

95 years
Lighting Up
Israel for

חברת החשמל
Israel Electric



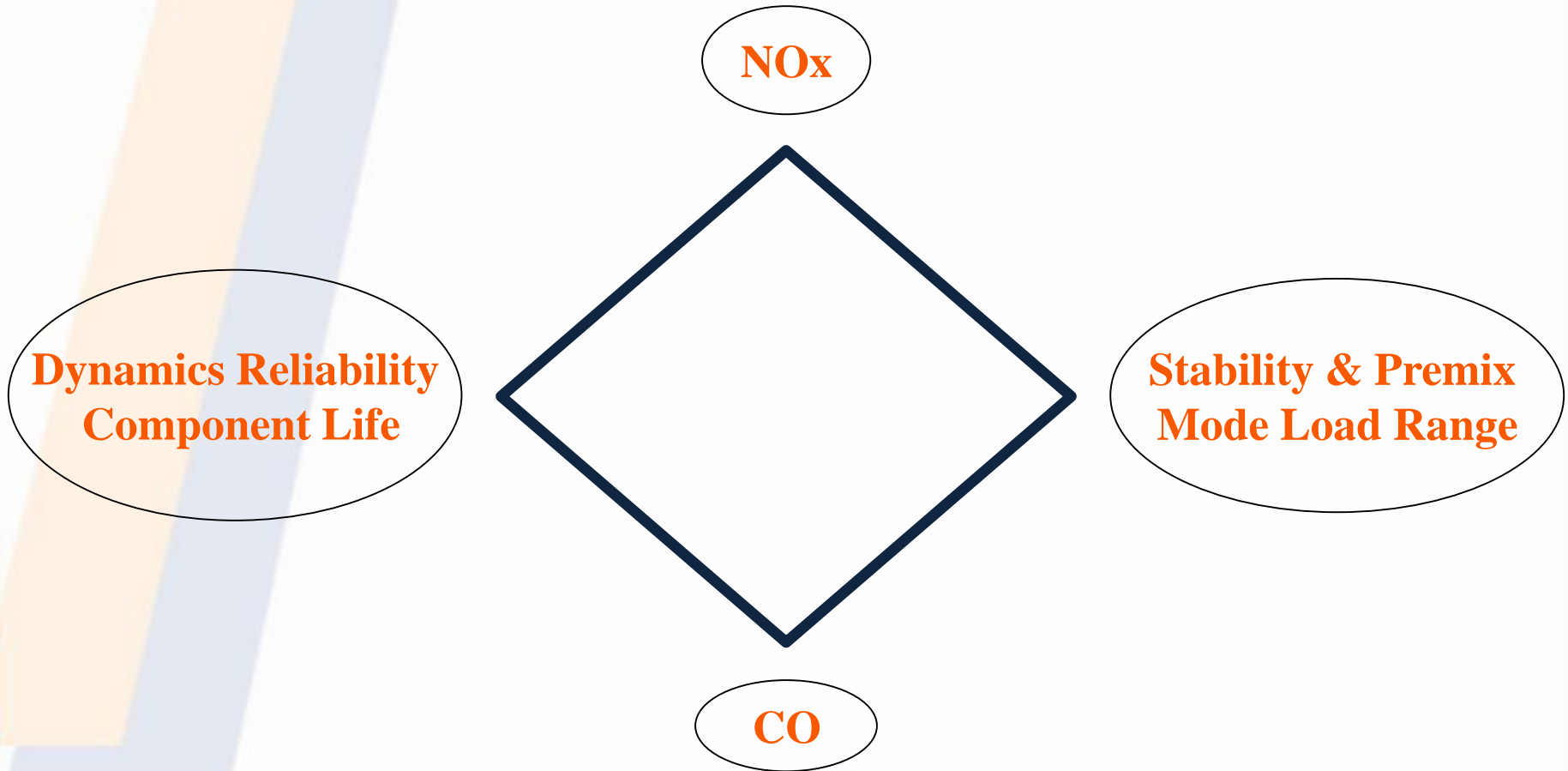
**Extended load
range operation
of GTs as a tool
for controlling
electricity grid
equipped with
renewable energy
suppliers.**

**Boris Chudnovsky
Ilya Chatskiy
Alex Lazebnikov
IEC**

**THE 18th ISRAELI SYMPOSIUM
ON JET ENGINES AND GAS
TURBINES**

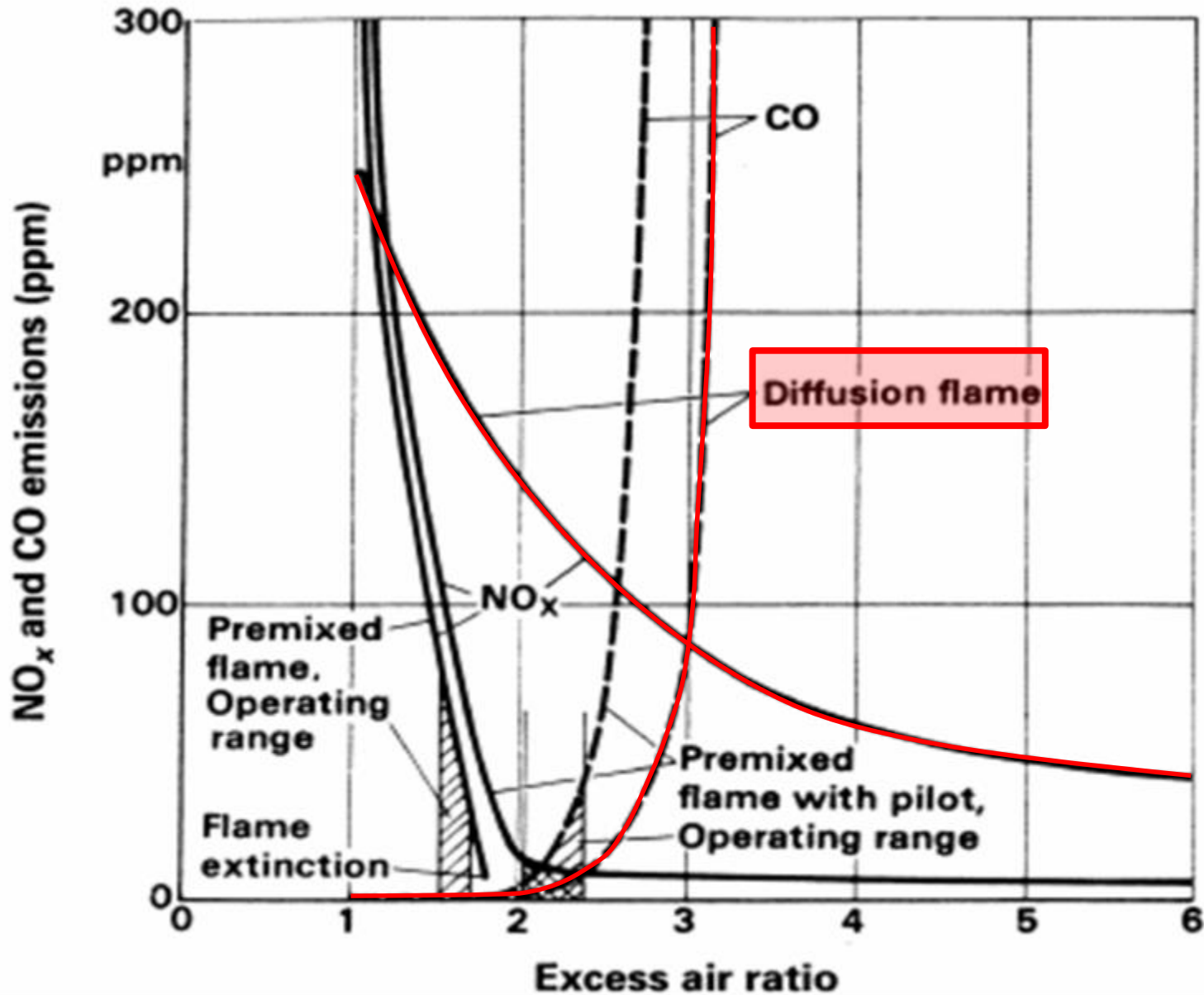
- Traditional methods of NOx reduction in combustion exists:
 - Modification of the firing system to Lean Premixed Combustion (**DLN – Dry Low NOx**)
 - Injection of water into the firing system (**WLN – Wet Low NOx**)
 - Post combustion flue gas treatment to remove NOx (such as SCR systems – **Selective Catalytic Reduction**)

Requirements for stable combustion

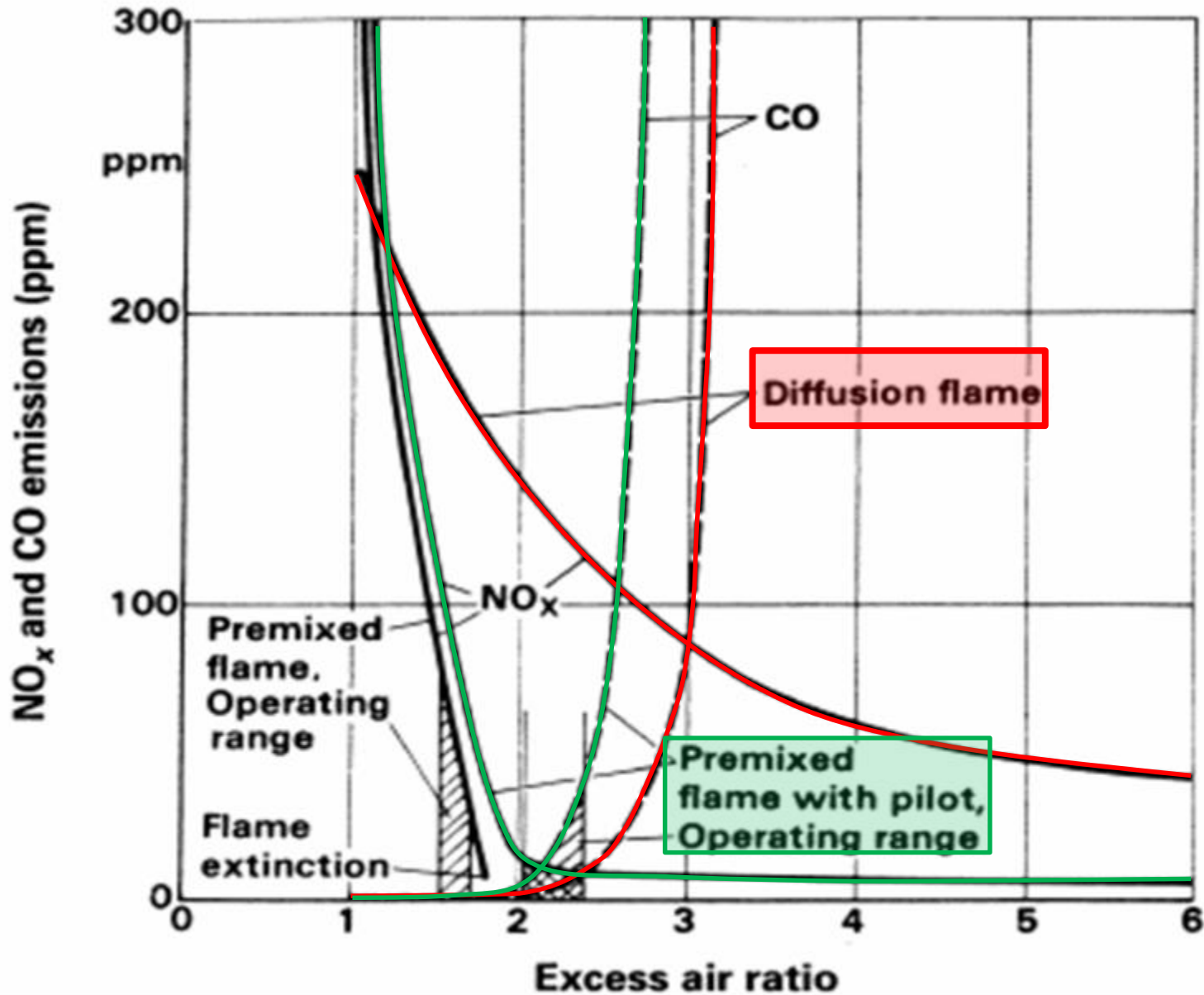


Design Technology – A Four Sided Box

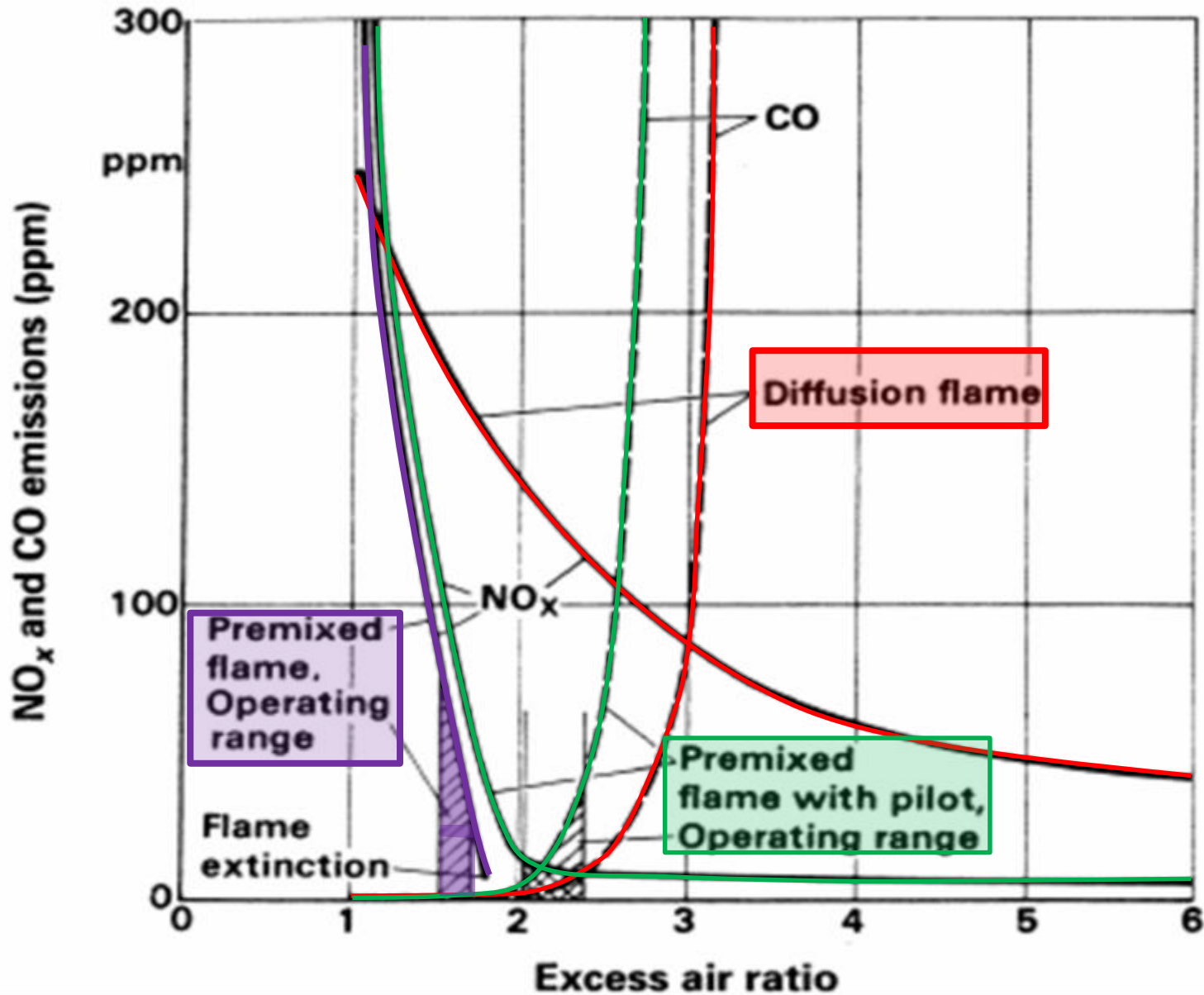
Emission formation in gas turbines



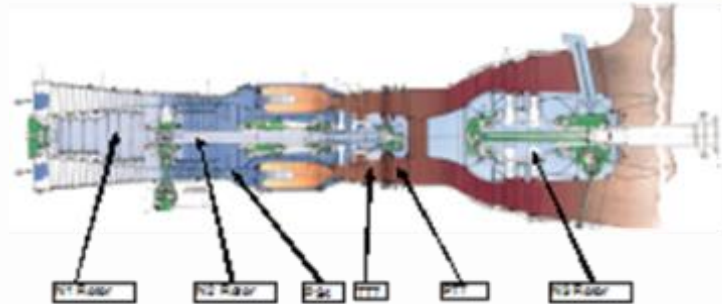
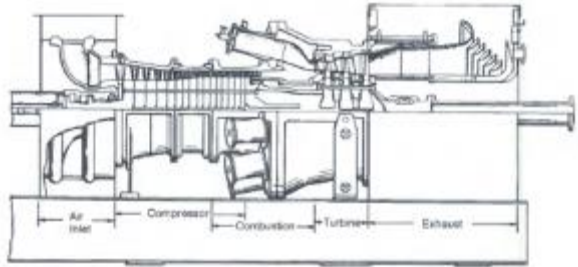
Emission formation in gas turbines



Emission formation in gas turbines



General View



Frame 6 GE GT

50 MW P&W FT4 GT

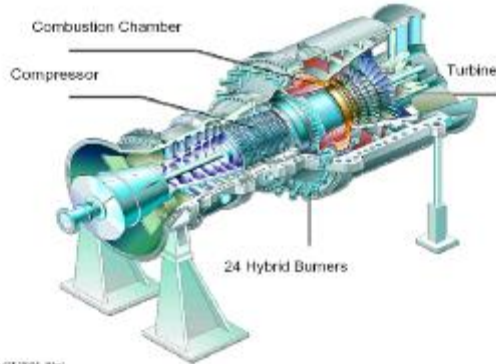
Lean Premixed Combustion Siemens

95 years
Lighting the
World

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SIEMENS

Siemens Vx4.3A Gas Turbine

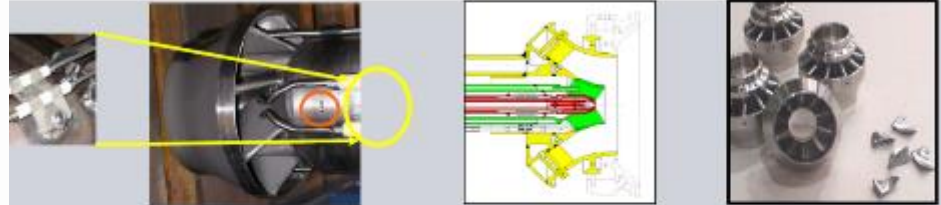
SIEMENS



Case 01 2004, Steil

3

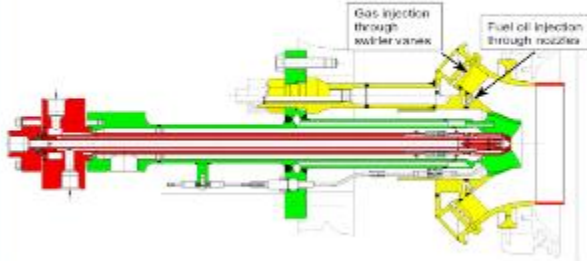
Burner Mod's & Up's Overview "2 SB" / "reduced swirl" / "PMP"



Burner	2-Stage Burner (2 SB)	Reduced Swirl Burner (RSB)	Premixed Pilot Burner (PMP)
Measures & Scope	<ul style="list-style-type: none"> New burner support De-commissioning of diffusion gas system I&C changes 	<ul style="list-style-type: none"> New diagonal burner swirler I&C changes 	<ul style="list-style-type: none"> New burner support & red. diagonal swirler De-commissioning of diffusion gas system I&C changes
Benefits	<ul style="list-style-type: none"> Start reliability increase Premix operation over full load range 	<ul style="list-style-type: none"> Combustion stability increase Power & efficiency increase with FTI Enables FGPH operation 	<ul style="list-style-type: none"> NOx reduction down to 15 ppm* Premix operation over full load range Start reliability increase

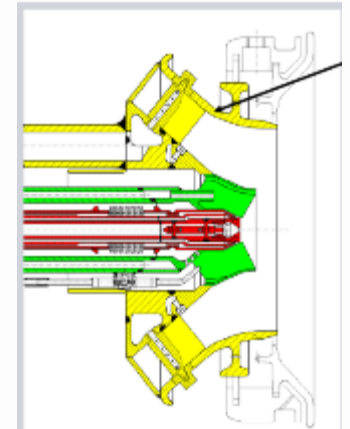
HR3 Burner

SIEMENS



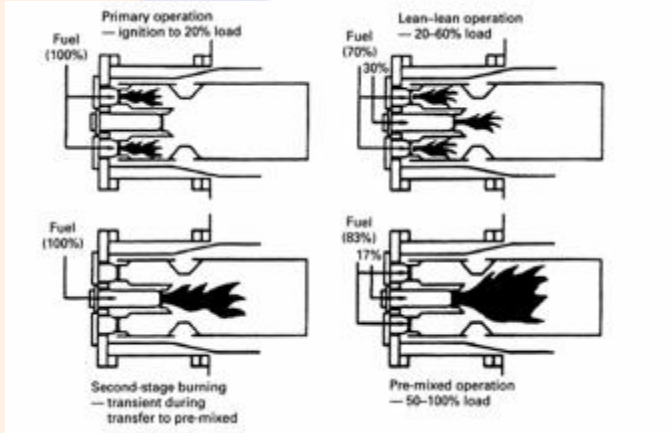
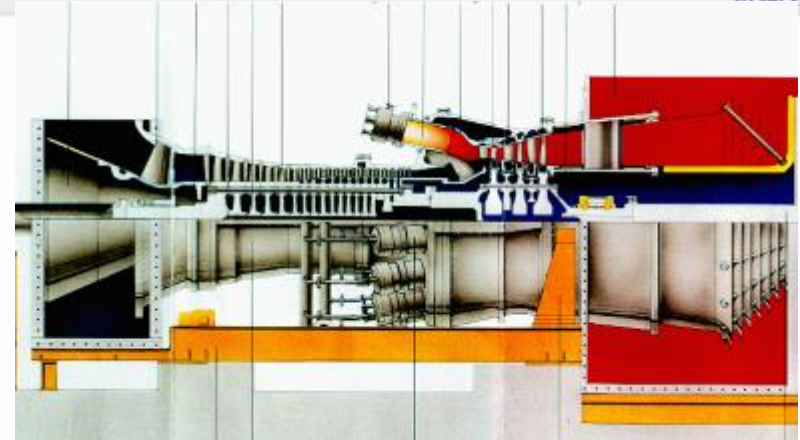
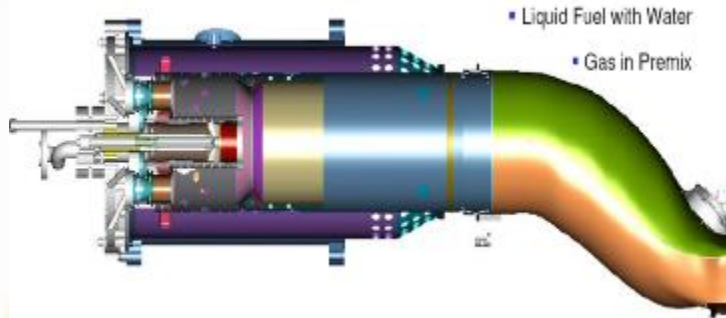
Upgraded firing system

Burner Upgrade Reduced Swirl Burner (RSB)



Siemens GT and Burner General view

Lean Premixed Combustion GE



DLN2.0+

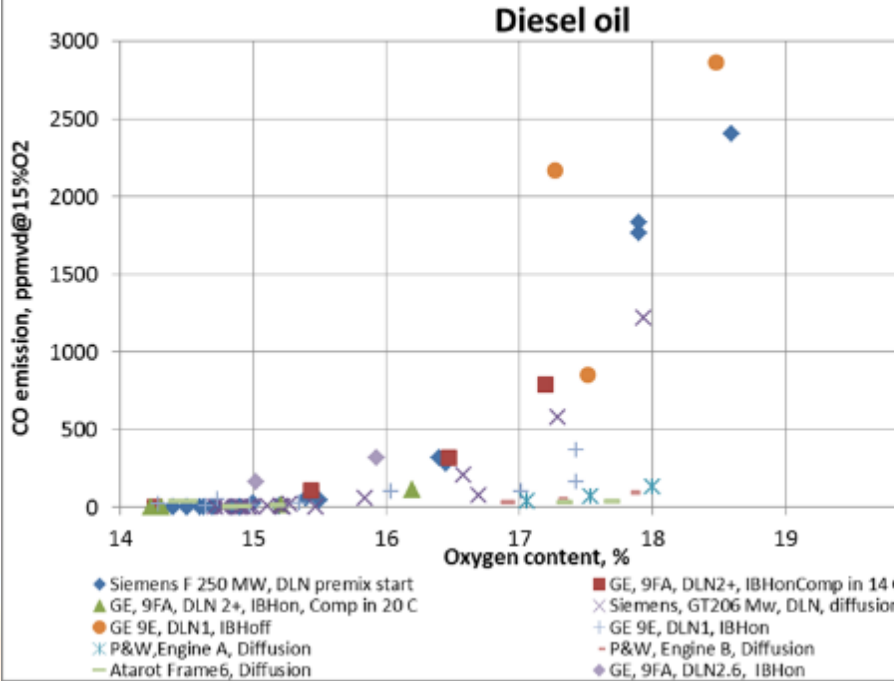
DLN2.6+

9E DLN1 GT General view

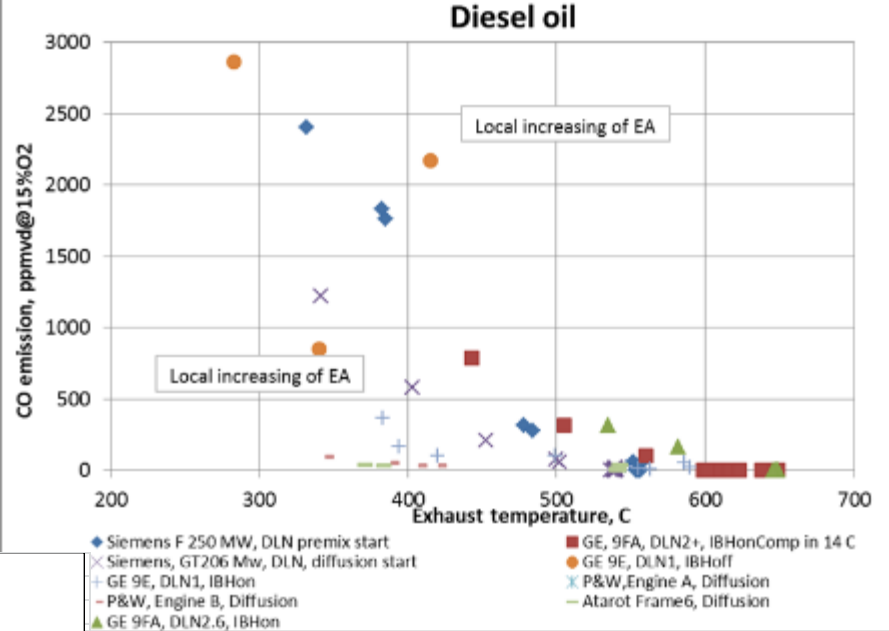
9F DLN2 GT General view

Gas Turbines Emissions

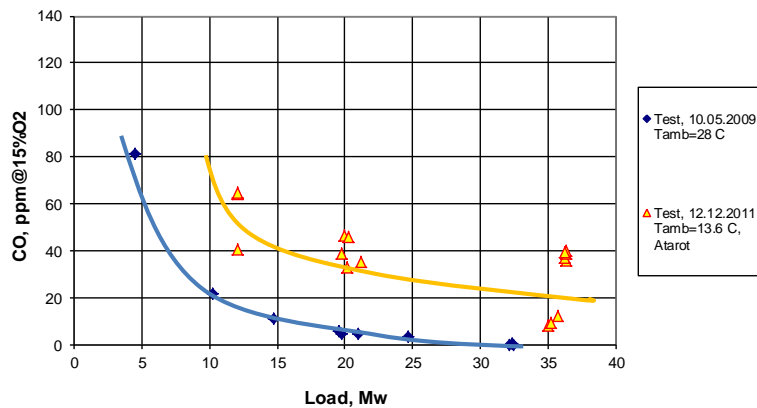
CO emissions as function of exhaust excess oxygen



CO emissions as function of exhaust temperature



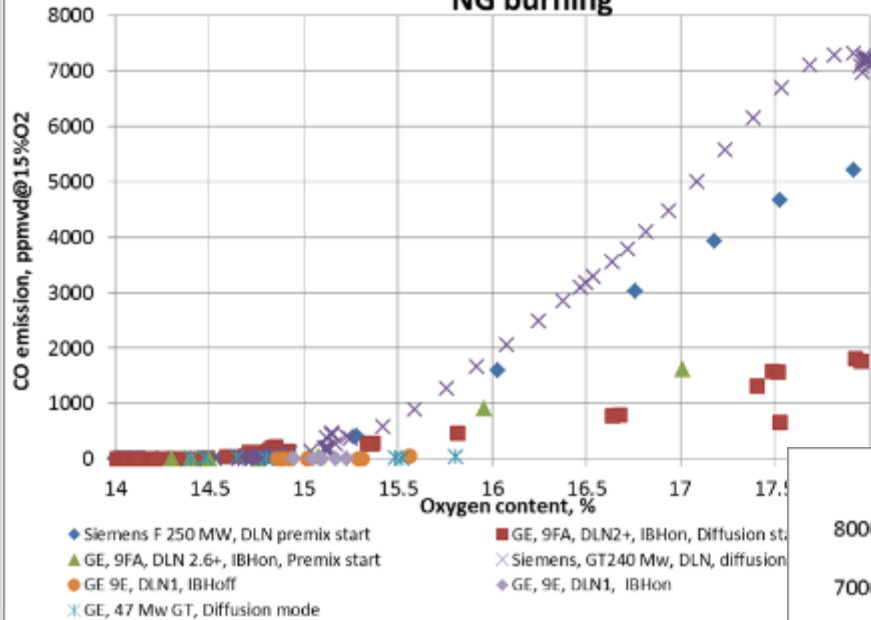
CO emission as function load



Gas Turbines Emissions

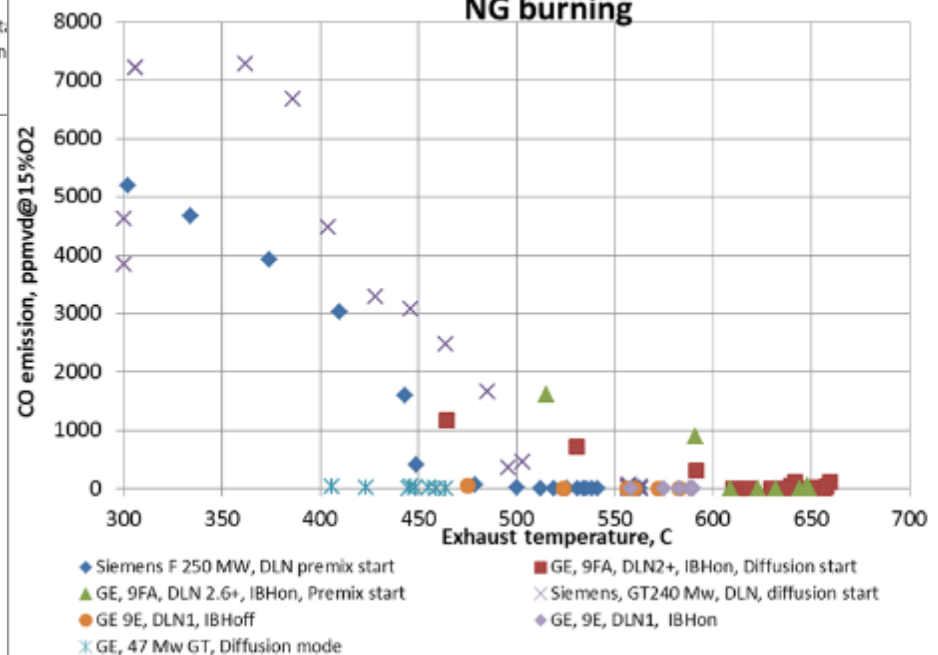
CO emissions as function of exhaust excess oxygen

NG burning



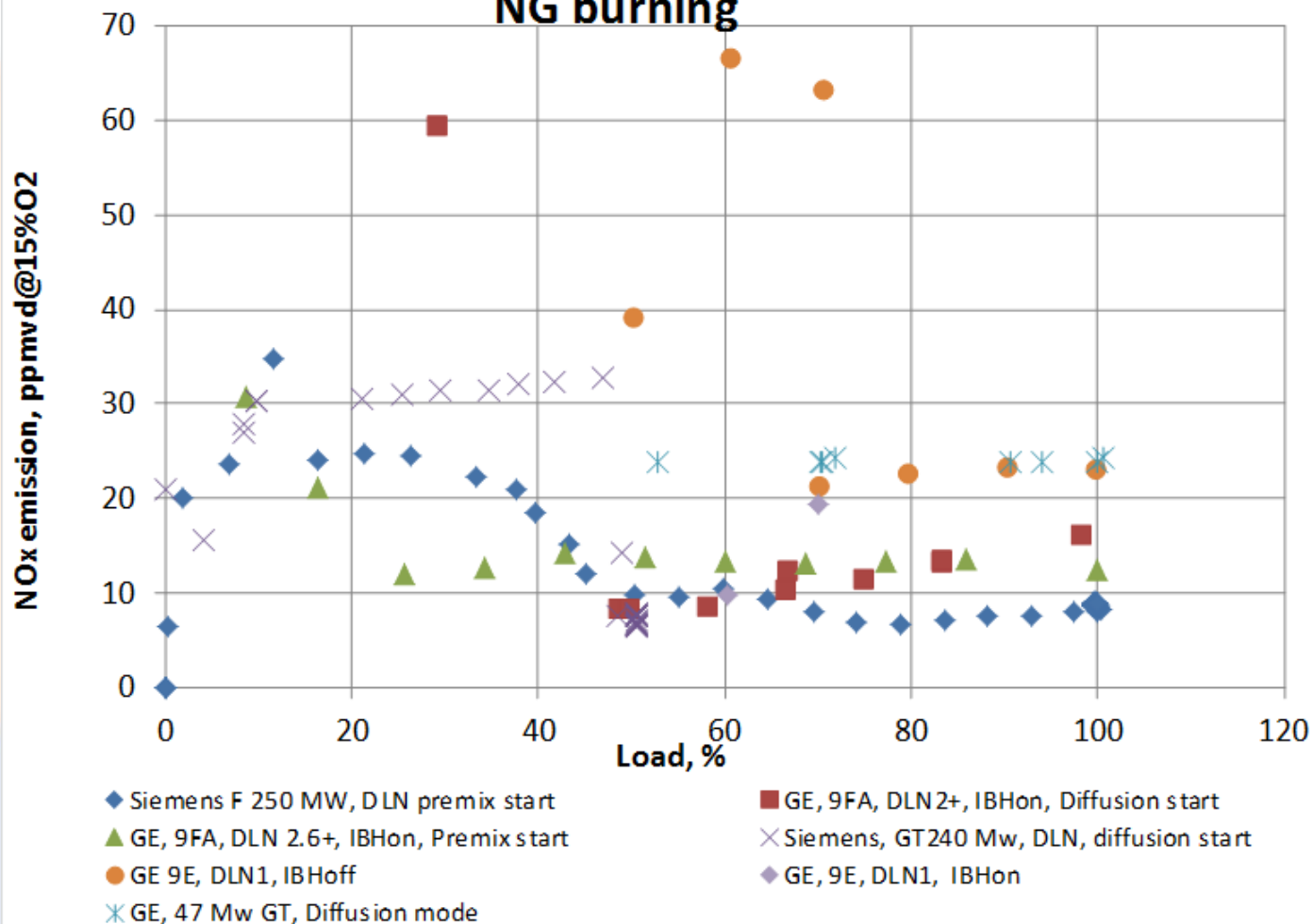
CO emissions as function of exhaust temperature

NG burning



NOx emissions as function of Load

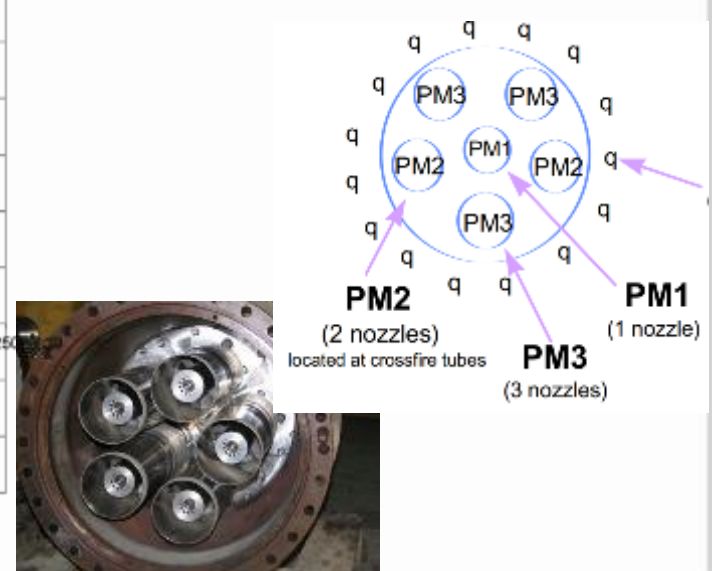
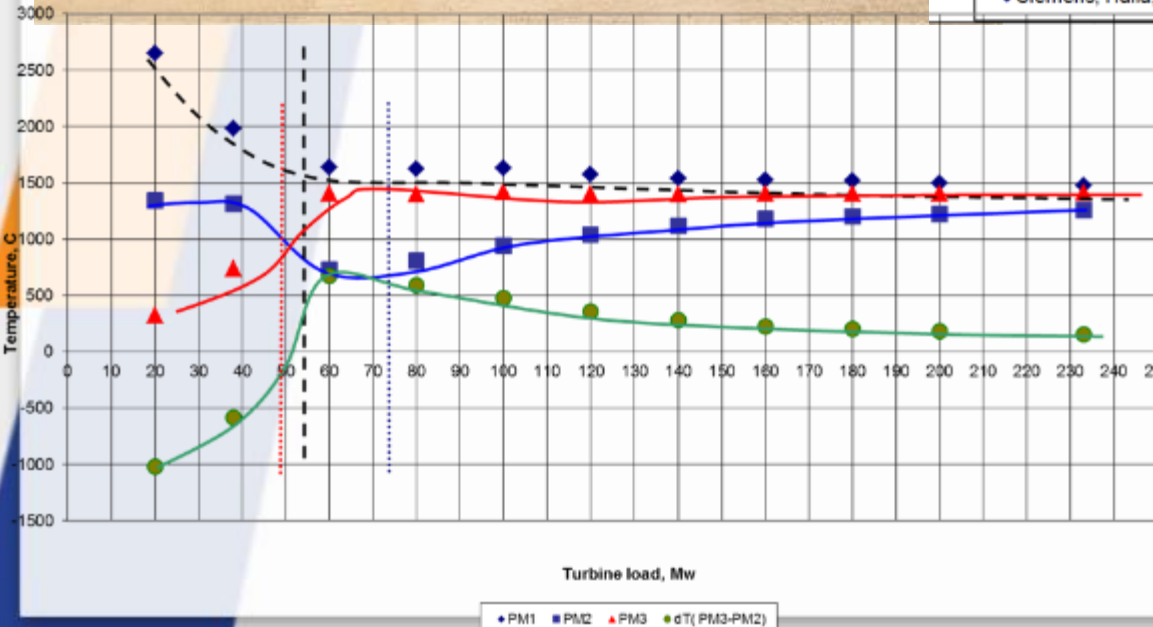
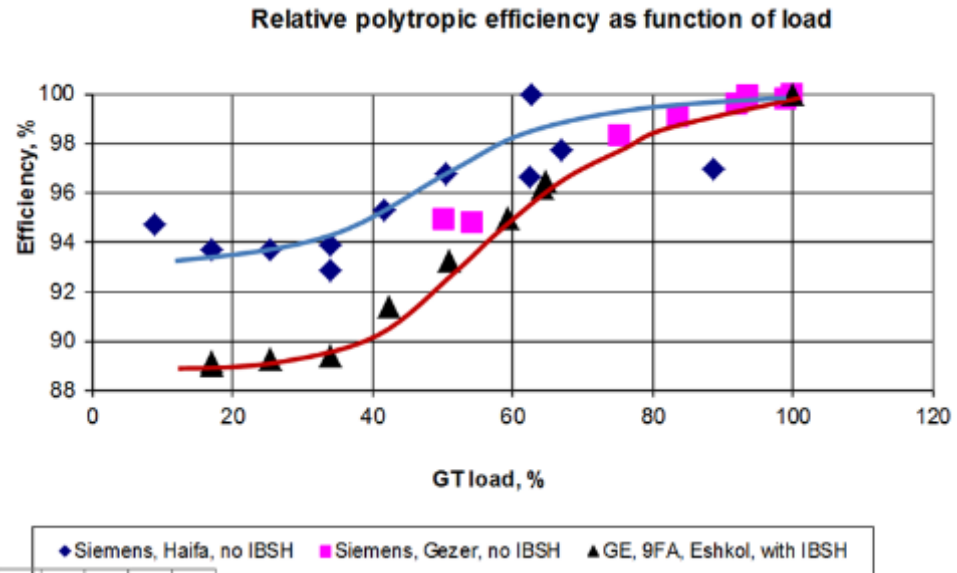
NG burning



Gas Turbines Emissions

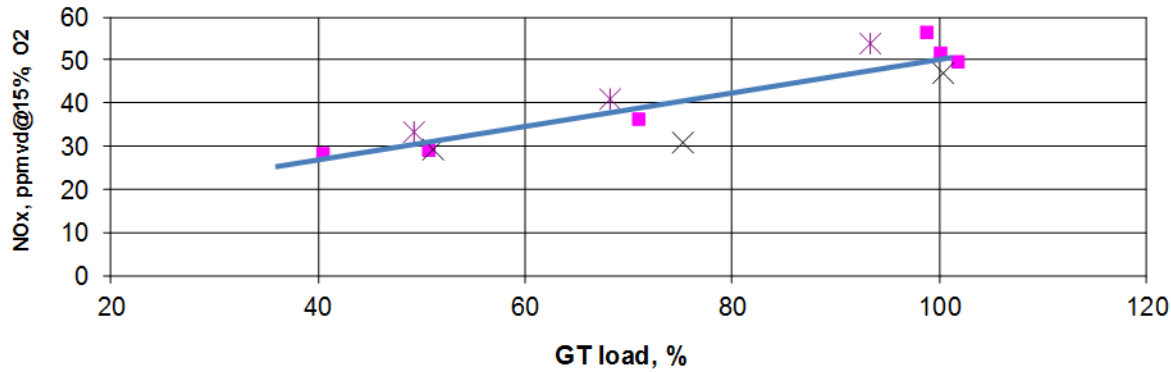


Temperature distribution in burners zone



Gas Turbine Emissions Methanol and LFO Firing

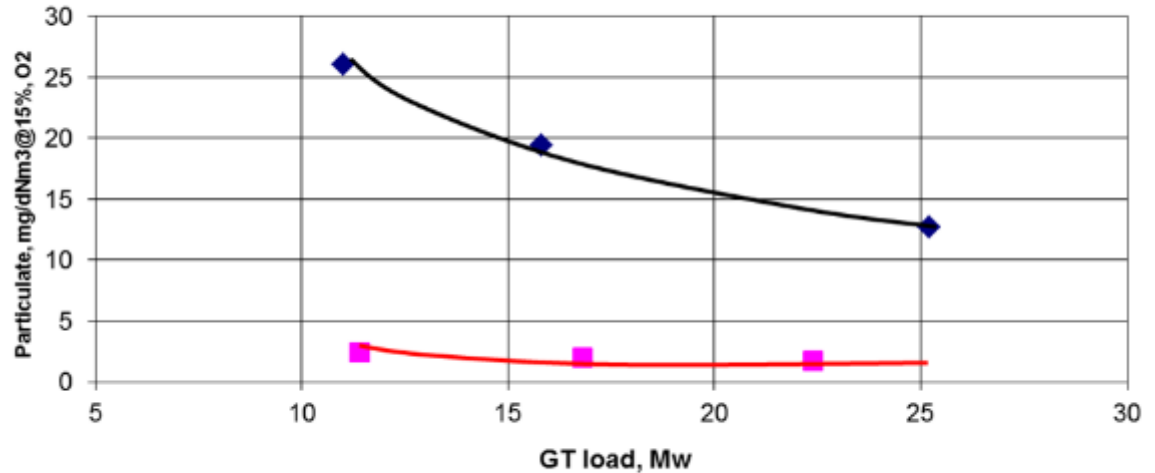
NOx emission as function of GT load
P&W GT, Eilat



■ Methanol, Delavan, High flow, Engine A, 24.03.14

× Methanol, Delavan, High Flow, Engine B, 09.14

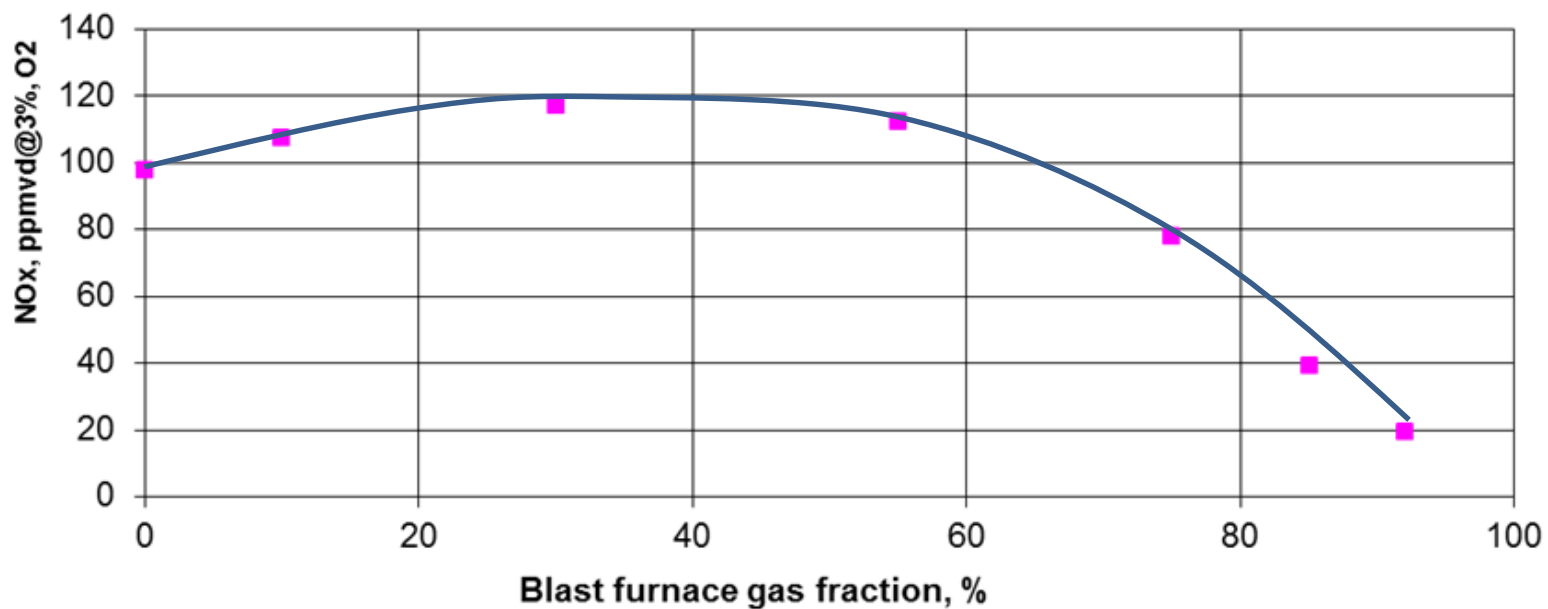
Particulate emission as function of GT load



◆ Oil#2 ■ Methanol

BFG Firing

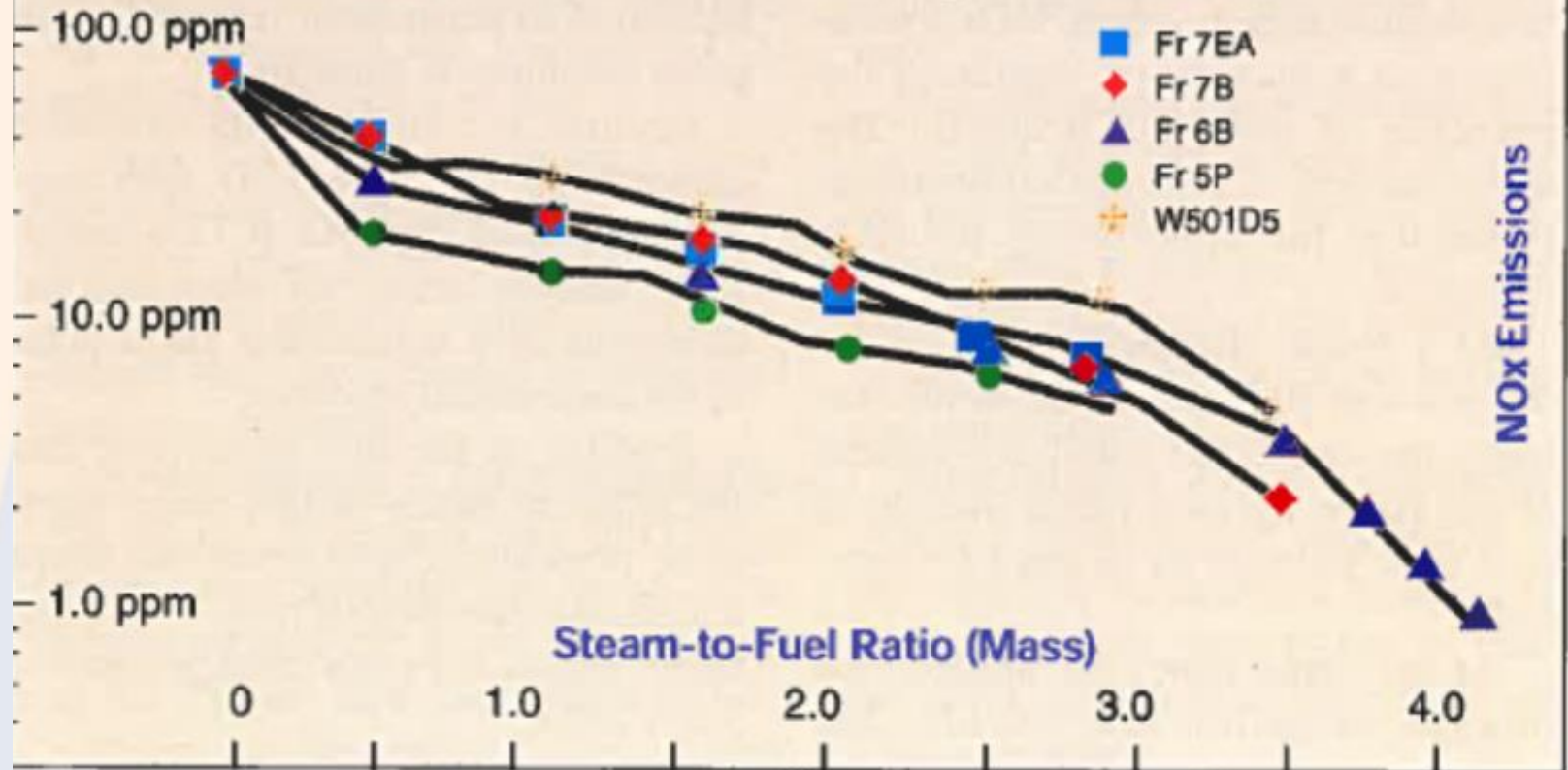
NOx emission as function of blast furnace gas fraction



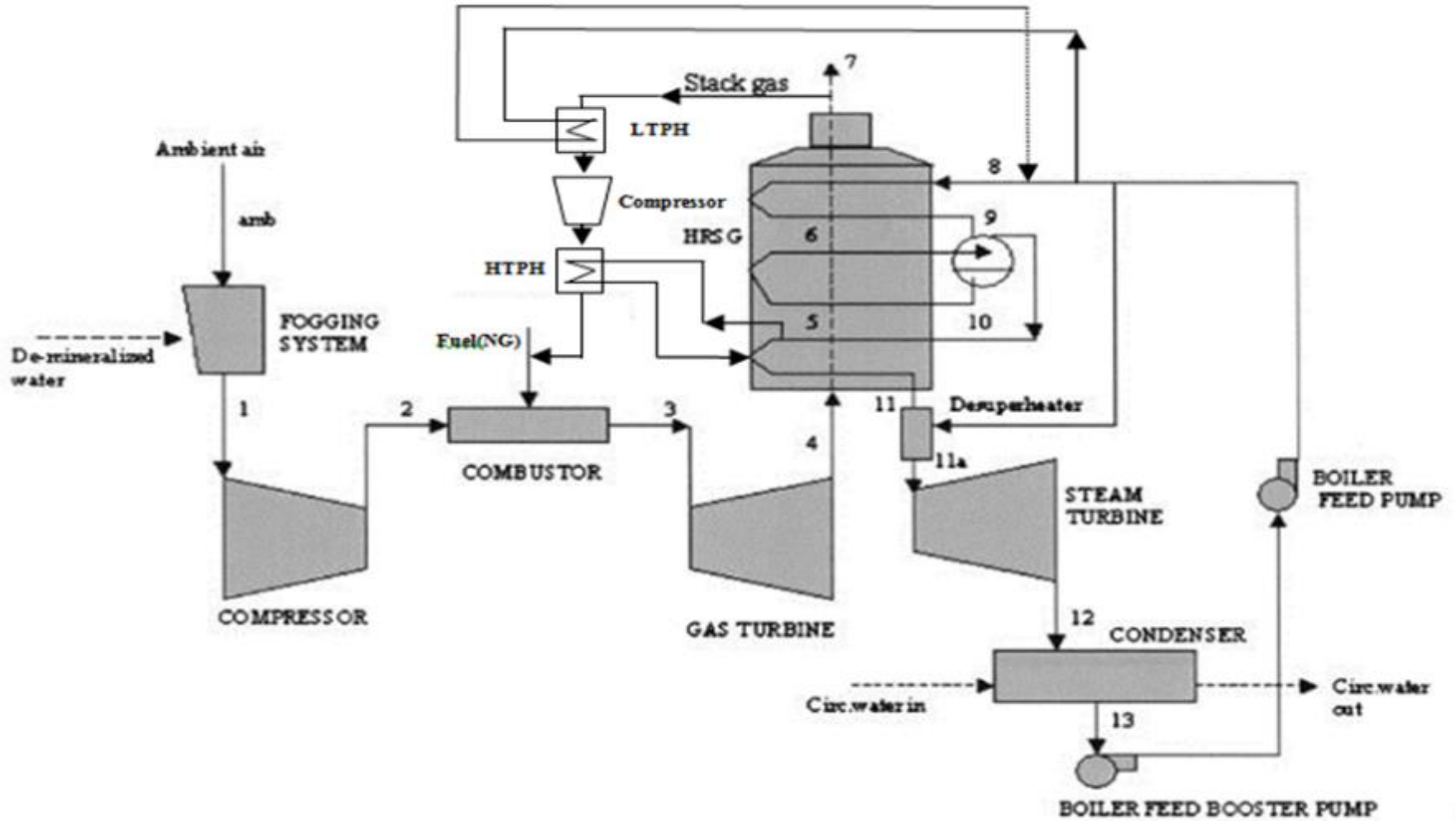
Gas Turbines Emissions Steam Injection

Summary of Test Stand Results

Cheng test stand data at 97.5% homogeneity demonstrate consistent reduction in NO_x with increasing steam-to-fuel ratio for all gas turbines tested.

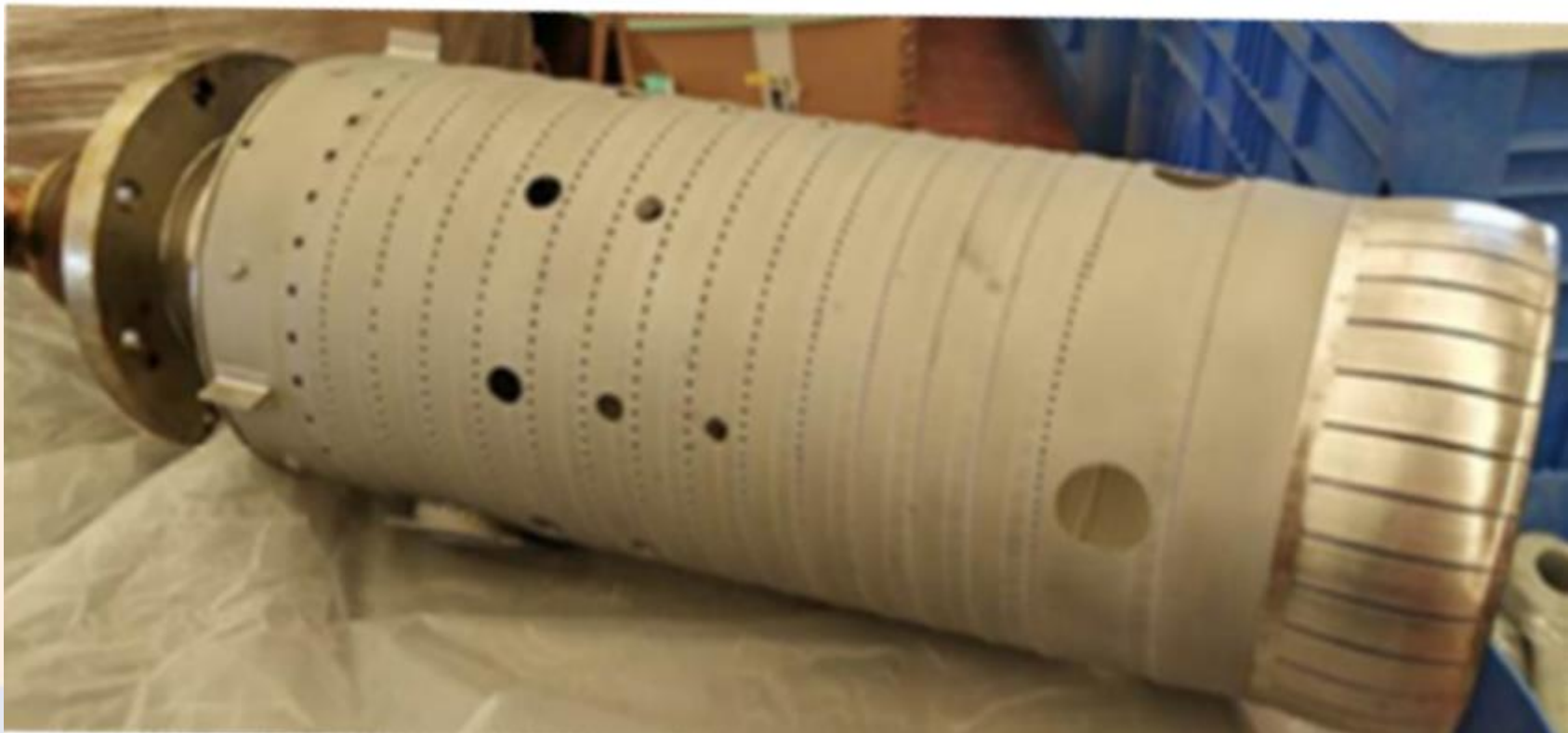


Proposed combined cycle arrangement

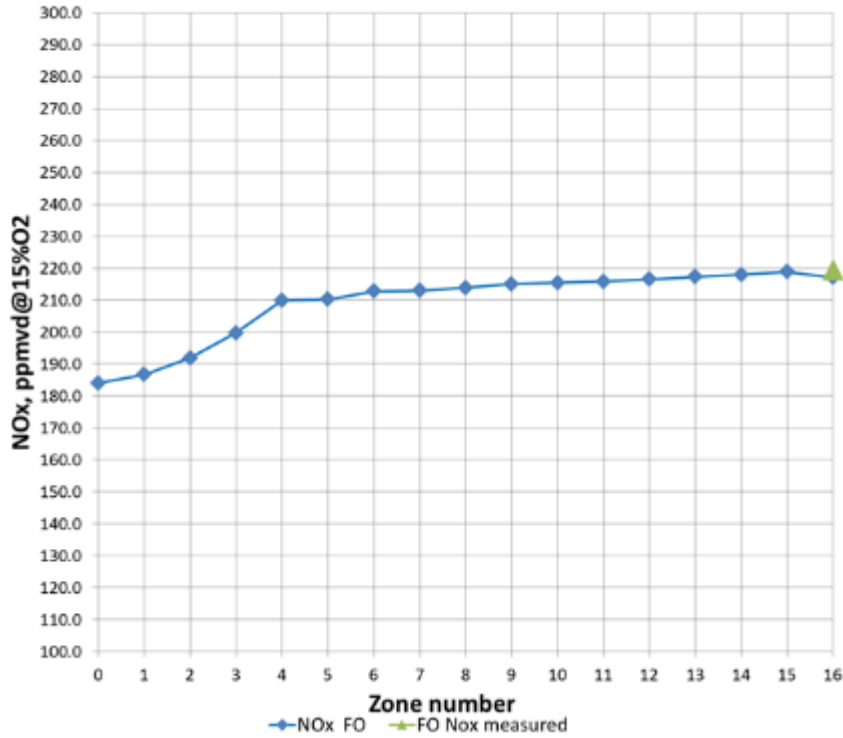


- Step 1 – Thermal balance and heat transfer calculations throughout the length axis of the combustor including (local values of burnout, O₂, Flue Gas temperatures and main flue gas constituents).
- Step 2 – Chemical Kinetics modeling and initial operation and validation to fit measured data Firing LFO/NG.
- Step 3 – Optimizing to reach the best Emissions vs. performance and combustion stability effect.

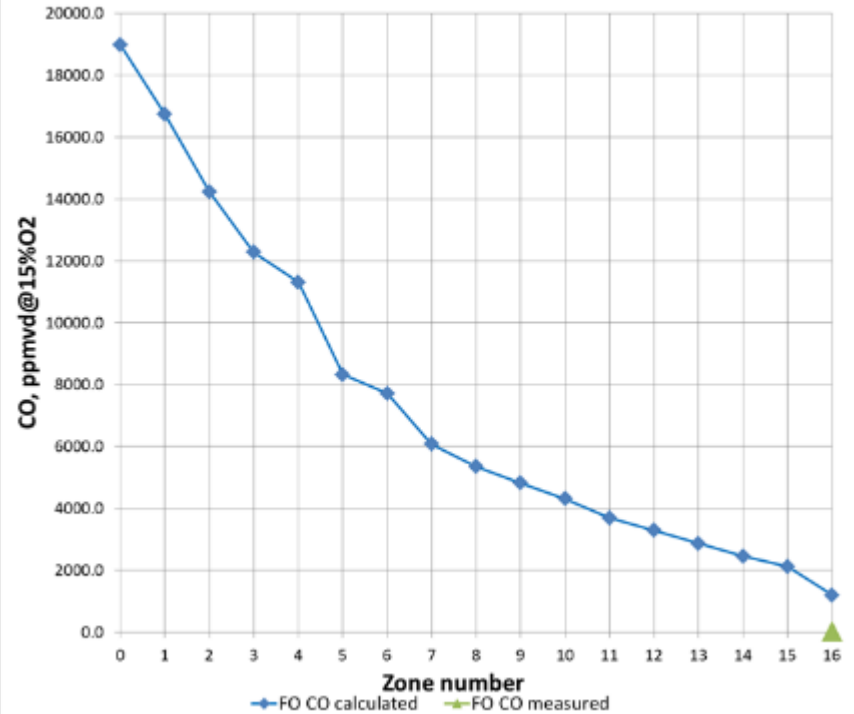
Combustor for simulation validation – GE Frame 6B



NOx distribution through liner length

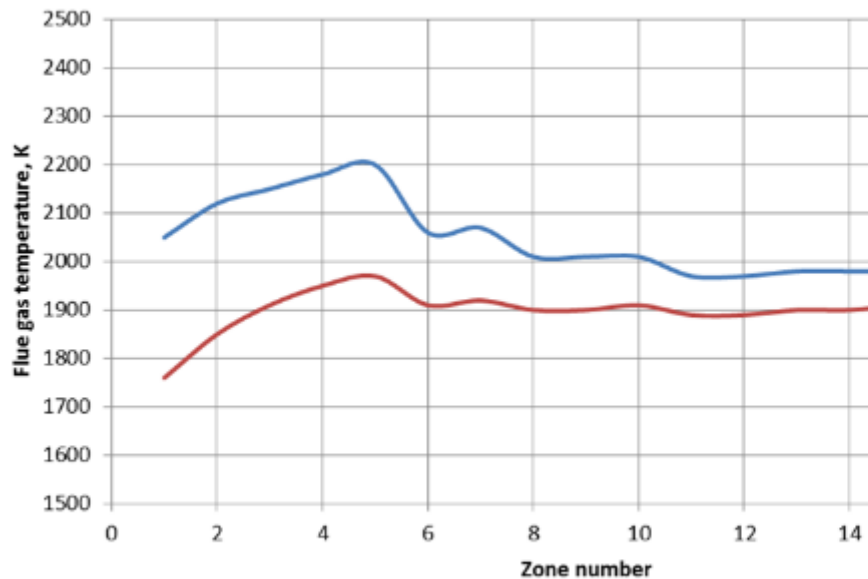


CO distribution through liner length

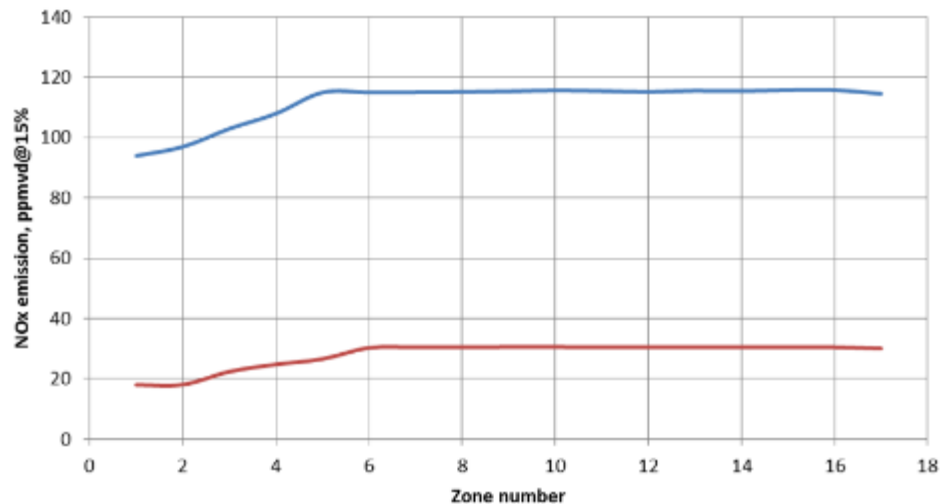


Frame 6 simulations results at base load

Flue gas temperature distribution through GT length

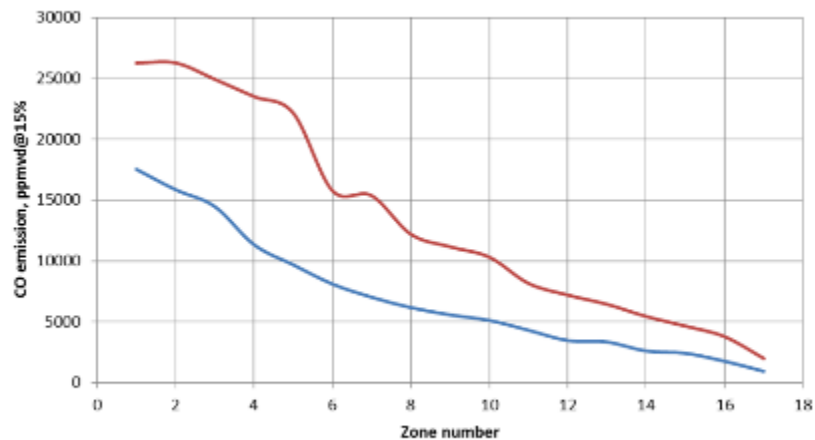


NOx emission distribution through GT length



— NG, Frame 6B, Base load, Diffusion mode — NG+30t/h FGR, Frame 6, Base load, Diffusion mode

CO emission distribution through GT length



— NG, Frame 6B, Base load, Diffusion mode — NG+30t/h FGR, Frame 6, Base load, Diffusion mode

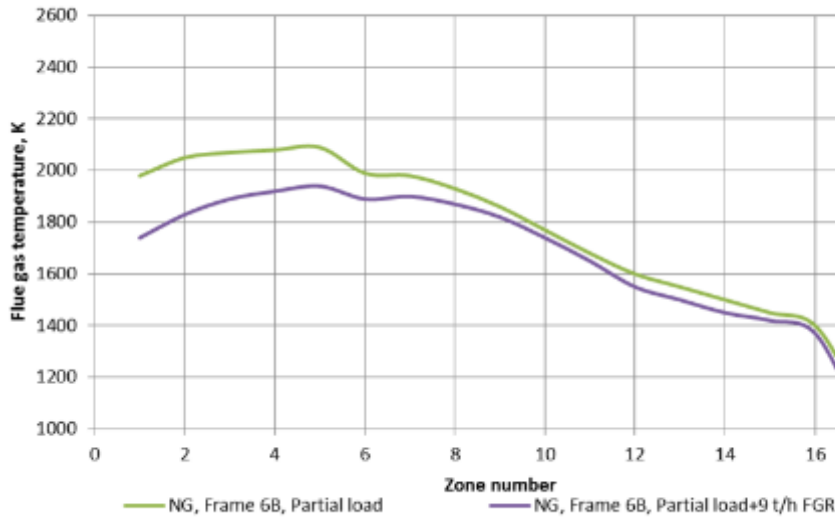
Frame 6 simulations results at part load



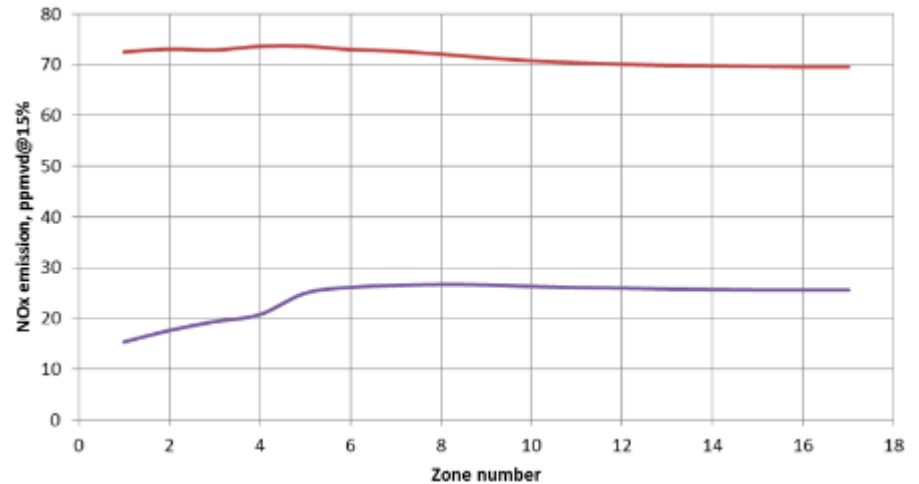
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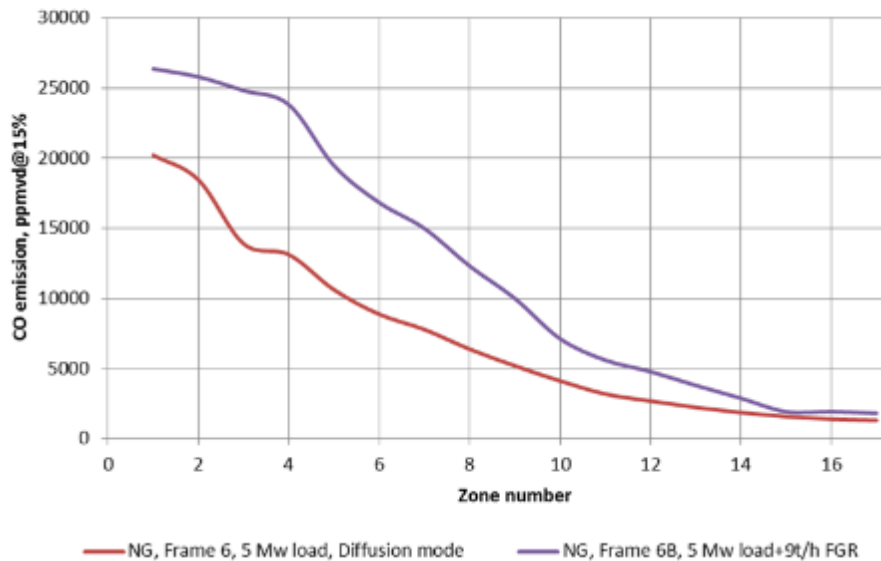
Flue gas temperature distribution through GT length



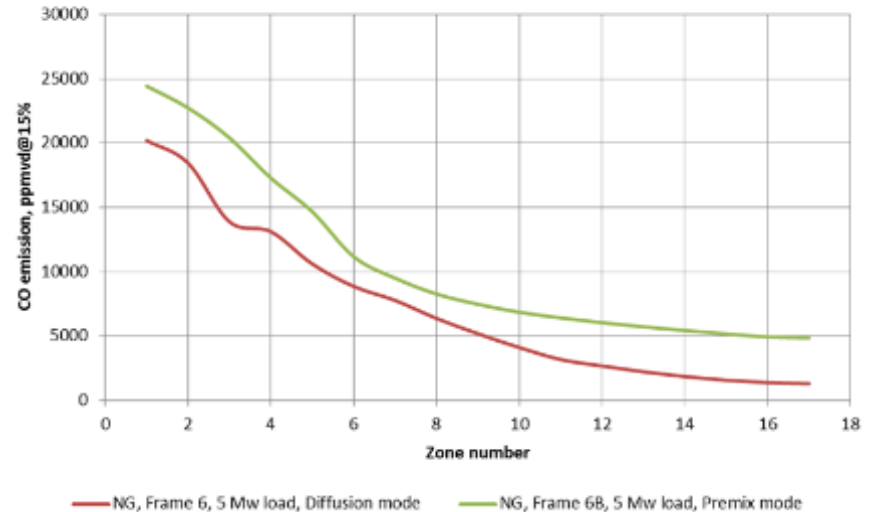
NOx emission distribution through GT length



CO emission distribution through GT length



CO emission distribution through GT length



Large "F" GT simulations results at base load

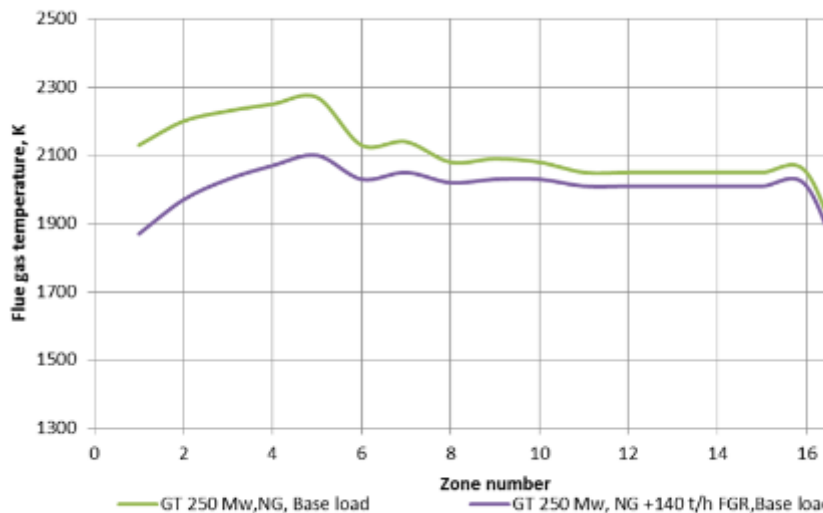


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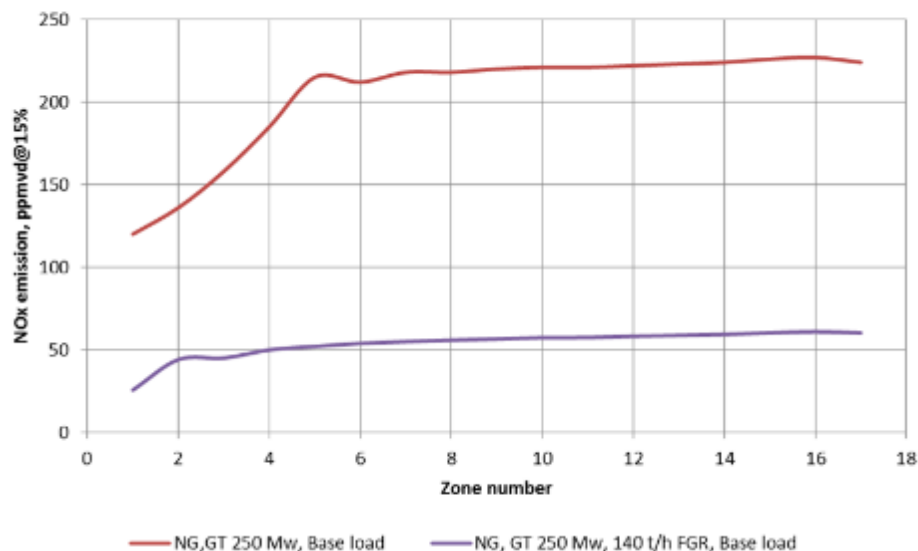


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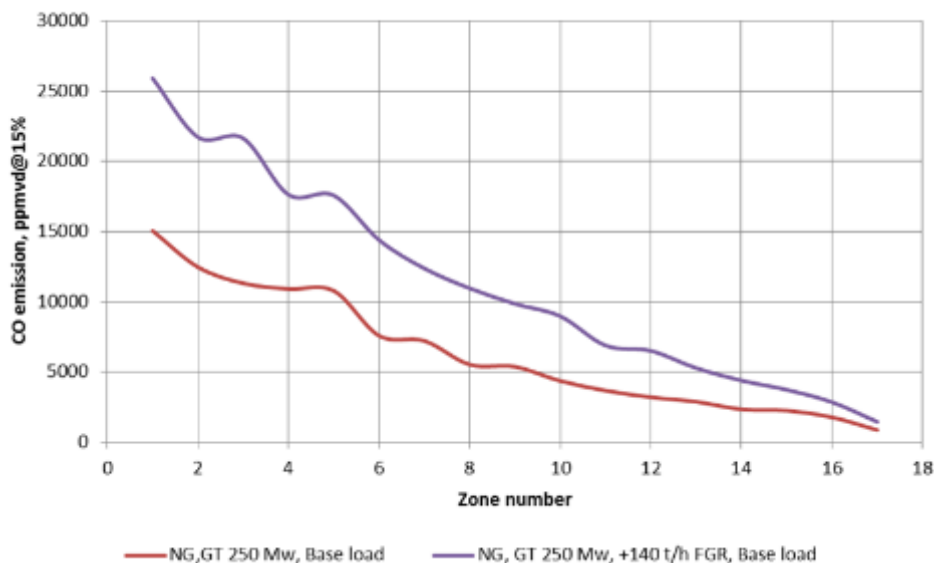
Flue gas temperature distribution through GT length



NOx emission distribution through GT length



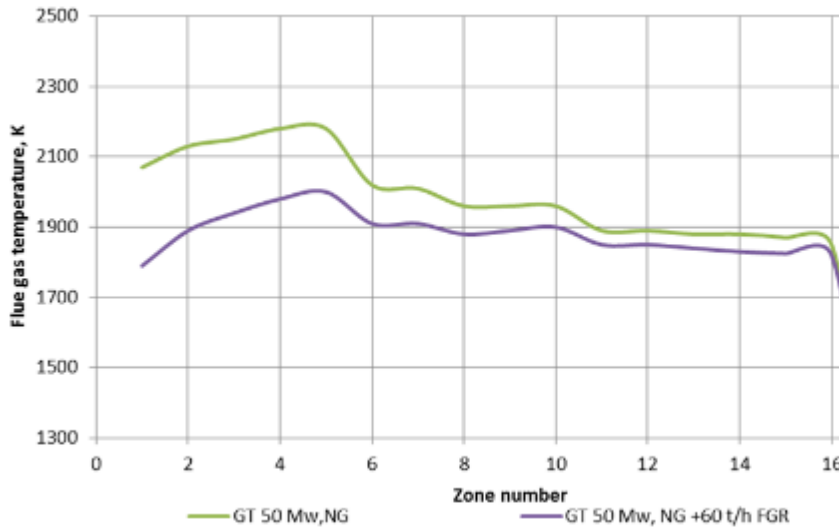
CO emission distribution through GT length



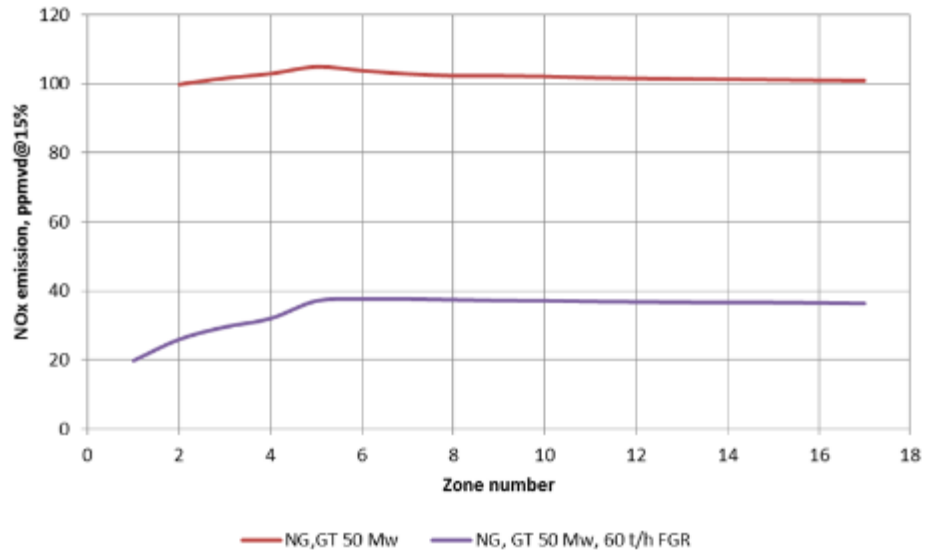
Large "F" GT simulations results at part load



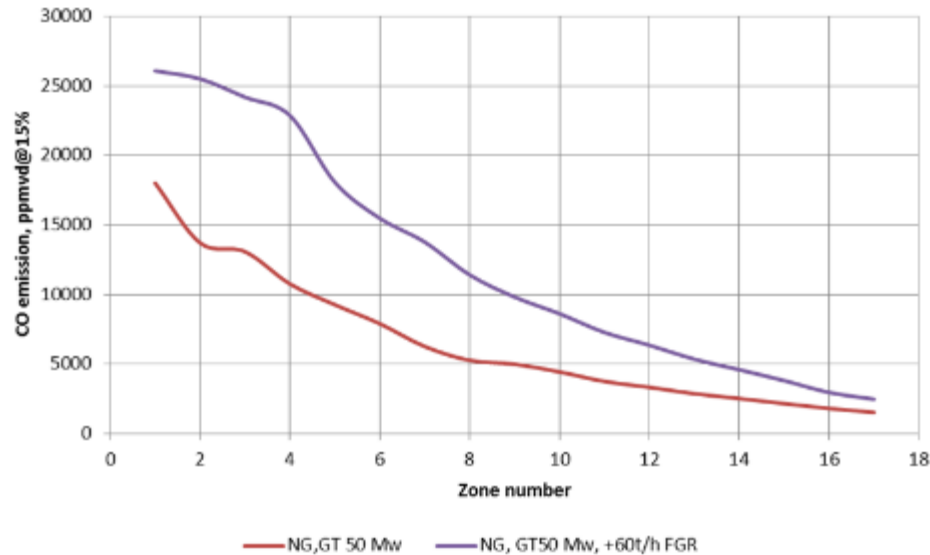
Flue gas temperature distribution through GT length



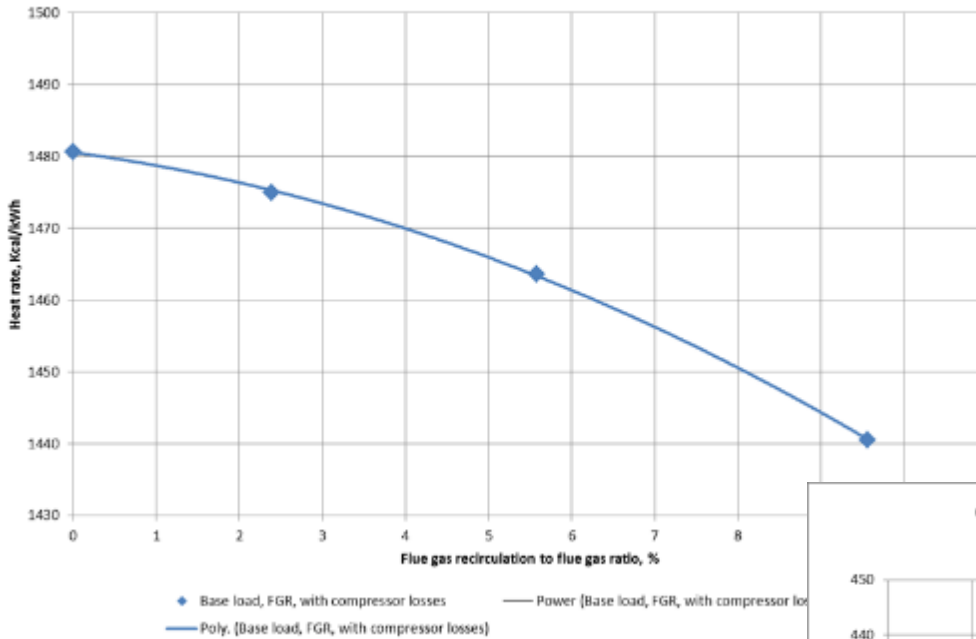
NOx emission distribution through GT length



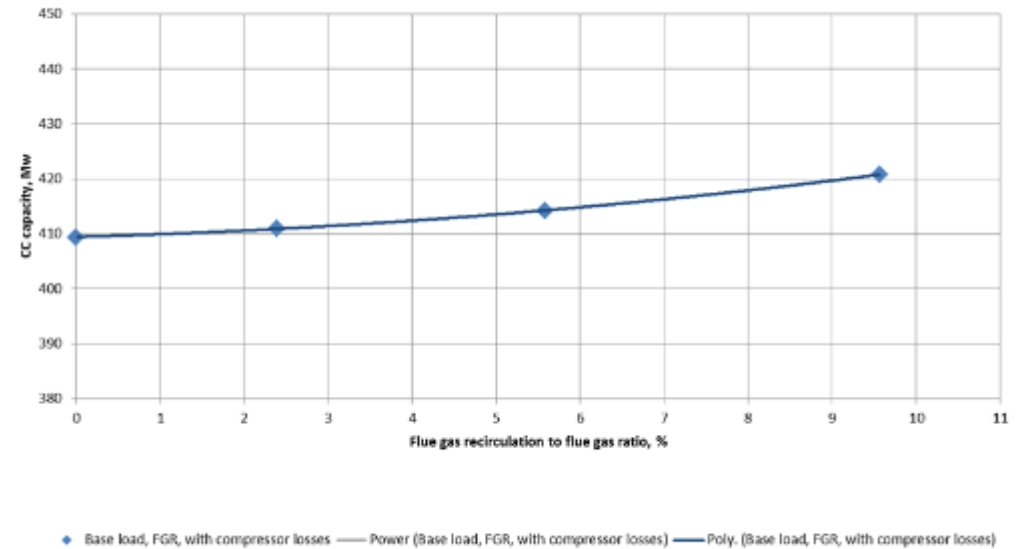
CO emission distribution through GT length



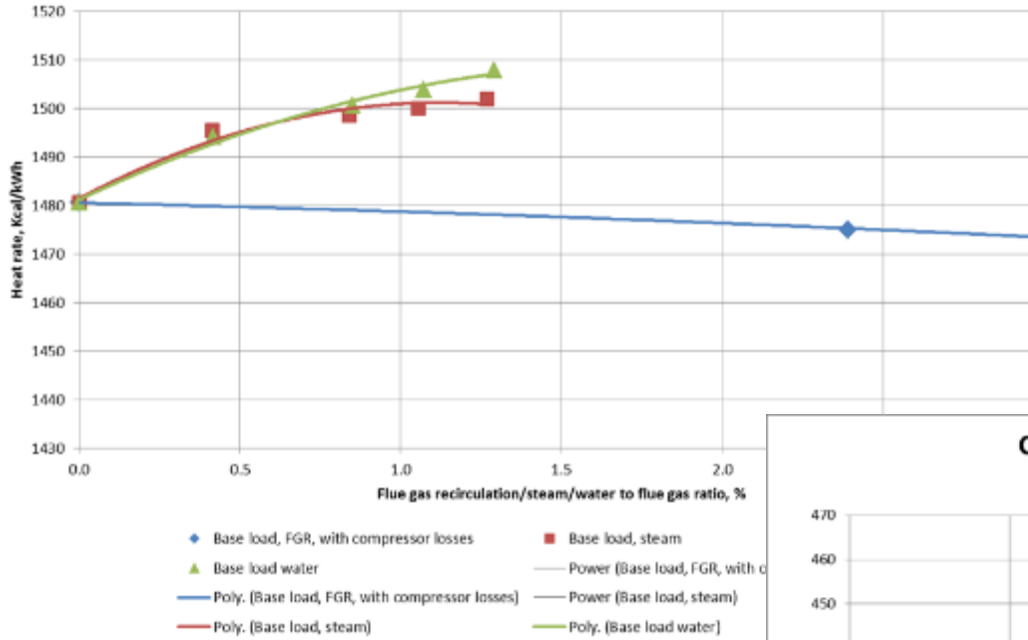
Combined cycle heat rate as function of flue gas recirculation



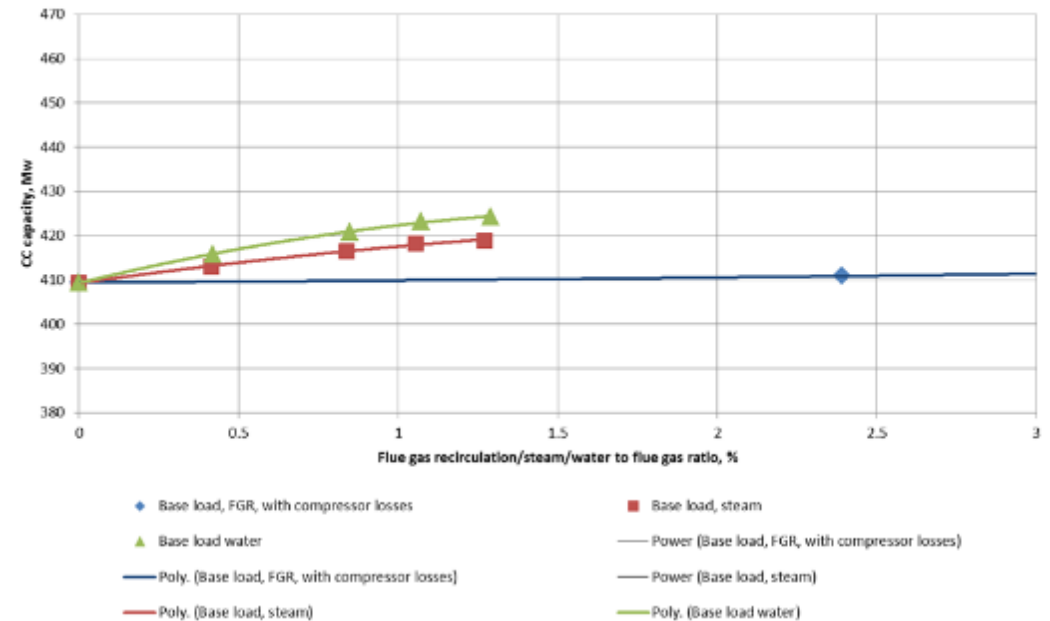
Combined cycle capacity as function of flue gas recirculation



Combined cycle heat rate as function of flue gas recirculation/steam/water ratio



Combined cycle capacity as function of flue gas recirculation/steam/water ratio



Based on the performed simulation it may be concluded that:

FGR mixing with fuel may be a useful tool for extended GT load range operation while keeping minimum emissions.

However, in order to make more accurate conclusion about the proposed technology a laboratory and full scale test are recommended.

Thank you