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# Pressure Gain Combustion: Concept & Applications


2024 Low Emission Advanced Power (LEAP) Workshop

15–19 September 2024, Washington, D.C.


Presenter: Sreenath Purushothaman


Sreenath Purushothaman[1], Abhishek Dubey[1], Alessandro Sorce[2], Alberto Traverso[3]

1. PhD Student, Thermochemical Power Group, DIME, University of Genoa, Genova, Italy
2. Associate Professor , Thermochemical Power Group, DIME,University of Genoa, Genova, Italy
3. Full professor, Thermochemical Power Group, DIME, University of Genoa, Genova, Italy


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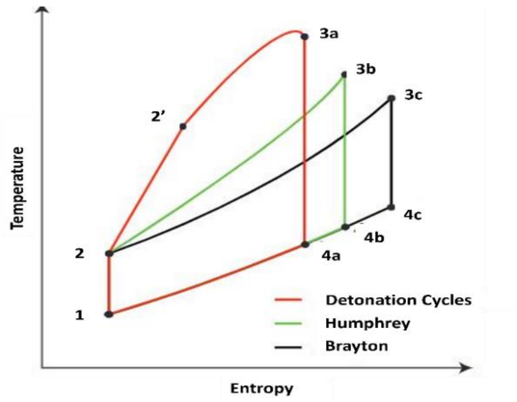
# Pressure Gain Combustion

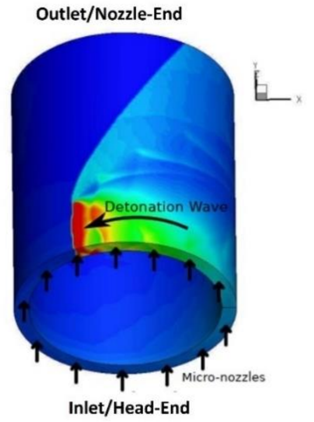
- Pressure Gain Combustion is one of the promising candidates for the next generation of **low emission**, **highly efficient** propulsion technologies.

- At **Thermochemical Power Group** of University of Genova, Italy, the **performance of aircraft engines** utilizing **PGC technology**, specifically RDC, are studied using the in-house simulation tool of, called '*TRANSEO*'.

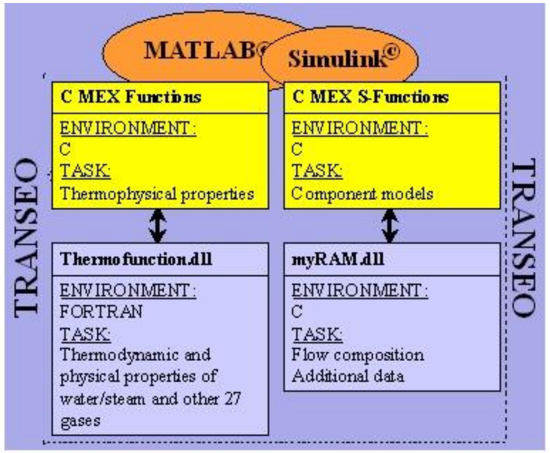
- This is part of the EU Horizon 2020 - Marie Skłodowska-Curie Innovative Training Networks Project **INS**piring **P**ressure gain combustion **I**ntegration, **R**esearch, and **E**ducation (**INSPIRE**) studies Pressure Gain Combustion for propulsion and power generation applications



**Temperature–Entropy diagrams for the ideal Detonation, Brayton, and Humphrey cycles**



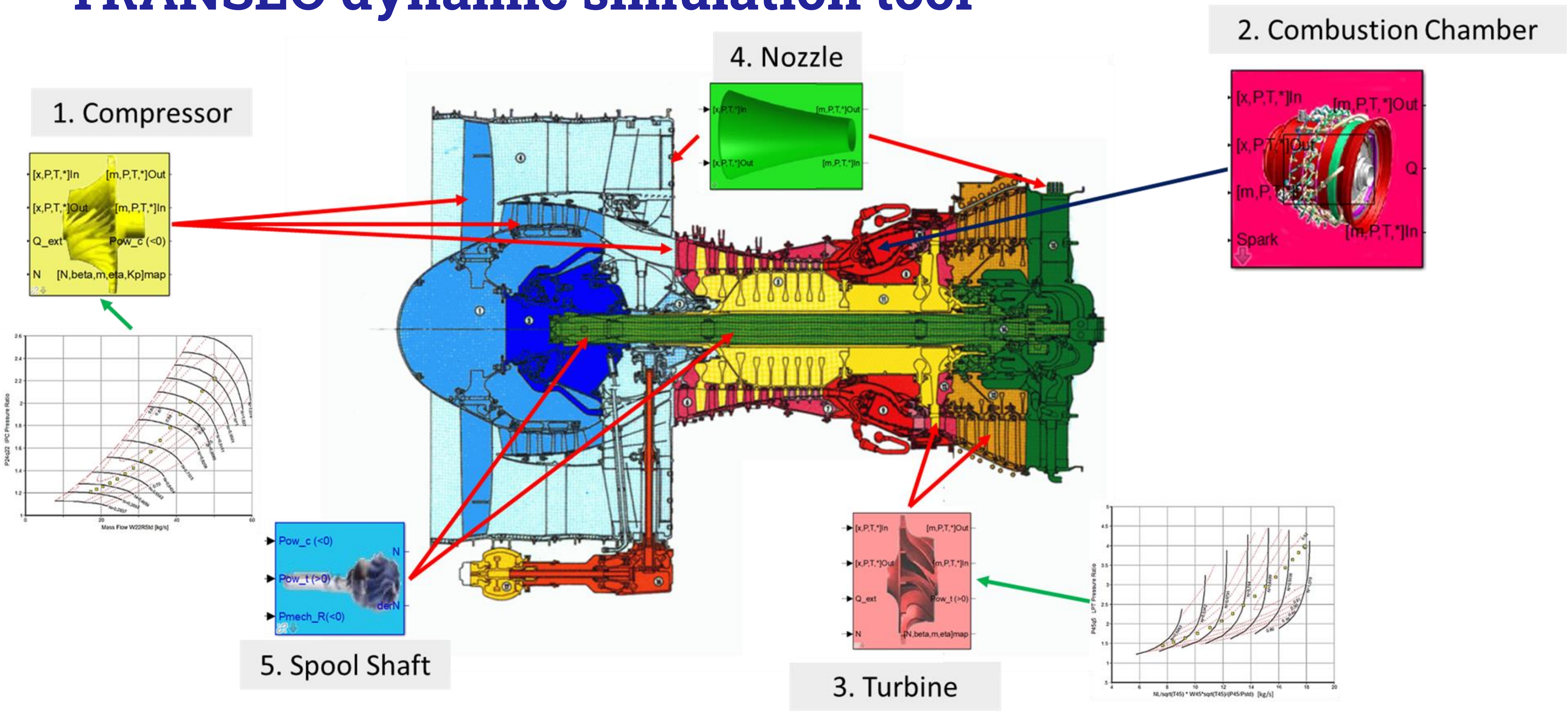
**CFD simulation of RDE combustion chamber**



**TRANSEO organization**

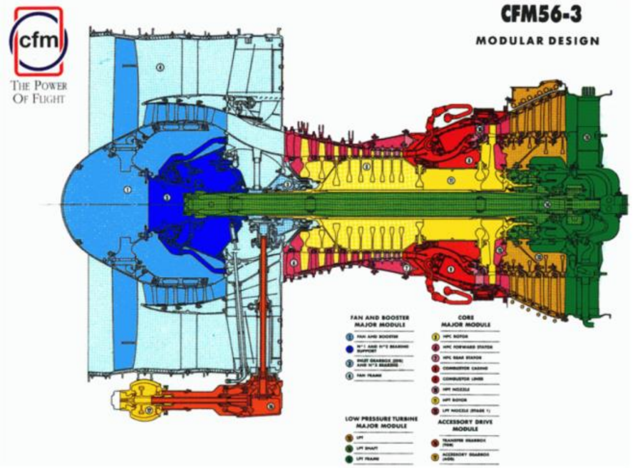

Stathopoulos, P., "Comprehensive Thermodynamic Analysis of the Humphrey Cycle for Gas Turbines with Pressure Gain Combustion," *Energies*, Vol. 11, No. 12, 2018. https://doi.org/10.3390/en11123521
Traverso, A., "TRANSEO: A New Simulation Tool for Transient Analysis of Innovative Energy Systems: PhD Thesis," University of Genova, Genova, Italy, 2004.
Schwer, D., and Kailasanath, K., 2011, "Numerical Study of the Effects of Engine Size n Rotating Detonation Engines," 49th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, American Institute of Aeronautics and Astronautics

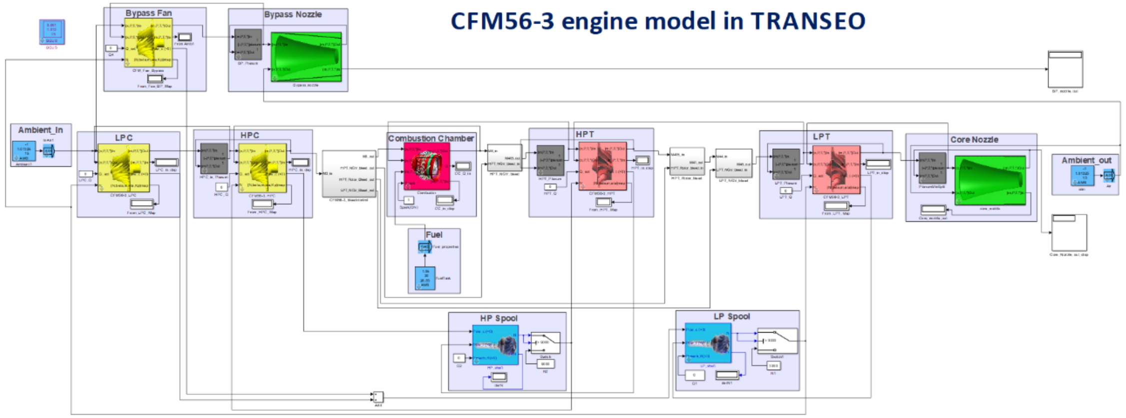
# TRANSEO dynamic simulation tool



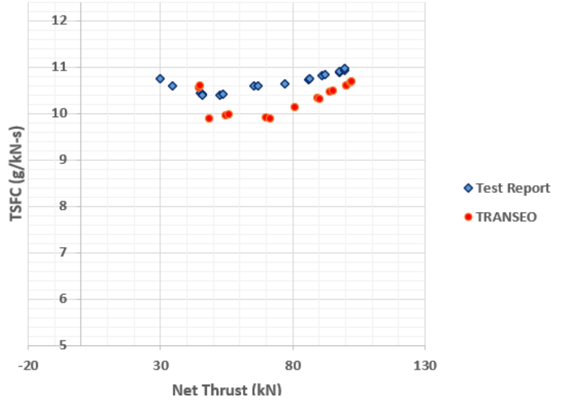

Traverso, A., “TRANSEO: A New Simulation Tool for Transient Analysis of Innovative Energy Systems: PhD Thesis,” University of Genova, Genova, Italy, 2004
Martins, D. A. R., 2015, “Off-Design Performance Prediction of the Cfm56-3 Aircraft Engine,” Tecnico Lisboa MSc Thesis..

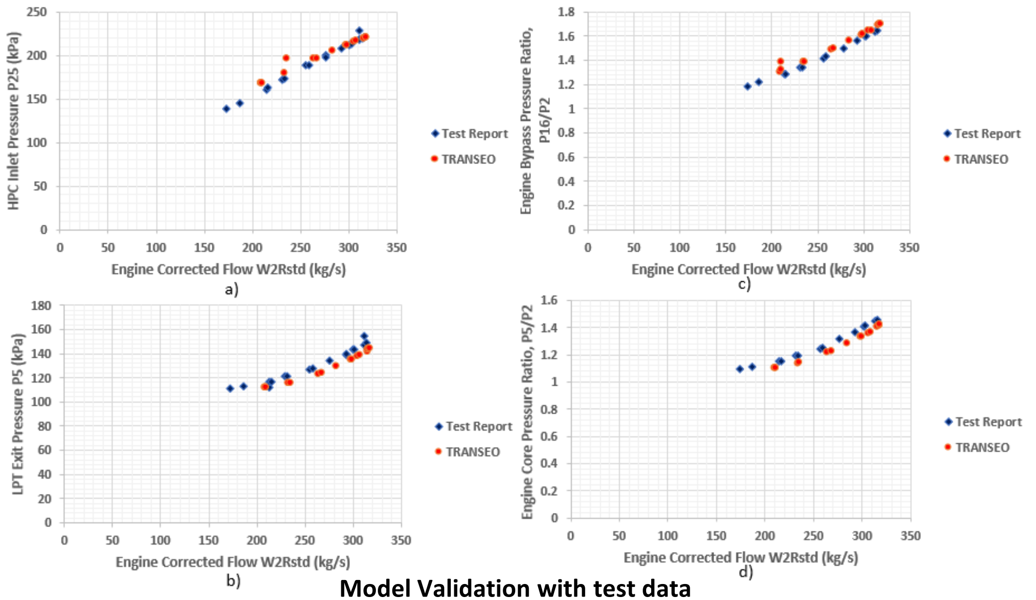
# Conventional Aircraft Engine modelling




CFM56-3 engine model in TRANSEO

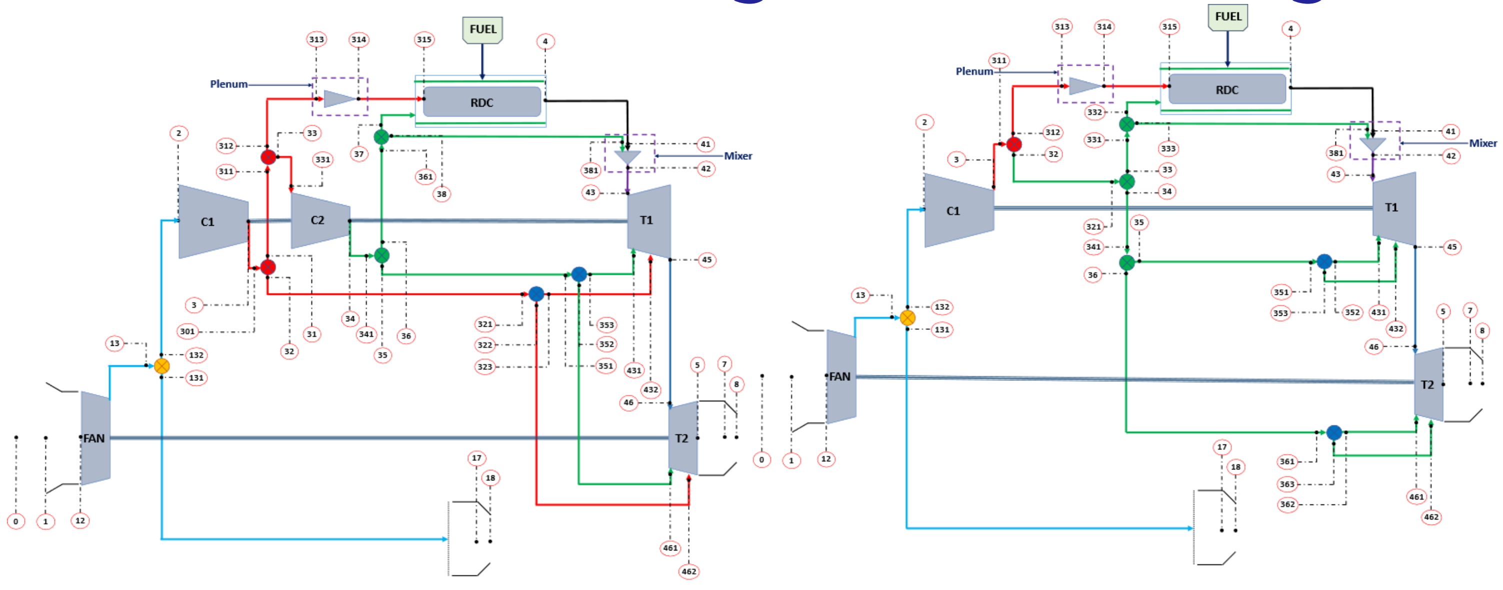


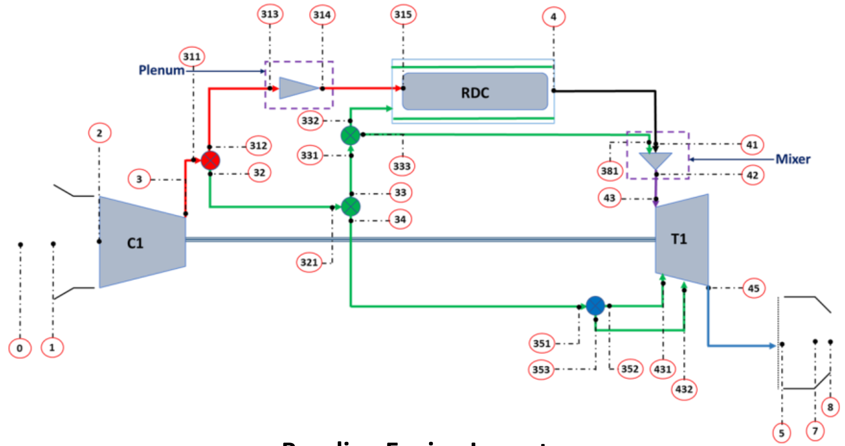

**Model Validation with test data**

Purushothaman, S., Sorce, A., Traverso, A., Gaillard, T. and Davidenko, D., 2024. Performance Modelling of a Pressure Gain Combustion Aircraft Engine. In AIAA SCITECH 2024 Forum (p. 0814).

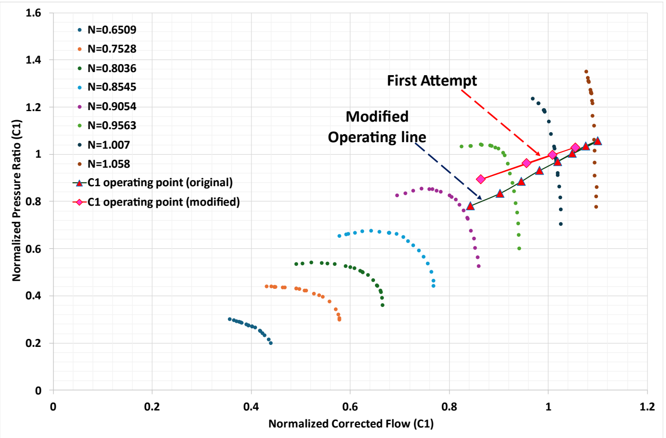
# PGC Aircraft Engine modelling




**Different PGC engine layouts**




**Baseline Engine Layout**




**Compressor stability in off-design**

- TRANSEO was has been used to model both conventional and PGC aircraft engines.
- On-design & Off-design performance, including dynamic modelling, of different PGC engine layouts are under investigation.
- Effect of fuel-air injection losses and dynamics of the engine are also being studied.

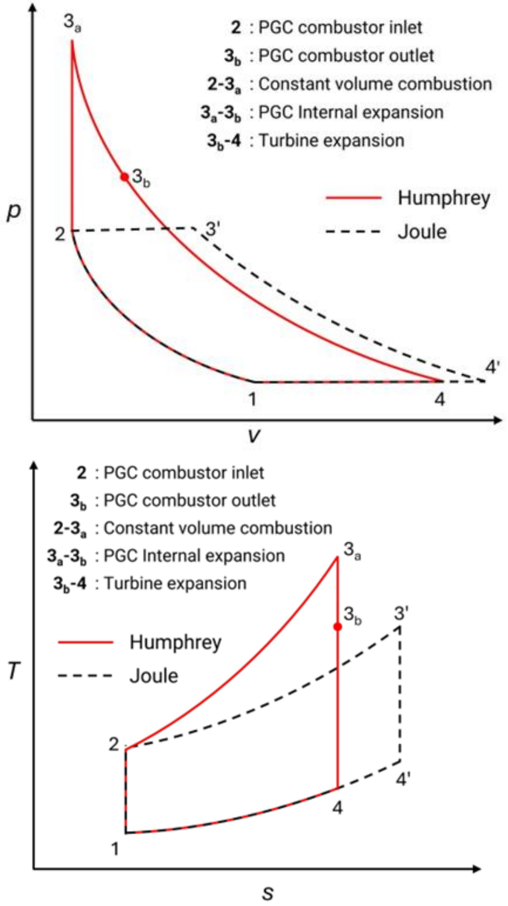
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No: INSPIRE-956803

INSPIRE-ETN

Purushothaman, S, Sorce, A, Traverso, A, & Gaillard, T. "Performance Comparison of Gas Turbine Layouts With Pressure Gain Combustion for Propulsion Applications." *Proceedings of the ASME Turbo Expo 2024: Turbomachinery Technical Conference and Exposition*. *Volume 5: Cycle Innovations*. London, United Kingdom. June 24–28, 2024. V005T06A028. ASME. https://doi.org/10.1115/GT2024-127816
Purushothaman, S., Sorce, A., Traverso, A., Gaillard, T. and Davidenko, D., 2024. Performance Modelling of a Pressure Gain Combustion Aircraft Engine. In AIAA SCITECH 2024 Forum (p. 0814).

# Pressure Gain Combustion for Power Generation

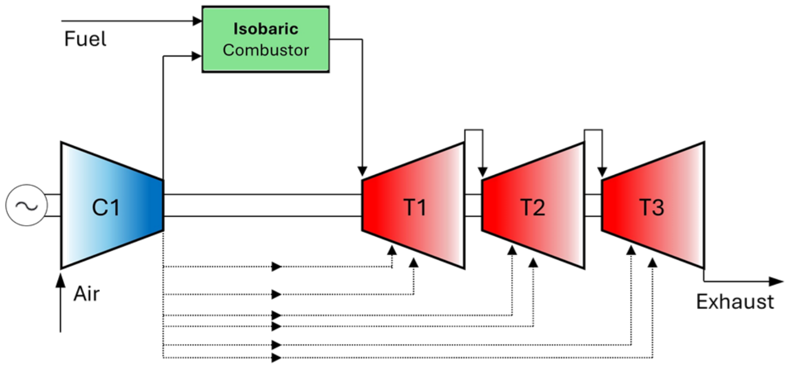
## Humphrey Cycle – Gas Turbine with Constant Volume Combustion



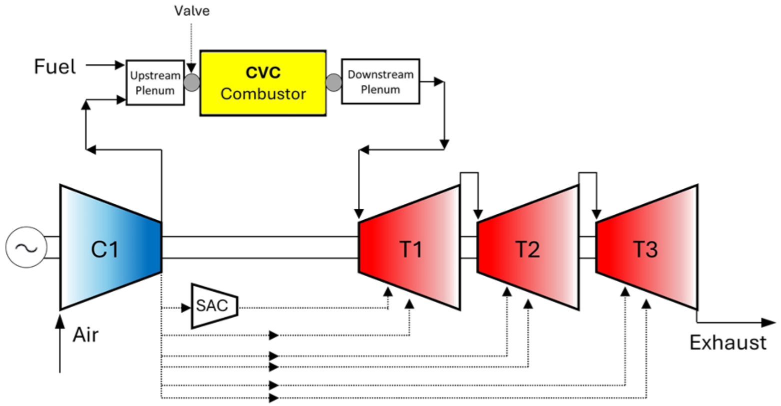

P-V and T-S diagrams of the Humphrey Cycle-based PGC model[1,2,3]

**PGC** is a fundamentally **unsteady process** whereby gas expansion by heat release is constrained, causing a **rise in stagnation pressure** and allowing work extraction by expansion to the initial pressure

- Higher cycle efficiency
- Higher power output
- Low emissions




Conventional Gas Turbine




Gas Turbine Cycle with Pressure Gain Combustion

[1]Nalim, M. R., 2002, J. Propuls. Power, 18(6), pp. 1176–1182.
[2]Dubey, A, Sorce, A, & Stathopoulos, P. Proceedings of the ASME Turbo Expo 2024. London, UK. doi.org/10.1115/GT2024-124972
[3]Dubey, A, Sorce. ATI Congress 2024. Savona, Italy

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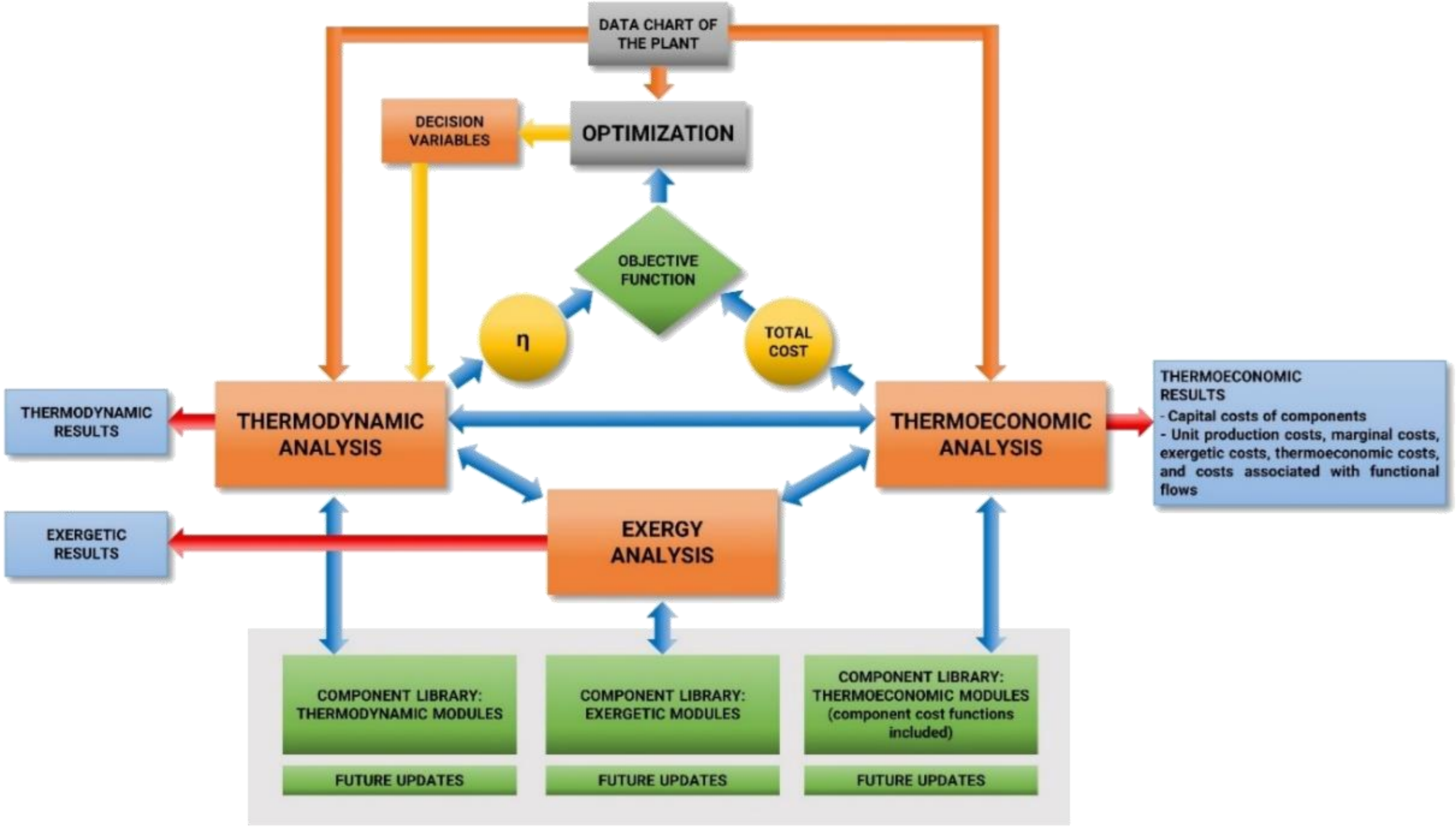
# WTEMP (Web based Thermo-Economic Modular Program)

## Humphrey Cycle – Gas Turbine with Constant Volume Combustion

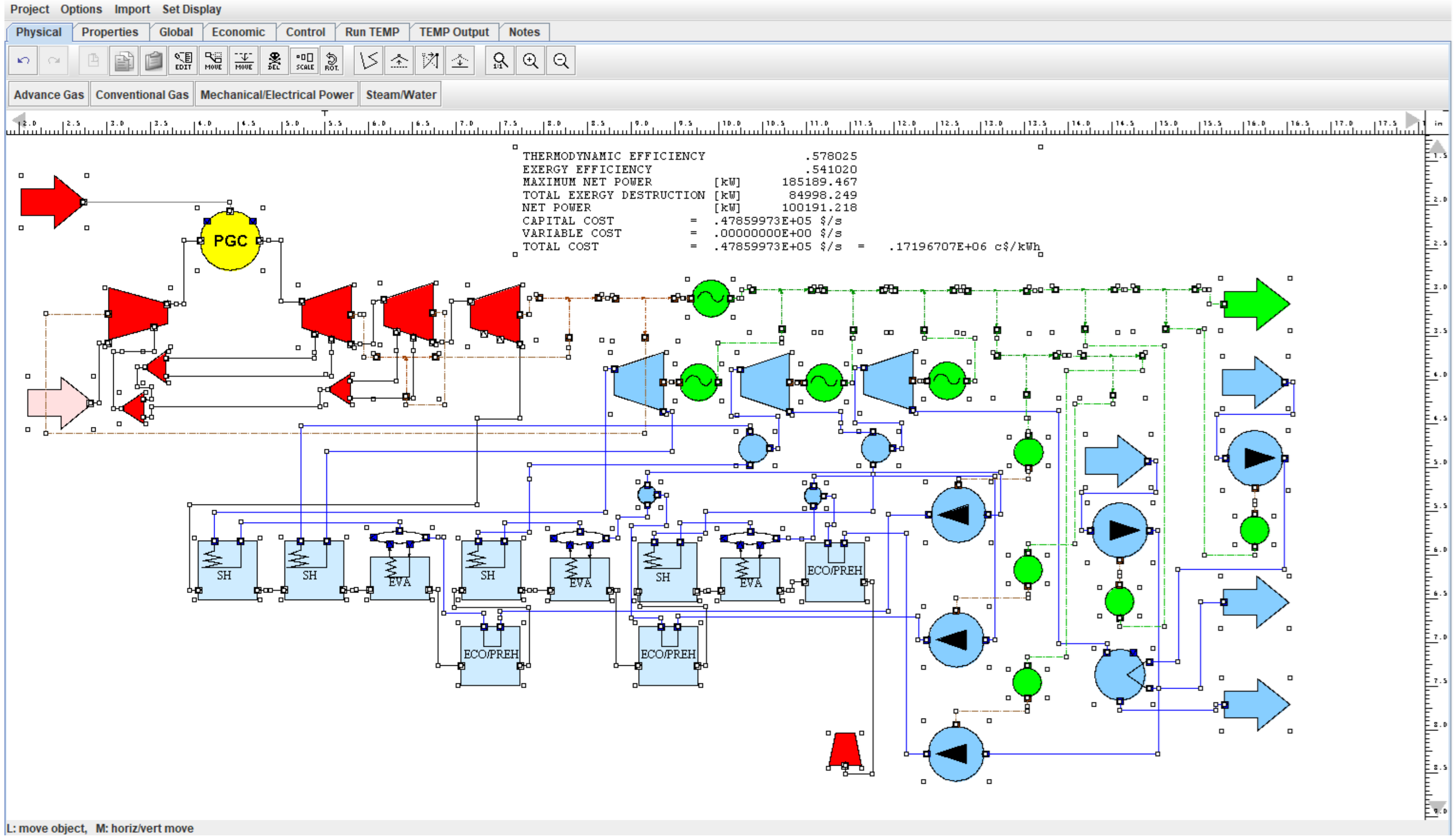
**WTEMP** is a modular and flexible software tool developed by **TPG**, which allows the **thermo-economic** and **exergo-economic** analysis of a large number of energy cycles in power and cogenerative operation.




**WTEMP Program Structure**

# PGC Combined Cycle in WTEMP – Modelling

PGC gas turbine has been modelled with **losses in practical PGC combustor**




**WTEMP Cycle Layout of 3PRH PGC-GTCC**

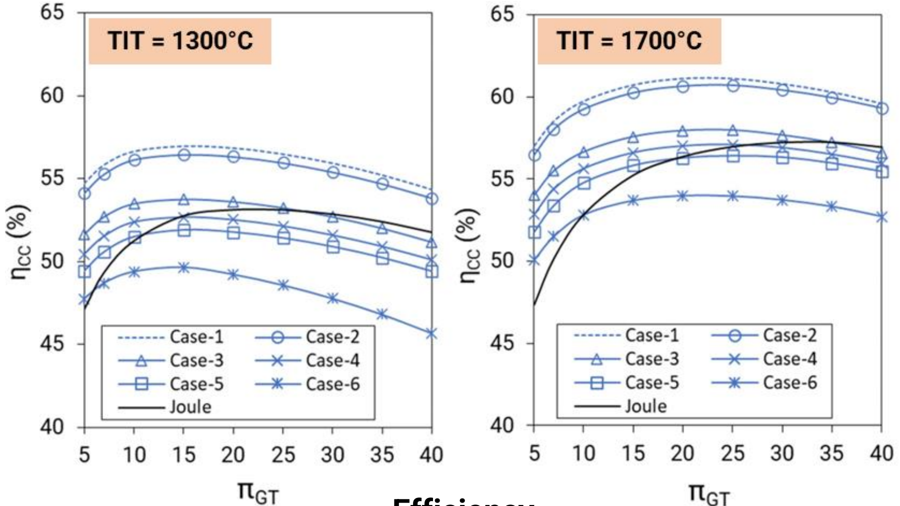
| | $m_{CPC}$ (%) | $\Delta P_{PGCin}$ (%) | $\eta_{pT1}$ (%) | $\eta_{pPGC}$ (%) |
|---|---|---|---|---|
| Case 1 | 0 | 0 | 90 | 100 |
| **Case 2** | **0** | **5** | **90** | **100** |
| Case 3 | 20 | 5 | 90 | 100 |
| Case 4 | 20 | 15 | 90 | 100 |
| **Case 5** | **20** | **15** | **90** | **90** |
| Case 6 | 20 | 15 | 70 | 90 |

**Cycle conditions with increasing practical losses**

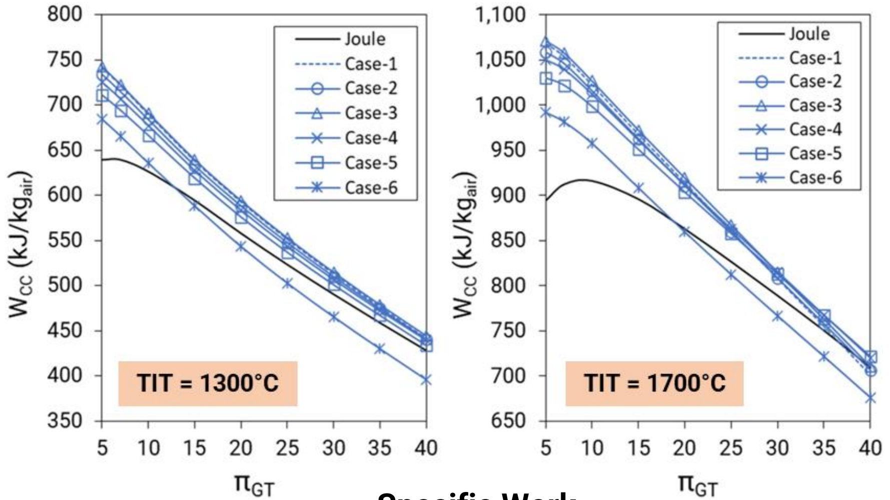
| | |
|---|---|
| $m_{CPC}$ | Degree of constant pressure combustion in PGC |
| $\Delta P_{PGCin}$ | PGC combustor inlet pressure loss |
| $\eta_{pPGC}$ | Isentropic efficiency of internal expansion in PGC |
| $\eta_{pT1}$ | Polytropic efficiency of first turbine stage |

# PGC Combined Cycle in WTEMP – Performance

## PGC Combined Cycle – 1 Pressure Level without Reheat




**Efficiency**



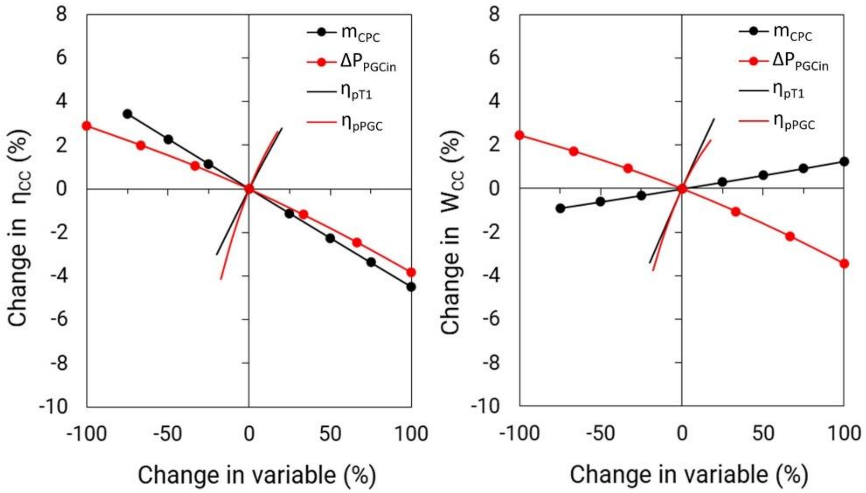

**Specific Work**

- With optimistic losses, combined cycle with **PGC combustion performs better** than conventional combined cycle in terms of **efficiency** and the benefit is higher at low cycle pressure ratios and high turbine inlet temperature.
- **Specific work** of PGC combined cycle is **always higher than conventional one** at all cycle conditions provided that the first stage turbine performance is not affected by pulsating PGC outflow (case 6).
- The impact of **constant pressure loss** in PGC combustor is **more than that of inlet pressure loss** in PGC combined cycle.

### Sensitivity Analysis with Loss Parameters – Combustor and Turbine Losses

| Parameter | Reference Value | Variance |
|---|---|---|
| $m_{CPC}$ (%) | 20 | 5 - 40 |
| $\Delta P_{PGCin}$ (%) | 15 | 0 - 30 |
| $\eta_{pT1}$ (%) | 75 | 60 - 90 |
| $\eta_{pPGC}$ (%) | 85 | 70 - 100 |

**Parameters and their Variation for Sensitivity Analysis (Pressure ratio = 10 and TIT = 1700°C)**




**1PNR combined cycle sensitivity with losses**

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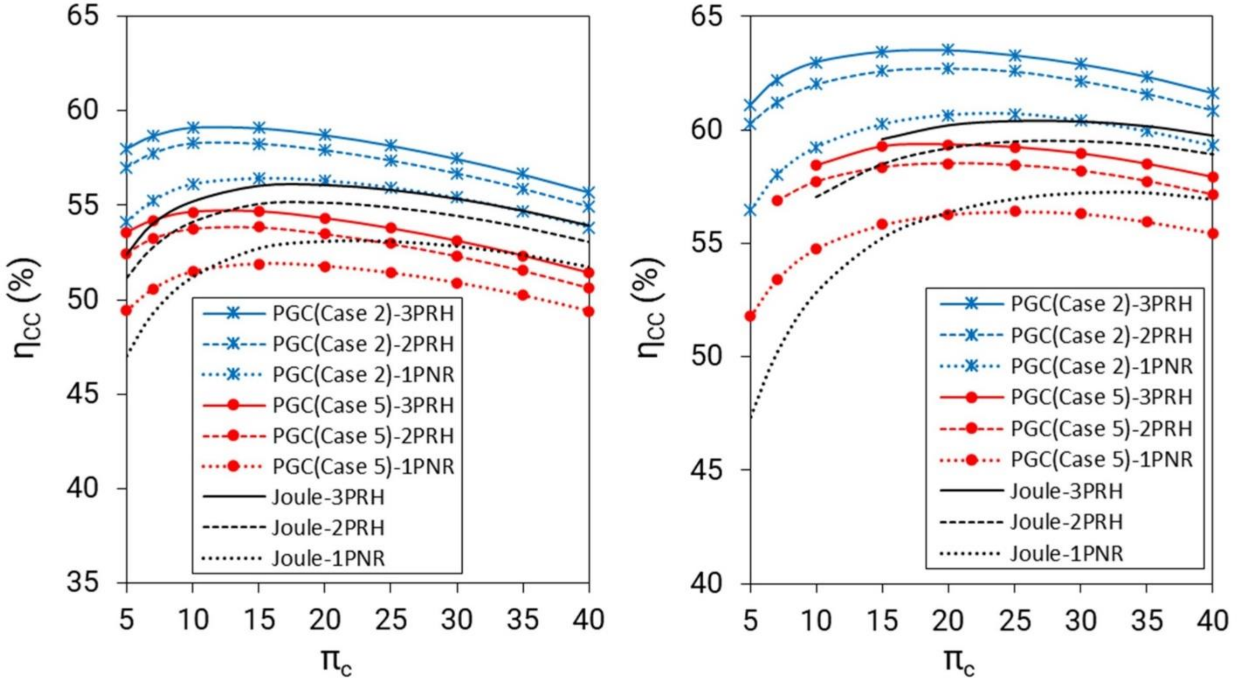
*Dubey, A, Sorce, A, & Stathopoulos, P. Proceedings of the ASME Turbo Expo 2024. London, UK. doi.org/10.1115/GT2024-124972*

# PGC Combined Cycle in WTEMP – Performance

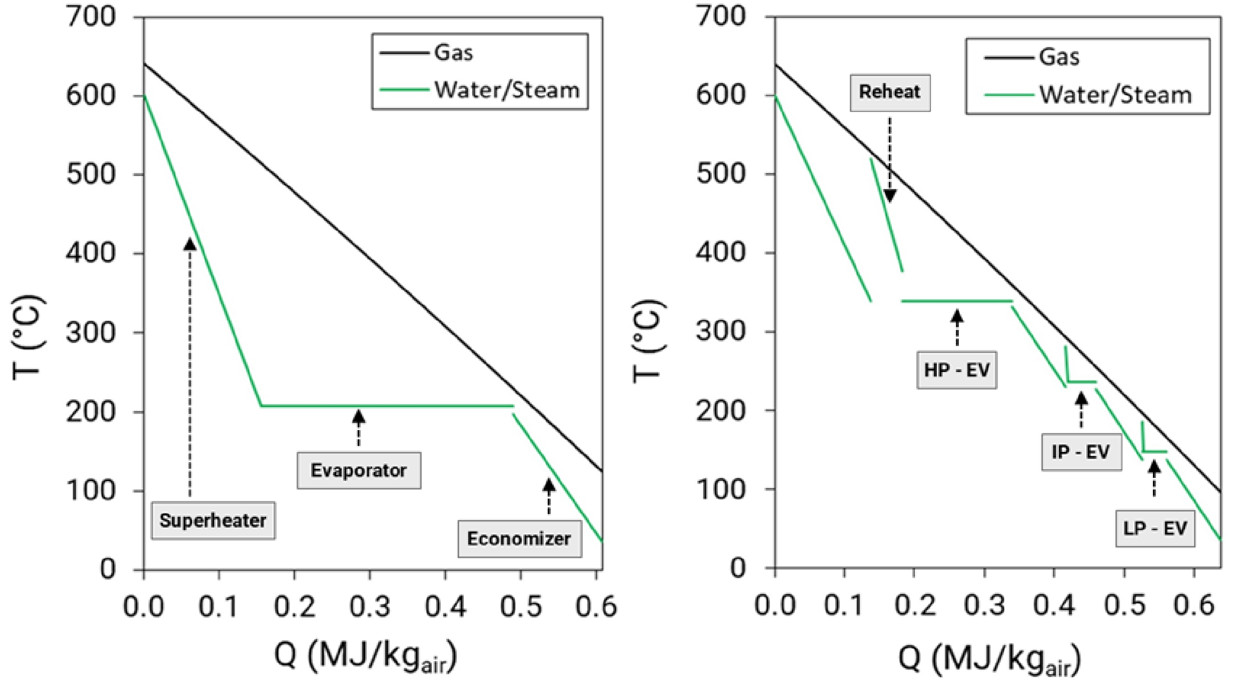
## PGC Combined Cycle – Multiple Pressure Levels

- 1PNR : 1 Pressure Level without Reheat (20 bar)
- 2PRH : 2 Pressure Level with Reheat (90/10 bar)
- 3PRH : 3 Pressure Level with Reheat (160/35/5)

- **Higher number of pressure levels** in bottoming cycle **allows more heat recovery** from GT exhaust and minimizes the exergy loss.
- 3PRH HRSG extracts **0.03 MJ/kg$_{air}$** more heat than the 1PNR.




**Combined Cycle Thermal Efficiency with 1PNR, 2PRH & 3PRH HRSG**




**Representative Heat Release Diagram For 1PNR and 3PRH HRSG Configurations**
**TIT = 1700°C and pressure ratio = 20**

*Dubey, A, Sorce, A, & Stathopoulos, P. Proceedings of the ASME Turbo Expo 2024. London, UK. doi.org/10.1115/GT2024-124972*

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