BREAKTHROUGH COMBUSTION TECHNOLOGY FOR GAS TURBINES

“Novel pressure gain combustion technology for low carbon GT operation: technology description and experimental result”

Session: TC1: Low carbon GT technologies.

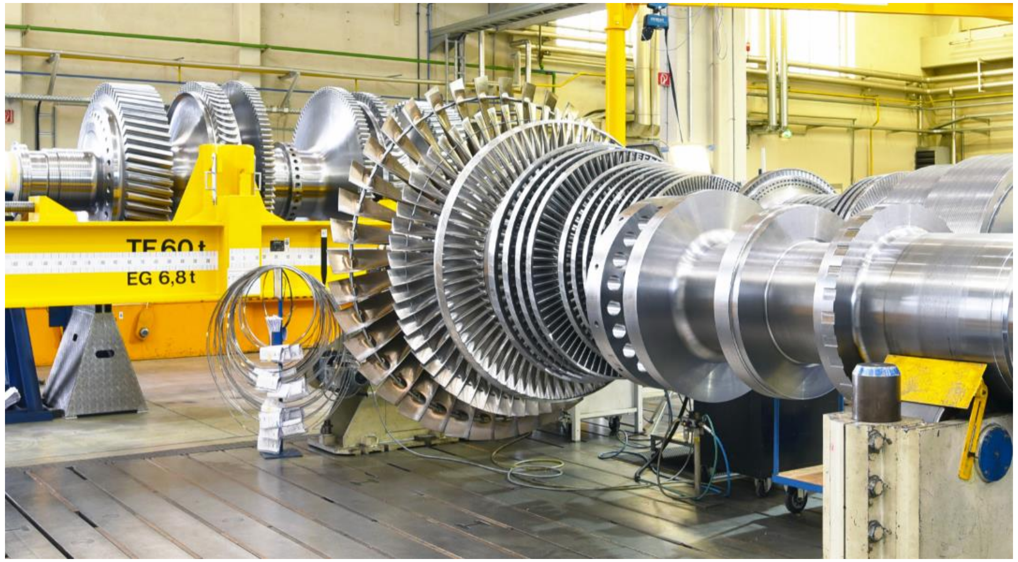
FINNO EXERGY

ETN AGM AGENDA

1. Gas turbine efficiency evolution and further improvement
2. Pressure Gain Combustion overview
3. Finno Exergy’s PGC technology: basic principles
4. Experimental results
5. Technology scalability
6. Potential for efficiency improvement
7. To date achievements and future goals

FINNO EXERGY

THE GAS TURBINE HAS A CENTRAL ROLE IN MODERN SOCIETY

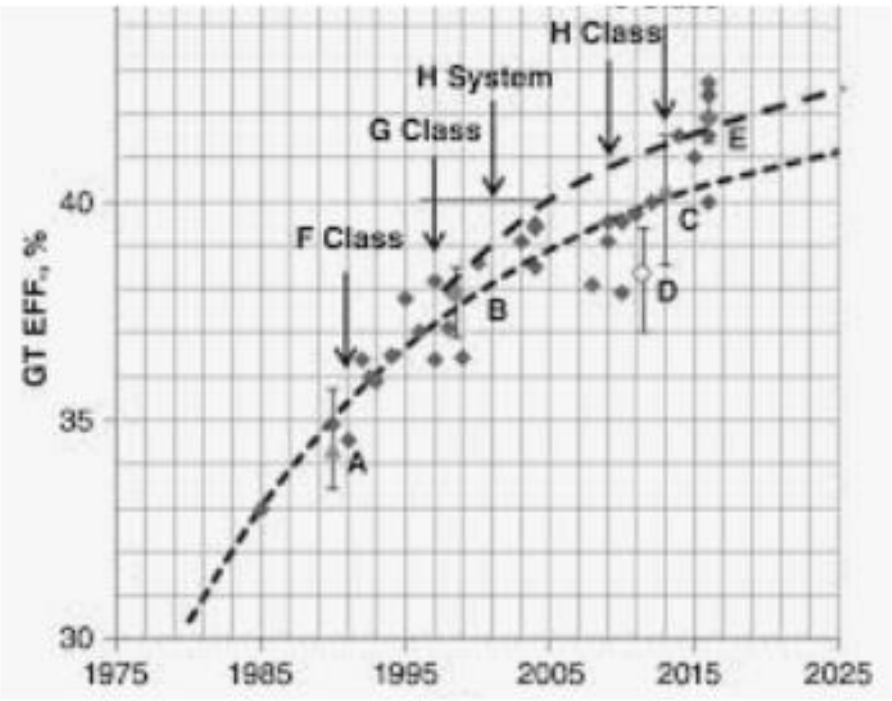


10 % improvement in efficiency would result in CO_2 emissions reduction equivalent to taking **ALL CARS IN EU OFF THE ROAD!**

FINNO EXERGY

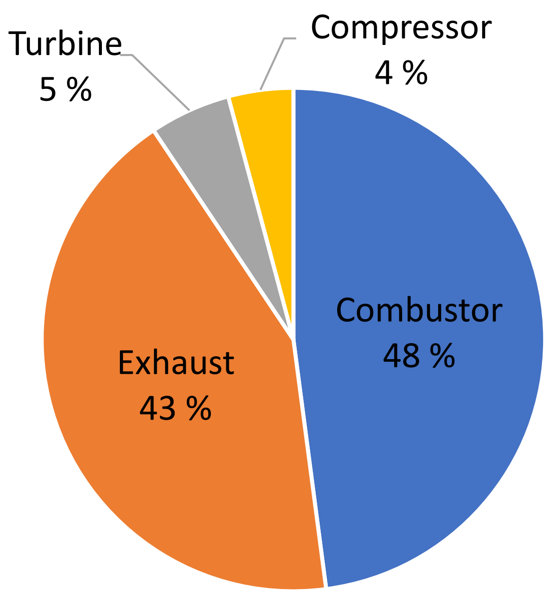
GAS TURBINE EFFICIENCY AND EXERGY DESTRUCTION

Gas turbine efficiency evolution



Source: Gülen, S. Can. 2019. Gas Turbines for Electric Power Generation. Cambridge: Cambridge University Press.

Gas turbine exergy destruction (loss of available energy)



Sources: Elfeituri, I.A., 2017, "Exergy Based Performance Analysis of a Gas Turbine Unit at Various Ambient Conditions", International Journal of Energy and Power Engineering

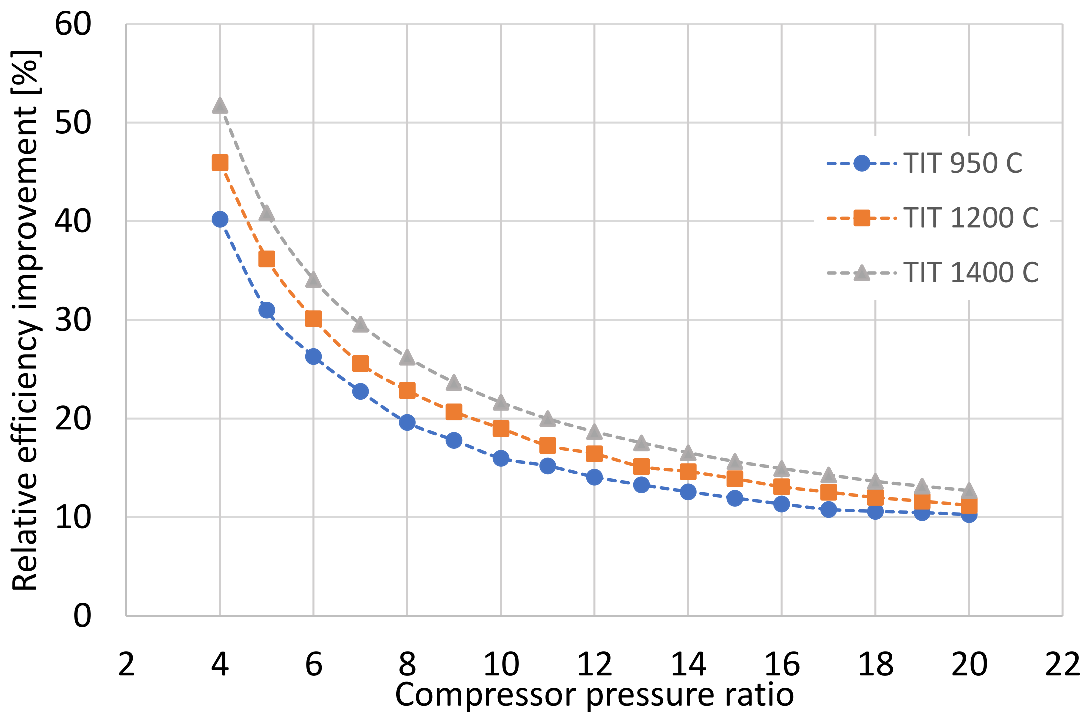
FINNO EXERGY

PRESSURE GAIN COMBUSTION

- Replacing Isobaric Heat Addition with Isochoric Heat Addition **(Pressure Gain Combustion) will greatly reduce entropy**
- From continuous combustion to **periodic combustion.**
- For the same compressor pressure ratio and heat input, **higher turbine inlet pressure**.
- **More power** can be extracted from turbine, for the same amount of fuel burned.

Higher thermal efficiency!

Potential gas turbine efficiency improvement due to PGC*



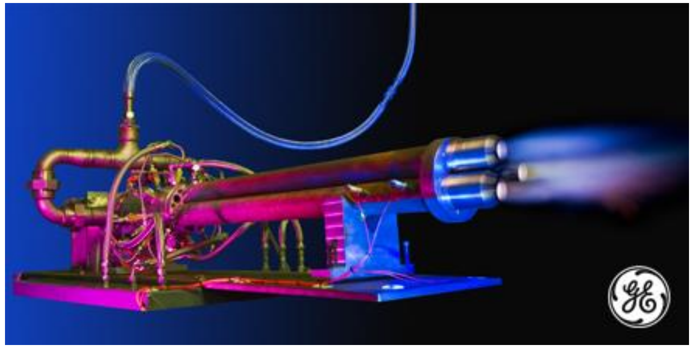
FINNO EXERGY

*Finno Exergy's calculation

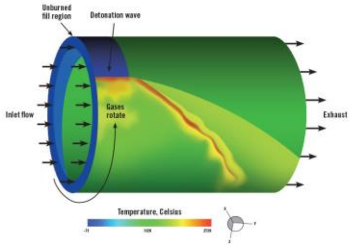
PRESSURE GAIN COMBUSTION

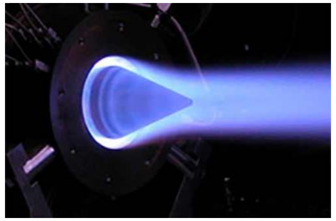
DETONATION

Pulsating detonation engine



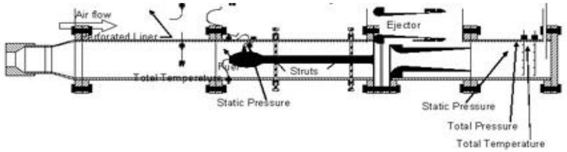
Rotating Detonation Engine



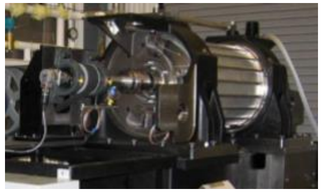


DEFLAGRATION

FINNO EXERGY



Pulsejet



Constant volume combustion

FINNO EXERGY

FINNO EXERGY'S PGC TECHNOLOGY BASIC WORKIN PRINCIPLES

- Fast deflagration combustion
- Unique proprietary design combustor has mechanically controlled input valves and open exhaust
- Record performance is achieved by fluidic control of flow and combustion inside the combustor unit
- Only proven engineering elements used in construction

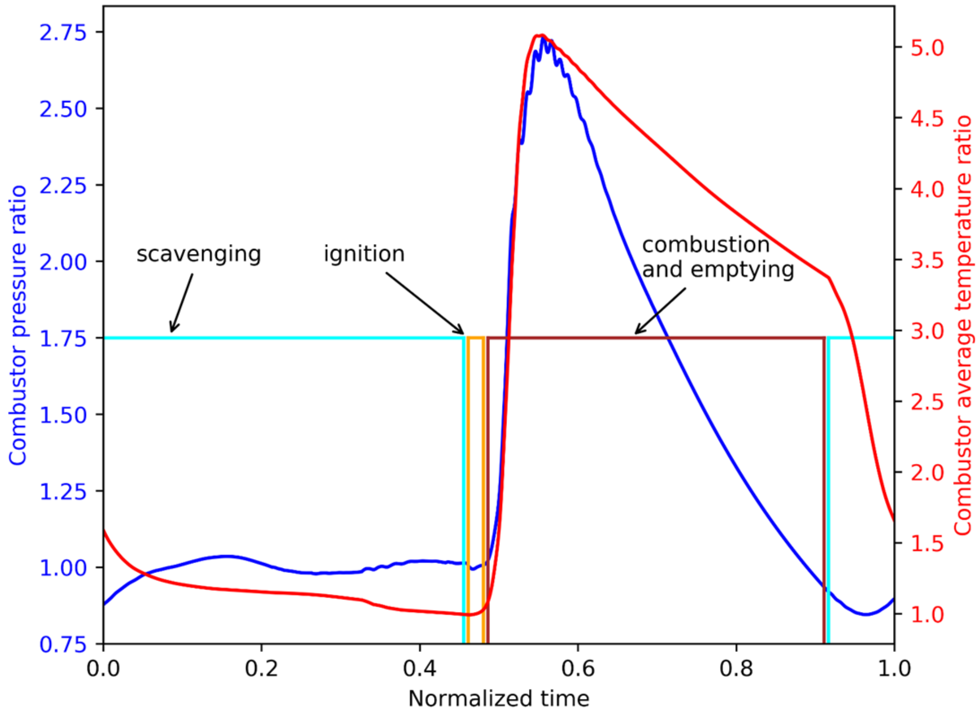
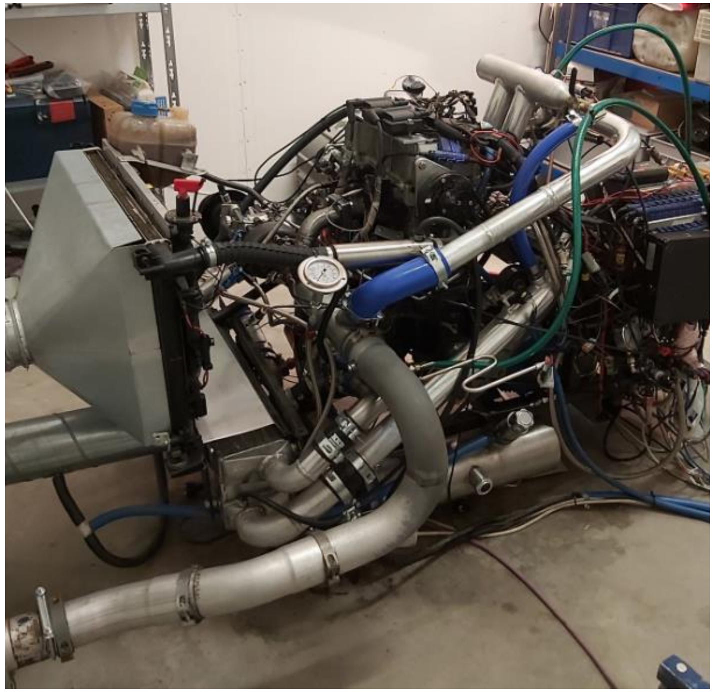
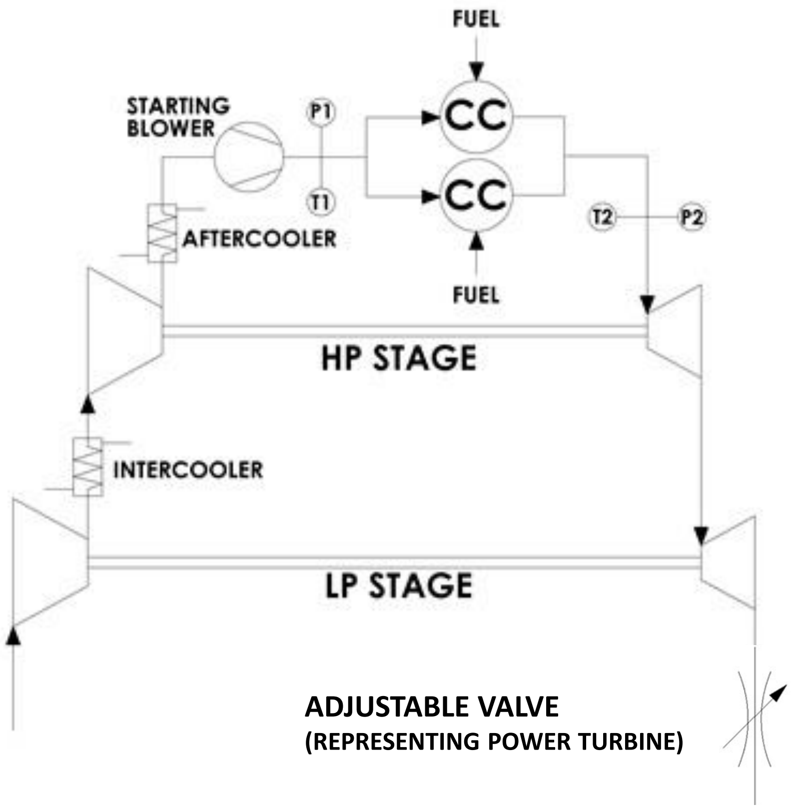


Figure on the left shows calculated instantaneous pressure and temperature ratio over a working cycle inside combustion chamber. Opening of valves initiates scavenging of residual gases from the previous cycle, and the filling of the chamber with fresh air. Fuel is injected and mixed with the fresh charge. The inlet valves close and an ignition source ignites the air-fuel mixture. A fast deflagration combustion process quickly elevates pressure and temperature within the combustor. The pressure rise created by combustion drives the expansion of the hot gasses through the open outlet towards the HPT (High Pressure Turbine) stage.

FINNO EXERGY

TEST UNIT: EXPERIMENTAL FACILITY DESCRIPTION





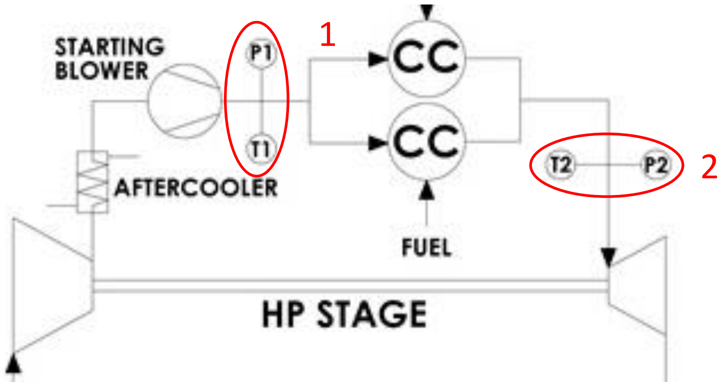
Main operative parameters for a typical test

Frequency [Hz]	15
Test duration [min]	3-5
Combustor pressure inlet [bar]	4
Turbine inlet temperature [K]	1193
Combustor Temperature Ratio	≈3.2
Air-Fuel Equivalent Ratio (λ)	2.0-2.8
Fuel Power [kW]	≈150
Automotive turbochargers type for LP and HP stages: (Mitsubishi)	TD02-TD04

FINNO EXERGY

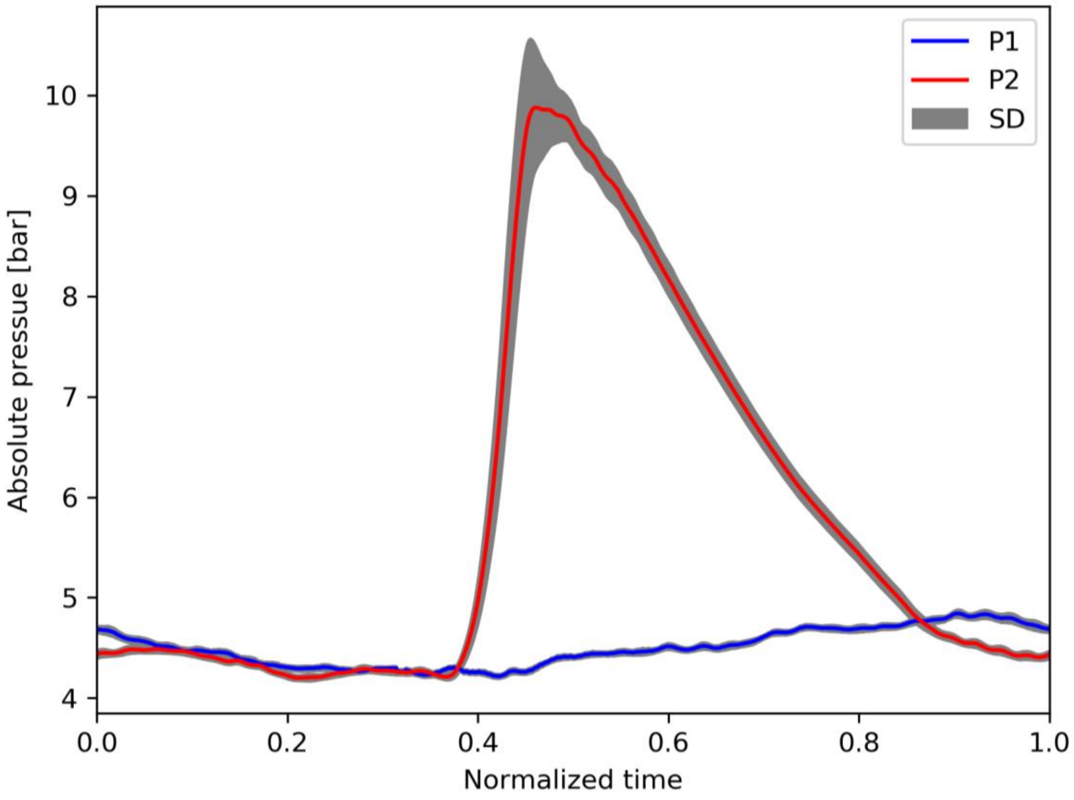
***TEST UNIT:* EXPERIMENTAL RESULTS ON PRESSURE GAIN CAPABILITY**

Operational frequency [Hz]	15
Logging frequency [Hz]	10800
N° of consecutive cycles	300
T_1 [K]	366
T_2 [K]	1222
P_1 [bar]	4.50
P_2 [bar]	5.75
Pressure Gain* [%]	27.9



Highlight of measurement stations 1 and 2

[Experimental Demonstration of a Novel Deflagration-based Pressure Gain Combustion Technology | AIAA Propulsion and Energy Forum]



Cycle average P1 and P2

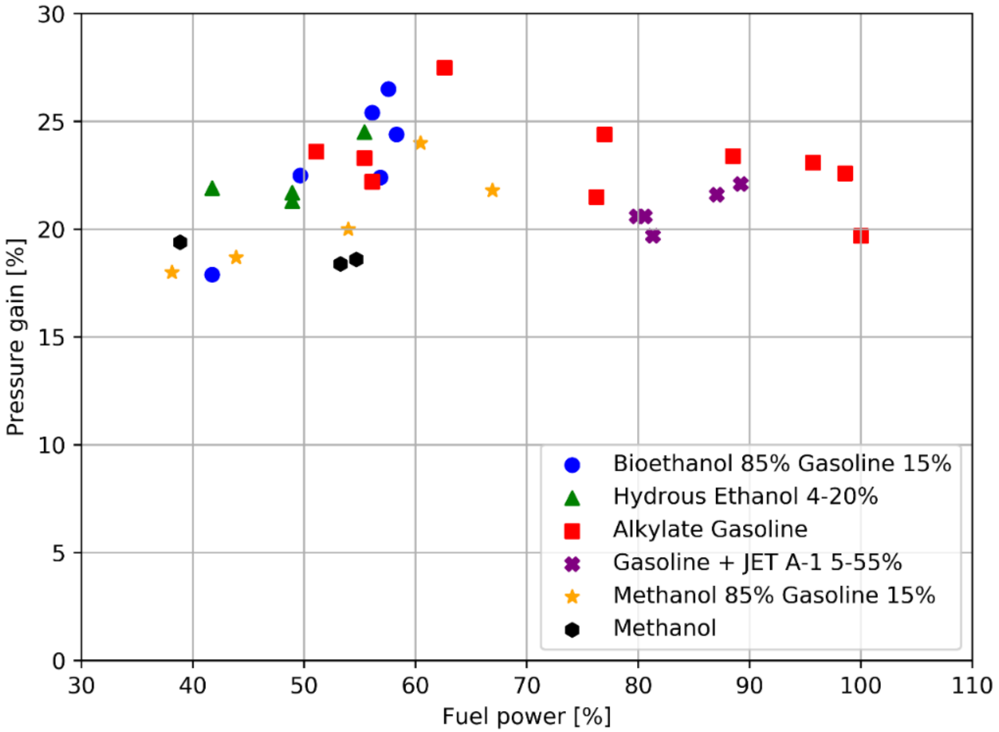
The red and blue curves are the result of averaging the pressure measured in each point in 300 consecutive cycles. Standard deviation in each point is represented as the grey area in the plot

$$* \; PG\% = \left(\frac{P_2}{P_1} - 1\right) * 100$$

FINNO EXERGY

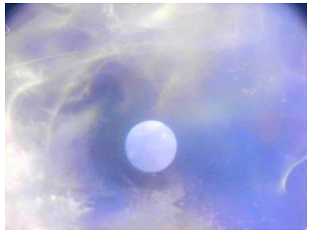
FUEL FLEXIBILITY AND HYDROGEN

Data collected from the test unit



Able to sustain pressure gain level over 20% with different setups, operating points, and types of fuel

Inside the combustor



Bioethanol

Methanol

Alkylate gasoline

Perfectly suited for hydrogen

- Finno Exergy's combustion system contains features to enable extreme fuel flexibility
- Simulations show that operational parameters of the combustion system can be adjusted to adopt 0-100% and 100-0% hydrogen - natural gas mixtures o the fly

FINNO EXERGY

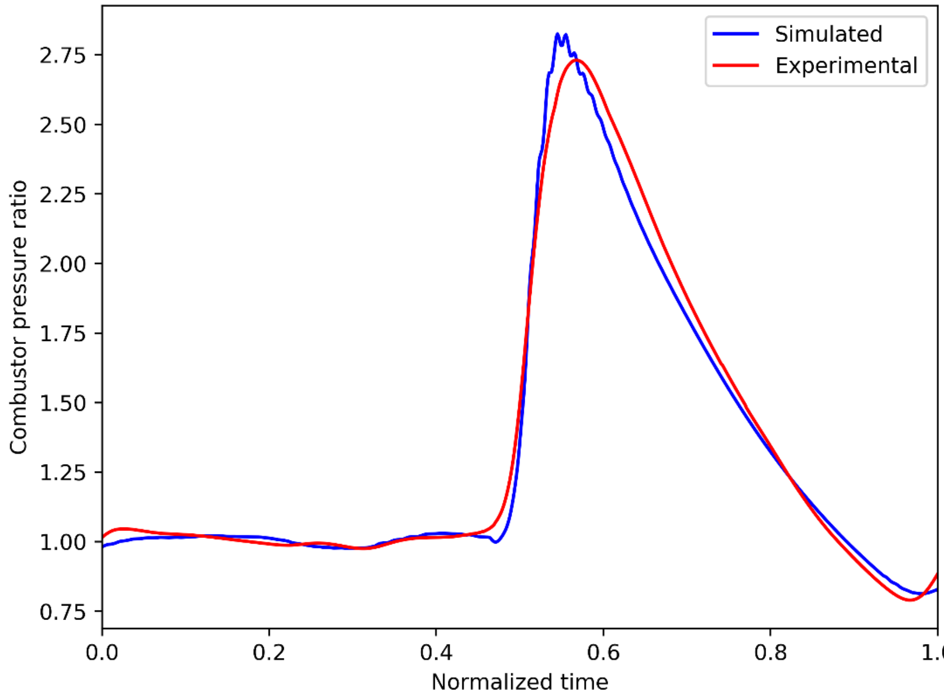
SIMULATIONS AND MODEL VALIDATION

- GT-Power simulation software by Gamma Technologies, Inc. was used for overall system modeling and optimization, run on a dedicated high-performance computer

- For three-dimensional modelling of flow and combustion inside the combustor; CONVERGE CFD by Convergent Science, run on a 144 core inhouse HPC cluster

Software	Converge CFD, GT Power
Hardware	144 core in-house cluster
Turbulence model	URANS RNG κ-ε
Combustion model	SAGE detailed chemistry
CFD boundary cond.	Imposed by GT-Power

➡ **An excellent agreement between measured and calculated results**



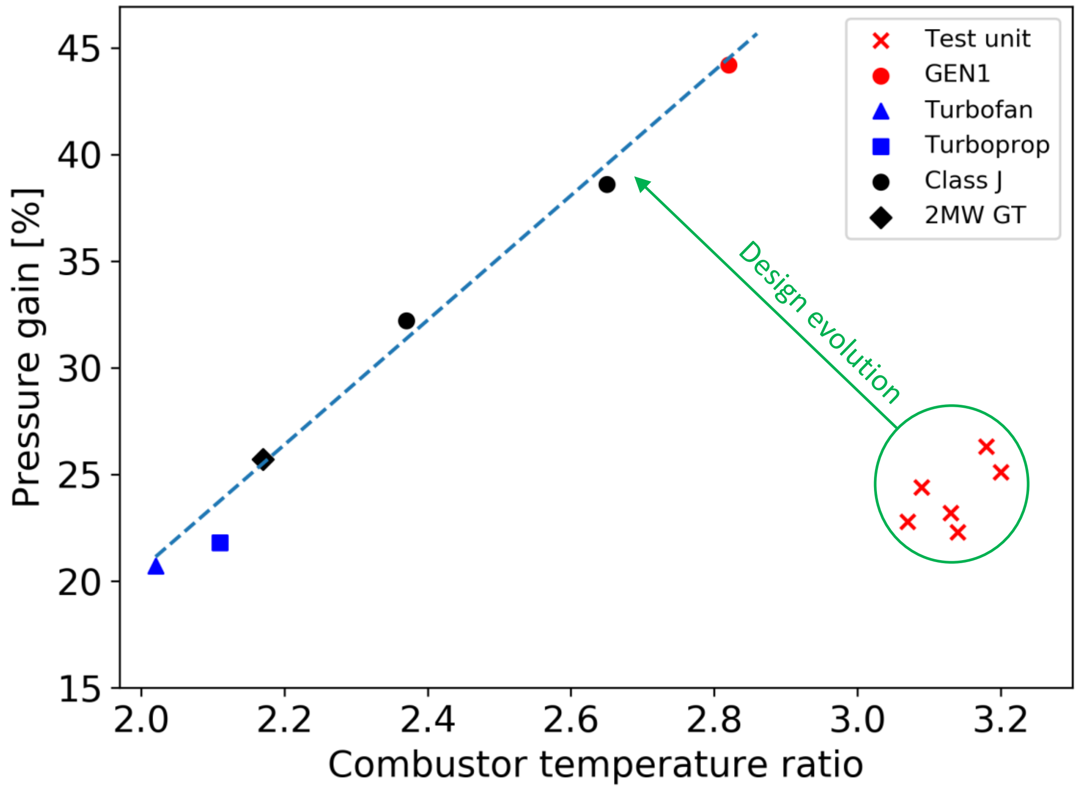
Deeper understanding of combustion process enabled evolving the design to considerably improved performance.

FINNO EXERGY

TECHNOLOGY SCALABILITY

SIMULATION PROCEDURE

- ✓ Dynamic 1D model of the selected GT to be studied.
- ✓ Replace traditional combustors with Finno Exergy's PGC system
- ✓ 3D CFD model with the correct dimensions of 1 singular combustor
- ✓ Extract heat release rate for CFD model and import it to 1D dynamic model
- ✓ Run the 1D model with the extracted heat release
- ✓ Report on achievable pressure gain and potential efficiency gain

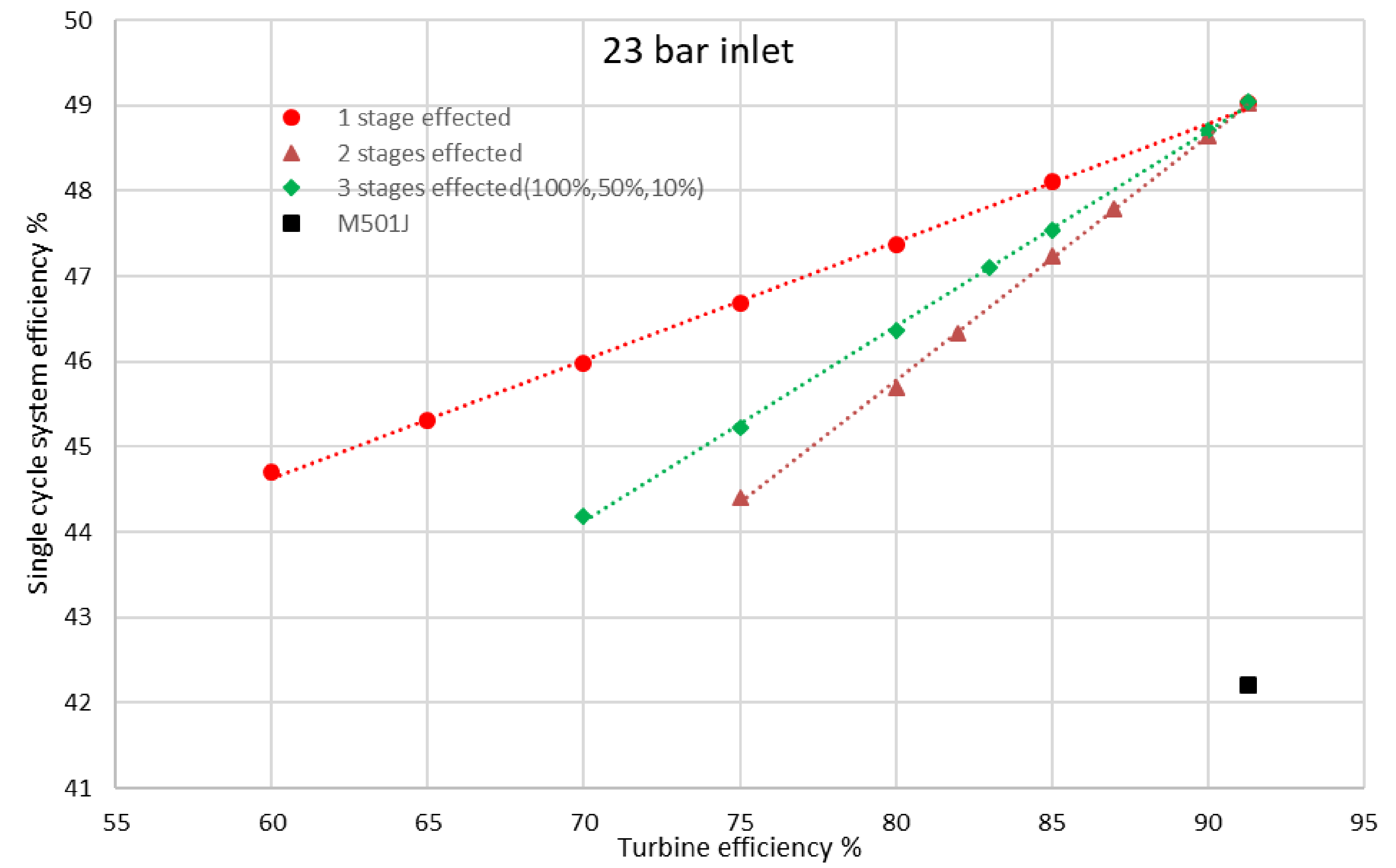


The graph shows the pressure gain capability of the optimized design for different applications, with a range of varying operating parameters.

FINNO EXERGY

EXAMPLE CASE: INDUSTRIAL HEAVY-DUTY GT

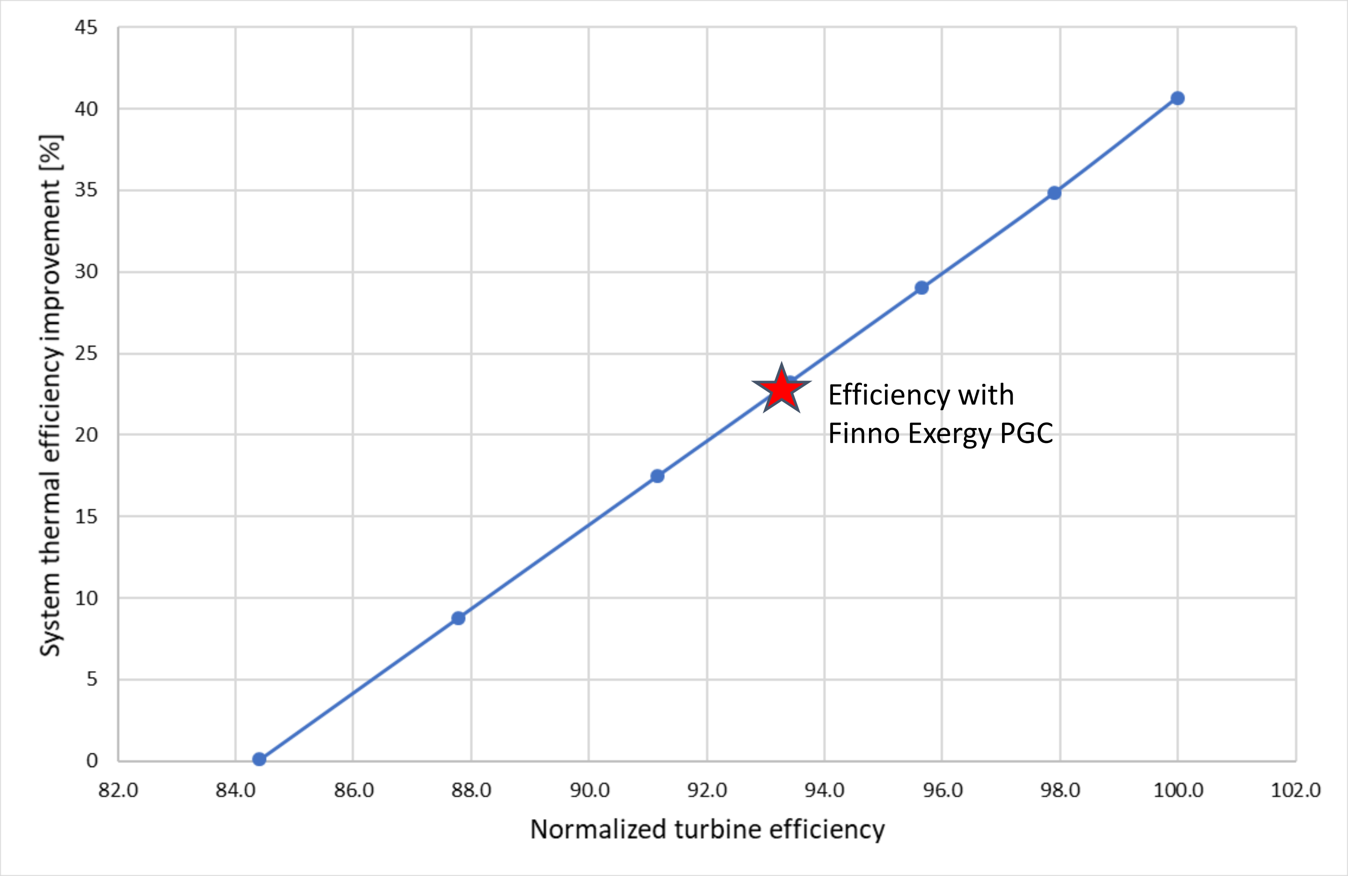
Industrial heavy-duty GT	Original GT	PGC-GT
Air mass flow [kg/s]	620	620
Compressor pressure ratio	23	23
Heat input [MW]	775	775
Mass average TIT [K]	1876	1876
Compressor efficiency [%]	88	88
Turbine efficiency [%]	91	90
Thermal efficiency [%]	**42.2**	**48.7**
Pressure Gain [%]		32



Sources: Mitsubishi Hitachi Power Systems

EXAMPLE CASE: SMALL INDUSTRIAL GT

Industrial heavy-duty GT	Original GT	PGC-GT
Air mass flow [kg/s]	10	10
Compressor pressure ratio	7	7
Heat input [MW]	8	8
Mass average TIT [K]	1223	1223
Thermal efficiency [%]	**26.2**	**32.5**
Pressure Gain [%]		25



TO DATE ACHIEVEMENT AND TECHNOLOGY DEVELOPMENT PLAN

TO DATE ACHIEVEMENT

- Over 25% pressure gain measured in closed loop operation
- Extreme fuel flexibility experimentally proven
- Simulations confirm the scalability of the tech to bigger GT applications

ONGOING WORK

- Victory of “New Energy Challenge”, project inside “Shell Game Changers” program

FUTURE GOALS

- Technology to market in a microturbine size unit for CHP
- Integrate the combustion technology in bigger power size applications

ULTRA-EFFICIENT FUEL FLEXIBLE NEXT GENERATION INDUSTRIAL GT

OPEN CHALLENGES:

→ High pressure turbine stage optimization for pulsating flow conditions

→ Integrate the combustion technology in traditional GT layout

→ HPT stage cooling under unsteady conditions

FINNO EXERGY

THANK YOU

Contact:

Fabio Ciccateri
fabio.ciccateri@finnoexergy.com

FINNO EXERGY