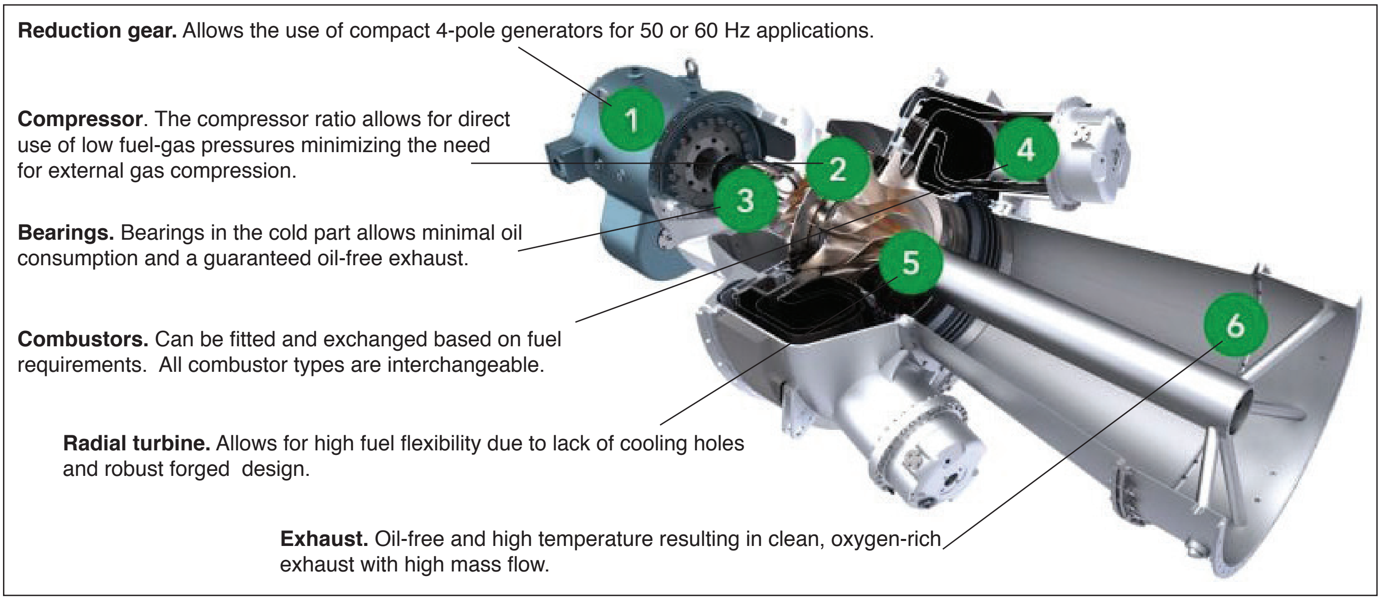


Figure 1. Hydrogen design. Although the bulk of the other internals remain as designed, there are some other considerations associated with the use of hydrogen-rich fuel mixtures.

If successful, this hydrogen combustion technology potentially represents an opportunity for owners to extend and improve the commercial viability window and extend the operational life of their asset longer than it otherwise might be by making a margin on balancing services and other emerging services.

"We've got all these gas turbine assets out there. They're not capable right now necessarily of burning hydrogen with very low emissions, but we can potentially adapt them with relatively minor upgrades. This allows existing equipment to be adapted to run as a battery using a synthetic fuel that will fill the need for energy storage," says Stuttaford.

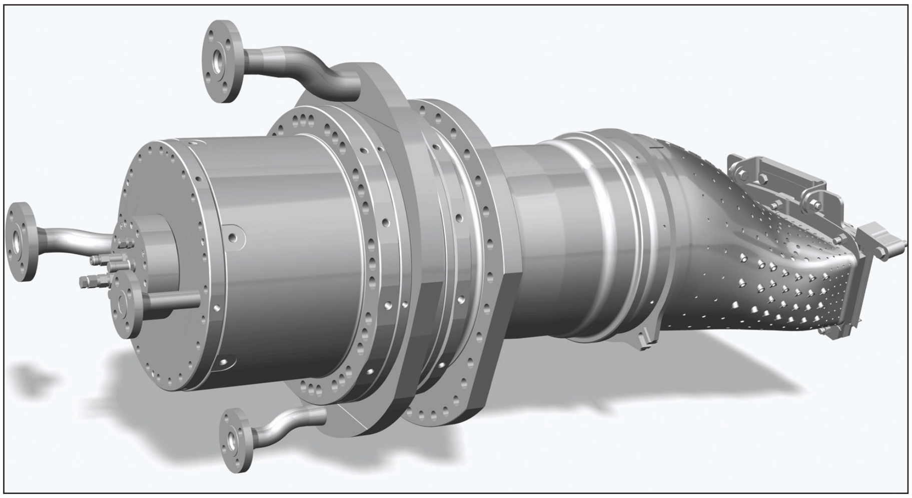


Figure 2. The patented aerodynamic trapped vortex FlameSheet™ is based on a two-stage nested combustor design.

Technical challenges

Considering the challenges of running a gas turbine on 100% hydrogen, in many respects the fuel is a direct analogue for natural gas and delivers comparable ramp rates and performance.

"There are already machines out there today that run 100% on hydrogen. Typically they are using standard-type diffusion combustion systems that require additional controls for NOx emissions such as costly diluent injection and selective catalytic reduction on the backend," says Stuttaford.

"We wanted to avoid the need for selective catalytic reduction and use dry premix combustion technology. That means that you can seamlessly operate between natural gas and hydrogen but it does come with significant technical challenges because of the high reactivity of hydrogen and the need to avoid damaging equipment with combustion occurring in the wrong place," he says.

Stuttaford adds: "This is the subject of the development work we are doing now, taking technology that we have which is suited towards these kind of highly reactive fuels and extending the capability so that we can operate flexibly between hydrogen and natural gas."

Using the system as envisaged, operators will be able to switch between varying amounts of either fuel from 0 to 100% seamlessly and on demand.

Stuttaford explains: "There's really three elements to that sort of flexibility. One is the control system that can compensate for these fluctuations. For that our AutoTune product, now already operating on more than 55 machines, is really well suited. In the Netherlands we already have three 9Es where we run commercially from 0 to 25% hydrogen and the AutoTune system is able to compensate on the fly for any variation in the fuel constituency without the need for a gas chromatograph, but just using the fuel gas manifold conditions."

He continues: "The second element is the fuel gas supply skid, which has to be appropriately designed and sized to be able to accommodate the fuel streams, whether it's hydrogen, natural gas or mixture thereof. The third element is the combustion system, which must be capable of burning this gas with emissions compliance over the normal load range and at the normal ramp rate, all those things."

The physical design changes are almost exclusively focused on the combustor system and although the bulk of the other internals remain as designed, there are some other considerations associated with the use of hydrogen-rich fuel mixtures.

"You have to look at the sealing of the gas system, of the valves and anything that's coming into contact with the hydrogen fuel to ensure that there's no deterioration because of the reactance of the fuel system with hydrogen," says Stuttaford.

"For the downstream components of the turbine you do see higher volumetric flow rates, as instead of producing CO_2 you have H_2O. That does affect the heat transfer rate of the turbine equipment," he says, adding: "That needs to be considered and also any potential impacts if it's a combined cycle. All these things will need to be evaluated, but we already do that sort of evaluation in performance upgrades to increase firing temperatures and output. There is a path and a safe one that we're implementing".

Fuel flexible combustor design

The major objective of the High Hydrogen Retrofit Project is to develop a cost-effective ultra-low emissions combustion system that can retrofit to existing installed gas turbines. Emissions are anticipated below 9 ppm for NOx and CO while the product will be suitable for machines across an output range from the smallest gas turbines at around 1 MW and right up to the largest frame machines with power outputs of around 300 MW.

Stuttaford explains: "There's probably going to be a shift towards more distributed energy just because of the nature of the renewable grid. You could see more local generation coming in and there will be a focus on smaller, highly flexible machines."

Fuel flexibility and stable operation from 100% natural gas to 100% hydrogen and any mixture thereof, is a key requirement. This is a key challenge as extreme changes in fuel reactivity

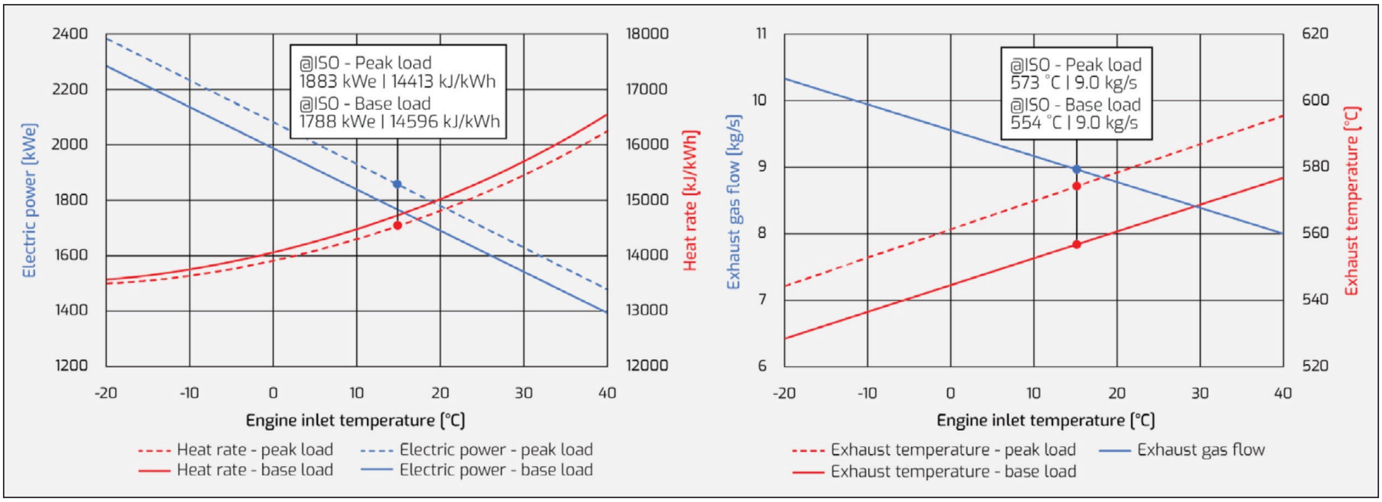


Figure 3. **Performance curves.** In many respects hydrogen is a direct analogue for natural gas and delivers comparable ramp rates and performance.

switching from natural gas to hydrogen can result in dramatic shifting of heat release within the combustor, which can be physically destructive if not well controlled. The combustor therefore does take some significant upgrades to run with such a highly reactive fuel.

Ansaldo Thomassen is a heavy-duty gas turbine specialist offering all possible services for GE-type gas turbines. At the centre of the project is the patented aerodynamic trapped vortex FlameSheet™ combustion technology platform, developed by sister service company PSM, based in Jupiter, Florida, and owned by Ansaldo Energia.

The FlameSheet combustion system is operating commercially in multiple 60 Hz F-Class gas turbine power plants and is achieving required NOx emissions levels across a range of fuels including hydrogen mixes of up to 5%. Although up to 80% hydrogen operation has been achieved on the FlameSheet with low emissions in a combustion test rig.

As Stuttaford notes: "The Flamesheet technology is already running on a large 7 FA machine in the 180 MW range, but we're pointing it downwards, down to the 20 MW range, which are still frame machines, but then even going down to the 1 MW range."

FlameSheet™ is based on a two-stage nested combustor design. This radially-inflow "combustor-within-a-combustor" concept allows staged operation under various load conditions. At high loads, both combustors are used, while at low loads, it is predominantly the outer combustor only. Leveraging trapped vortex stabilization aerodynamics, the outer combustor remains sufficiently hot and stable even at very low loads to consume CO. The outer combustor flame structure looks like an annular sheet of flame around the inner combustor.

The technology claims benefits such as up to a 30% increase in operating load range with single digit NOx and CO as well as superior fuel flexibility characteristics such as a 30% Modified Wobbe Index (MWI) variation. This, says Ansaldo, makes the design ideally suited for alternate fuel operation, including hydrogen, whilst maintaining low emissions.

Project execution

In the first phase of the project, gas turbine manufacturer OPRA and the other partners will design and test a prototype combustor based on Ansaldo's FlameSheet combustor.

The main testing will take place at OPRA's combustion test facility in Hengelo, in the Netherlands. This experimental rig includes a gas mixing station that can mimic virtually any type of gaseous fuel while key combustion parameters are measured. Together with advanced numerical methods, this will result in future low-emission and fuel-flexible combustion systems.

Initially, atmospheric testing will use the OP16, a 1.6 MW gas turbine from OPRA that combines robustness and simplicity with high performance.

Featuring an all-radial design and moderate pressure ratios, OPRA Turbines advanced combustion systems already offer multi-fuel capability, giving the OP16 the ability to handle a wide range of liquid and gaseous fuels at low pressures.

The four external can-type combustors allow easy access to the hot gas path in the turbine hot flow path reducing the amount of downtime during maintenance. Turbine bearings are located in the cold section of the machine in an overhang design ensuring an oil-free exhaust flow. This also improves reliability and allows the OP16 to achieve a 40,000-hour service interval, according to OPRA.

With a small footprint and low weight, the OPRA turbine is typically packaged within two 20 ft standard con-tainers, one containing the air filtration system, allowing for quick and easy installation. These compact and low-weight packages enable easy transporta-tion and installation. The standard OP16 Package has a noise emission level of below 80 dB(A) while additional layers of sound insulation can bring this down to as low as 70 dB(A).

Combustors can be fitted and exchanged based on fuel requirements and all of the combustor types are interchangeable. For example, the OP16-3B is a pre-mix dry low NOx combustor capable of handling gaseous fuels between 30-52 MJ/kg.

Stuttaford notes: "The project is

expected to demonstrate the ability to use an atmospheric rig that can do 0 to 100% hydrogen and do that flexibly in 2020. The second phase is the potential engine demonstration on a small engine and high pressure testing. The phase after that would be testing in a frame machine as we get to 2023."

Pre-commercial or full serial roll out is anticipated several years later. "That depends a little bit on what size machine you're looking at. For the large frame machine we want to demonstrate commercial operation in 2023," says Stuttaford.

He continues: "We have in place the subsidy agreement and the partnership and that's a signed agreement and potentially covers all phases all the way up to engine demonstration. Right now we've got to focus on phase one and the success criteria to consider phase two. We have got to get through these hurdles to be able to justify going forward to the next steps. Investment certainly grows in the next phases. Engine demonstrators are multi-million euro projects. To justify those kind of expenditures we need to have some proof that this is all going to work."

Nonetheless, together with contributions from the various partners, the half million euro subsidy is sufficient to execute the initial phases of the programme. As Stuttaford says: "It's quite enough to do phase one; selecting a small machine for the demonstration keeps the cost down. Also, the partners are typically bringing something of their own to the project. For example, we're going to use the test facilities at OPRA to do the atmospheric demonstration. We're bringing a lot of in-kind engineering at cost to the project. Financially, the investment is about 50:50 so we get about half from the subsidy and then half from the partnership and all partners are contributing with engineering hours, sometimes with cash."

Delft University of Technology, for instance, is providing advanced theoretical, computational and experimental experience in support of advanced high hydrogen combustion development.

Costing storage with hydrogen

In terms of the cost of its solution, Ansaldo says it is aiming to match other kinds of storage technologies, such as lithium ion batteries, redox flow batteries or compressed air for example. But there is another considerable advantage associated with the hydrogen conversion solution.

"When you look at the cost of any kind of new power plant it's significant. Without the further heavy investment of a new asset, it's possible to take an existing power plant and at a small fraction of the initial capital cost keep it performing to achieve the requirements of the market place which can be carbon free, can be flexible," notes Stuttaford, adding: "Utilizing equipment which can be retrofitted is the differentiator with this particular solution. You're not throwing out your equipment, you're just modifying it."

Figure 4. Wind turbines can be used to produce hydrogen. There is a growing opportunity where excess renewable generation can be harvested and stored and released through the gas turbine during peaks.

Looking forward, like much of the energy sector, Stuttaford suggests the coming years will be characterized by a steadily changing transition period as new fuels and new technologies emerge. He says: "I don't see necessarily that you're going to be running these large 300 MW machines on 100% hydrogen in the near future, the real issue is the fuel and the cost of the hydrogen. But, we do see this opportunity growing where excess renewable generation can be harvested and stored and released through the gas turbine during peaks."

He continues: "I suspect that initially we will be talking about growing proportions of hydrogen offsetting natural gas. So what you need is flexibility. The amount of hydrogen available may vary during the day and we can burn whatever is available and supplement that with natural gas. Hydrogen has got a lot of potential with its energy density, it's all going to come down to cost and how cost effectively can hydrogen be produced. I think that's the big unknown, but if we can start harvesting the green energy and that becomes a significant amount then there could be a tremendous opportunity."

As for the FlameSheet hydrogen project it all comes down to a flexibility upgrade for future energy.

"Hydrogen is one of those key upgrades where you not only get clean energy, but fast starting, fast ramping – making machines more flexible so that they can respond to the market place. Flexibility can produce good revenues in a very challenging market place and there's going to be space for that in this renewable world that we're heading to," says Stuttaford.

He concludes: "That's one of the main advantages of the gas turbine, its tremendous flexibility in operating range and mode. Able to ramp up and down and change load very quickly, gas turbines are able to run cleaner and with zero carbon output if we provide them with the right fuel." ■