DIMA – Sez. Macchine (Ing-Ind-08)

[Fluid Machinery for Energy Conversion Systems]

Research Team Members:

Roberto Capata Ph.D., Assist. Prof. [RTD]
Roberta Masci, Doctoral Candidate
Roberto Melli, Adjoint Professor (Ric. in pensione)
Pier Francesco Palazzo, Doctoral Candidate
Lorenzo Tocci, Doctoral Candidate
Raffaele Ruscitti, Professor
Enrico Sciubba Ph.D.***, Professor***
Claudia Toro Ph.D., Junior Researcher [Assegnista]
Federico Zullo Ph.D., Junior Adjoint Researcher

Total of 40 Journal publications from 2011 to 2016

Research Fields:

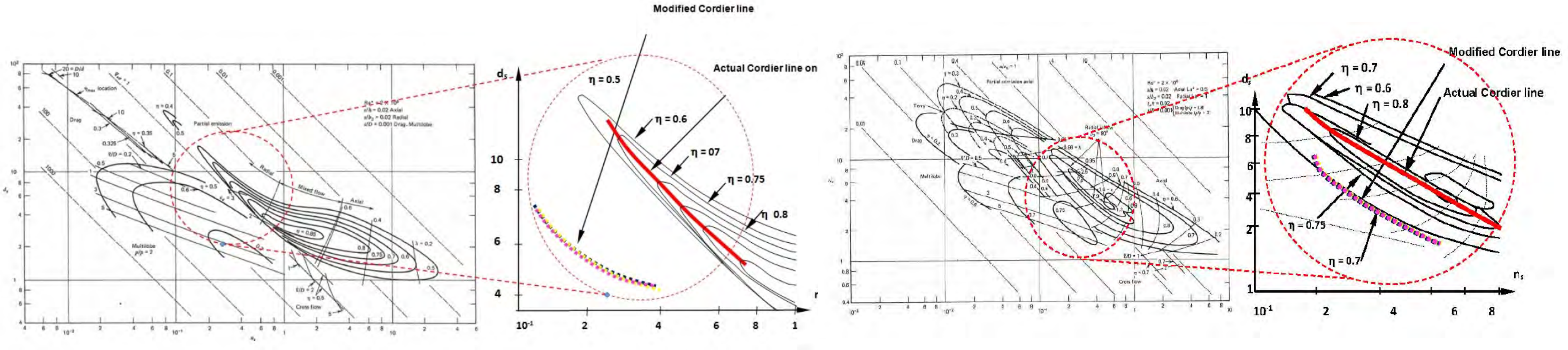
a) Turbomachinery: Theory, Thermo-Fluiddynamic analysis, Applications

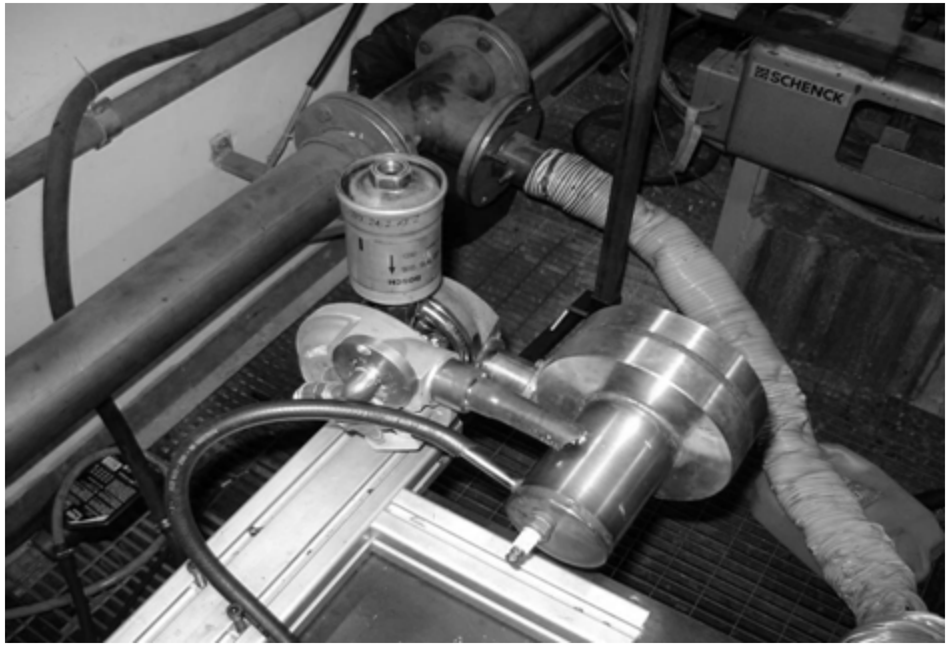
b) Theoretical & Applied Thermodynamics

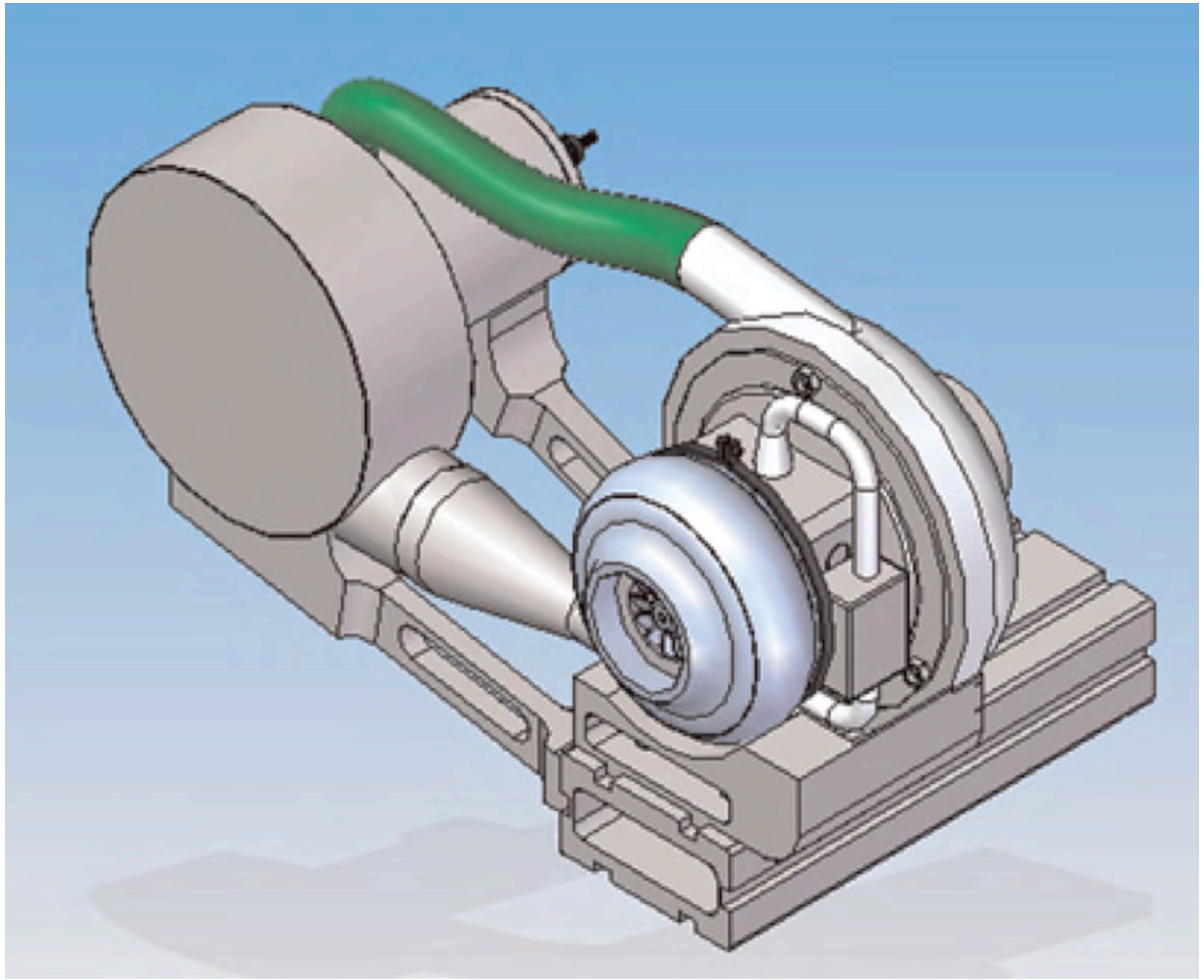
Turbomachinery - 1

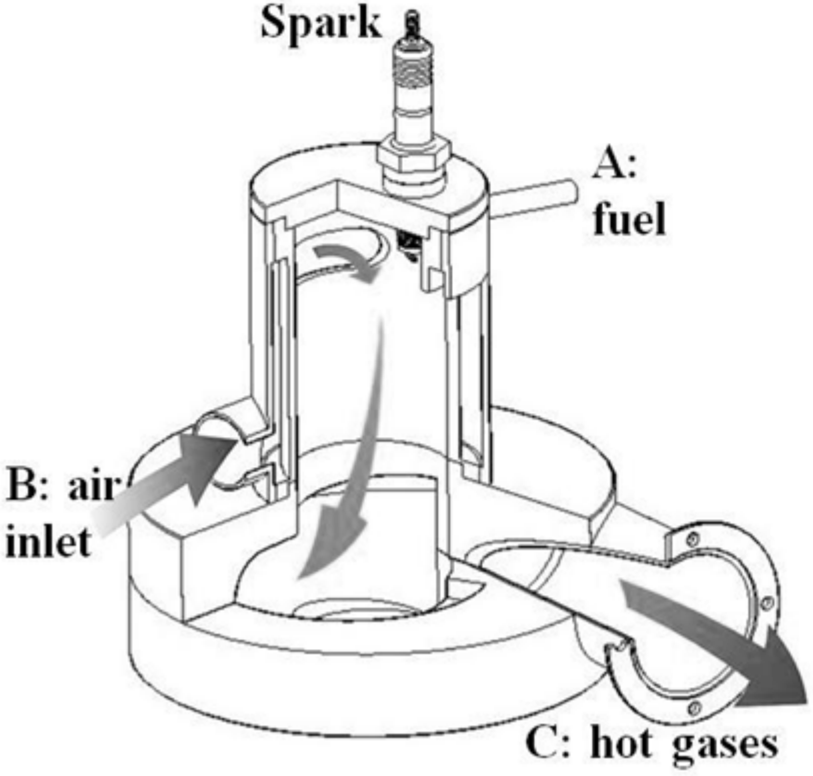
i. Theoretical & applied study of the feasibility of a standalone microturbogas (UMGT, Ultra-Micro Gas Turbine). Ideally, on the basis of dimensional analysis, **the power density of a Turbogas increases inversely to its main dimensions** (external rotor diameter). We have integrated zero- and one-dimensional studies with 3D CFD simulations (fluid- & thermal fields) and 3D structural calculations to identify the most convenient operational ranges for a back-to-back radial configuration in the range of **D_{rotor}=0.01-0.03 m**. The result was **a novel correlation** which can be directly applied to the Balje maps to estimate the **actual efficiency for the Reynolds numbers relevant to these dimensions (~10^4)**. A prototype was built and tested which did not reach self-sustaining power generation. A second prototype, based on the modification of an existing commercial UMGT, is in the works.
The first part of the study was funded by an external Agency.

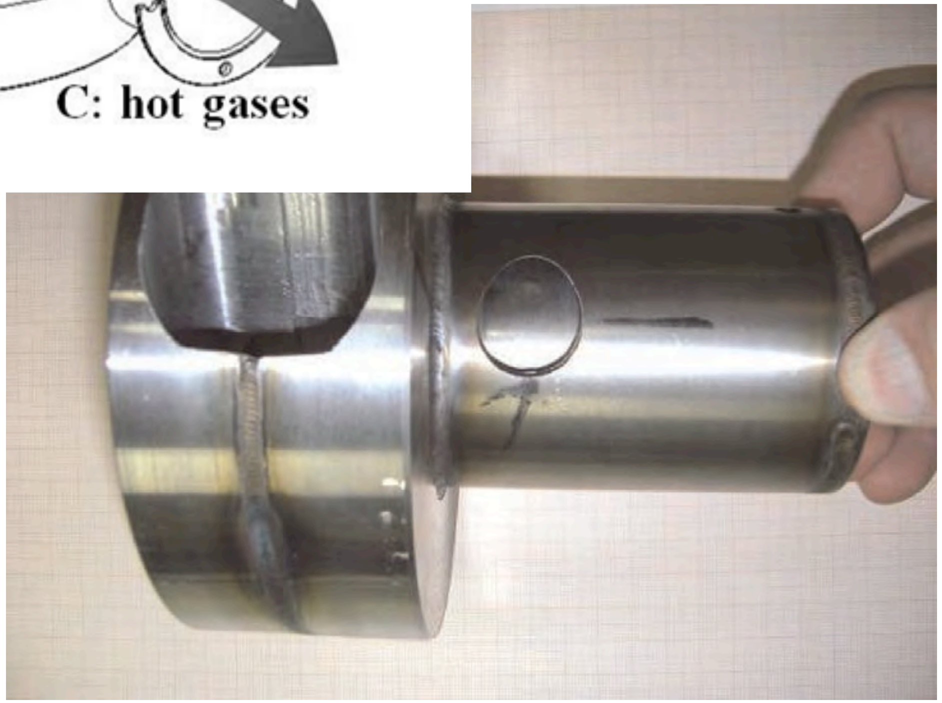
Participants: R.Capata, E.Sciubba

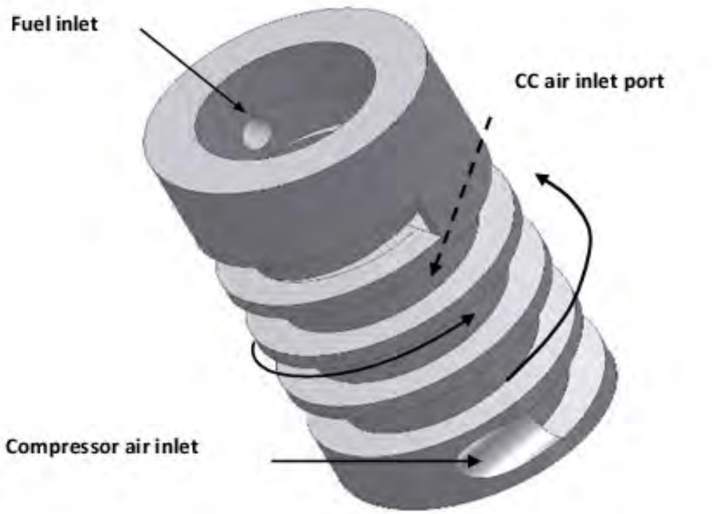


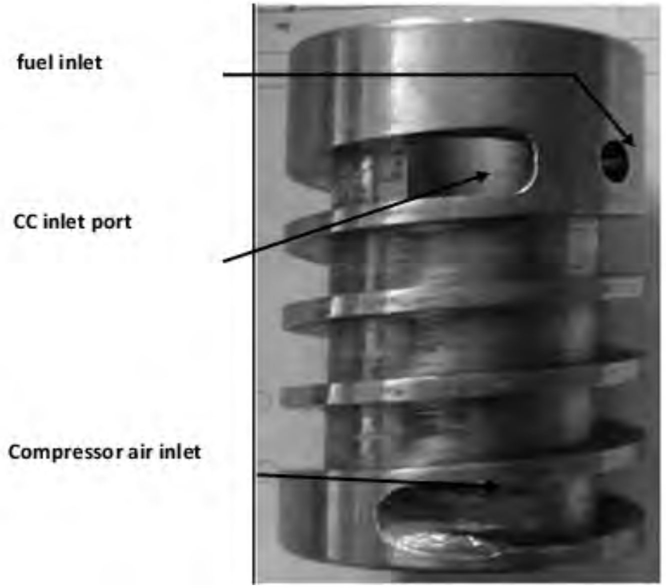

SCHENCK




Spark
A:
fuel
B: air
inlet
C: hot gases



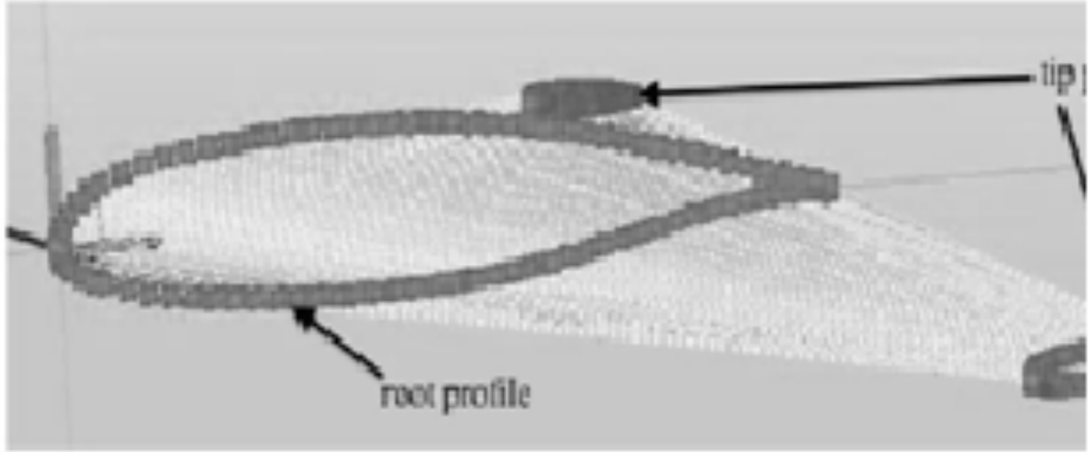

Fuel inlet
CC air inlet port
Compressor air inlet

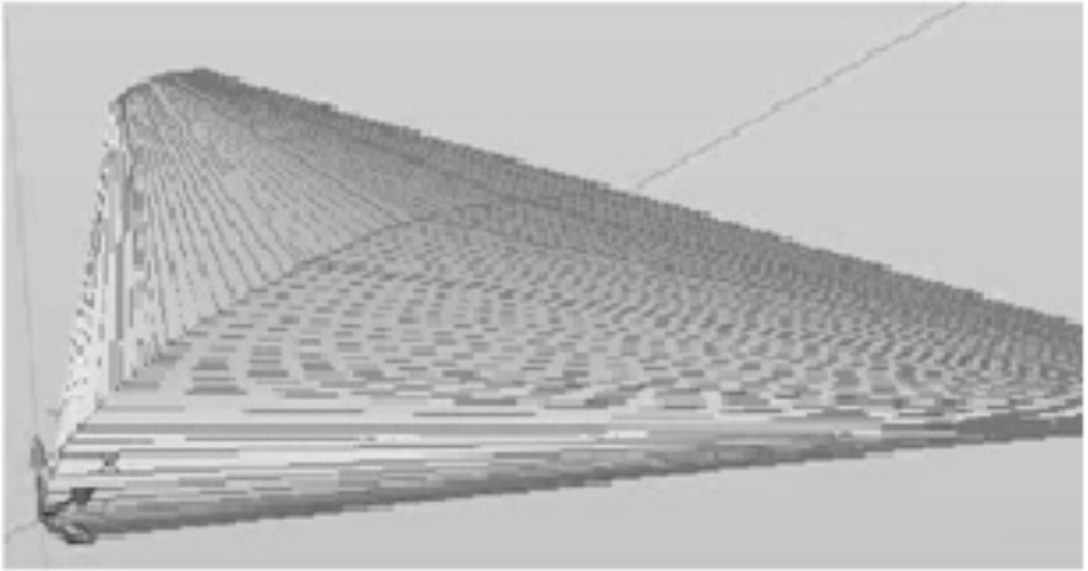

fuel inlet
CC inlet port
Compressor air inlet

Turbomachinery - 2

ii. The concept of the UMGT designed under Phase (i) above was applied to a **Hybrid UAV**: the technological advances in brushless electric motors make a fully electric propulsion (via a suitable propeller) interesting. In the scheme developed here, we envision a UAV propelled by an electric motor powered by a small battery: when the battery SOC falls below a preset limit, the turbogas is switched on, recharging the battery. This peculiar mode of operation allows for a **fully «thermal» propulsion in the operational ranges in which noise is not an issue, and for a very low-dB propulsion in specific parts of the mission.**

The study was funded by an external Agency.



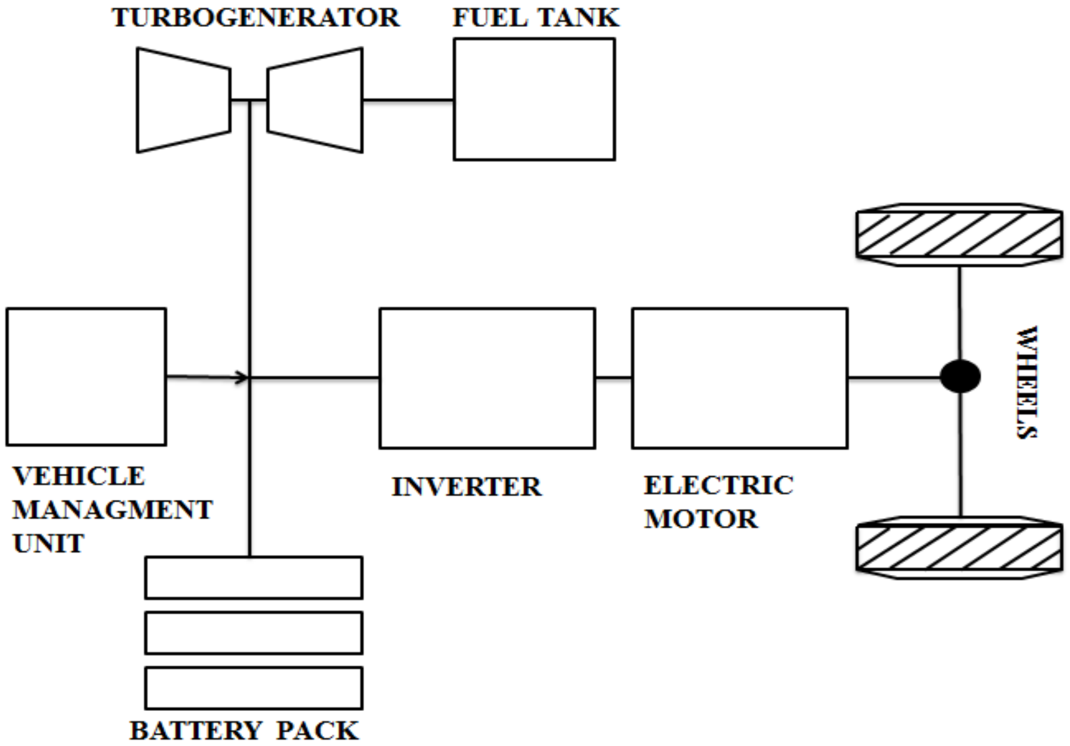


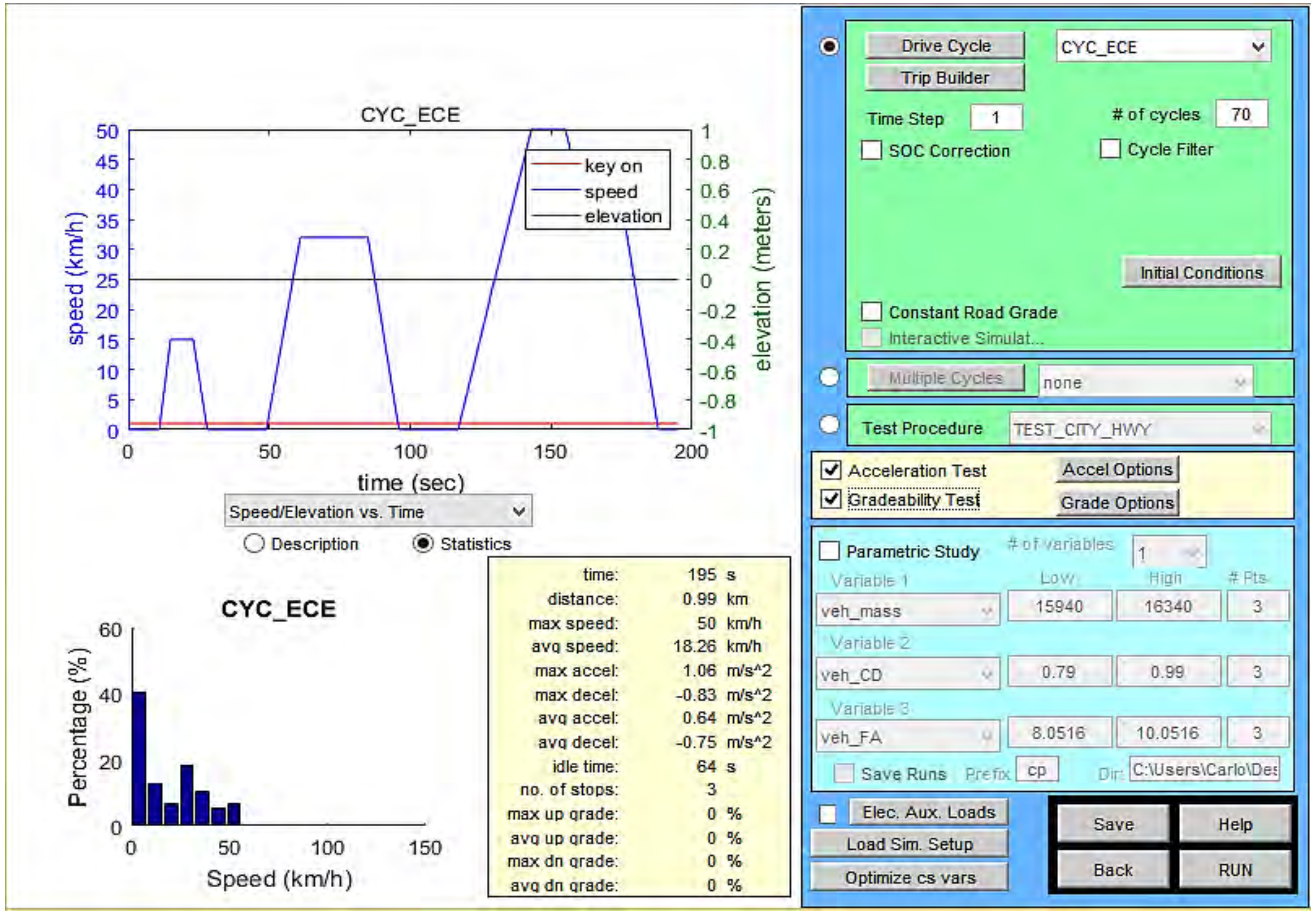
Participants: R.Capata, L.Marino, E.Sciubba

Turbomachinery - 3

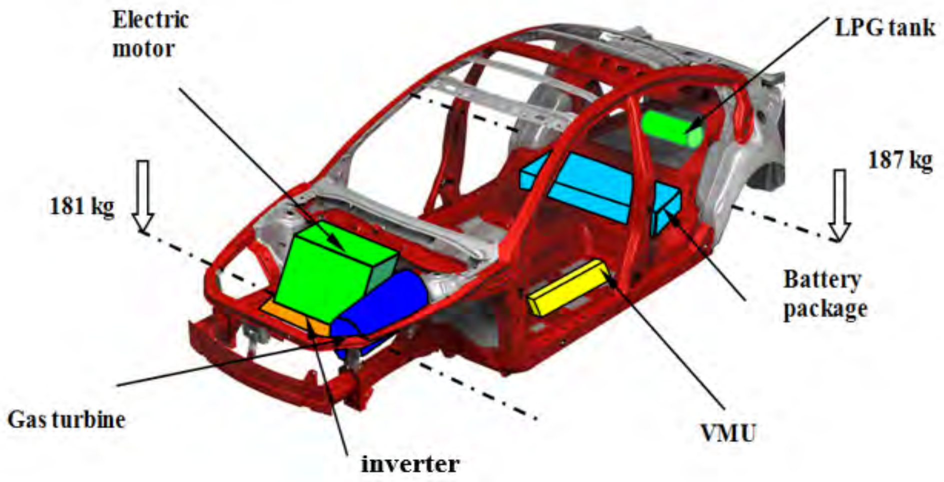
iii. As a logical spinoff of Phases (i) and (ii) a mini-turbogas concept was developed for a **Hybrid Vehicle**. One or two electric motors (depending on whether the traction is on one- or on both axles) power the vehicle. The electric power is provided by a battery pack. When the SOC of the batteries falls below a certain preset limit, a small turbogas is switched on, recharging the batteries. This configuration is called «series hybrid powertrain» (we nicknamed it Low Emission Turbo-Hybrid Engine - **LETHE**), and has several advantages: consumption per mission is lower; the fuel can be CH_4 or GPL; the weight of the electrical engine plus the GT is much lower than that of an equivalent ICE; the vehicle can be run in an all-electric mode in city centres and be repowered on the highway. Two sets of simulations were performed, for an **urban sedan** and for a **bus**: the results show that the concept is feasible, environment friendly and technologically advantageous. Funding is being provided by an external sponsor.

Participants: R.Capata, E.Sciubba, L.Tocci

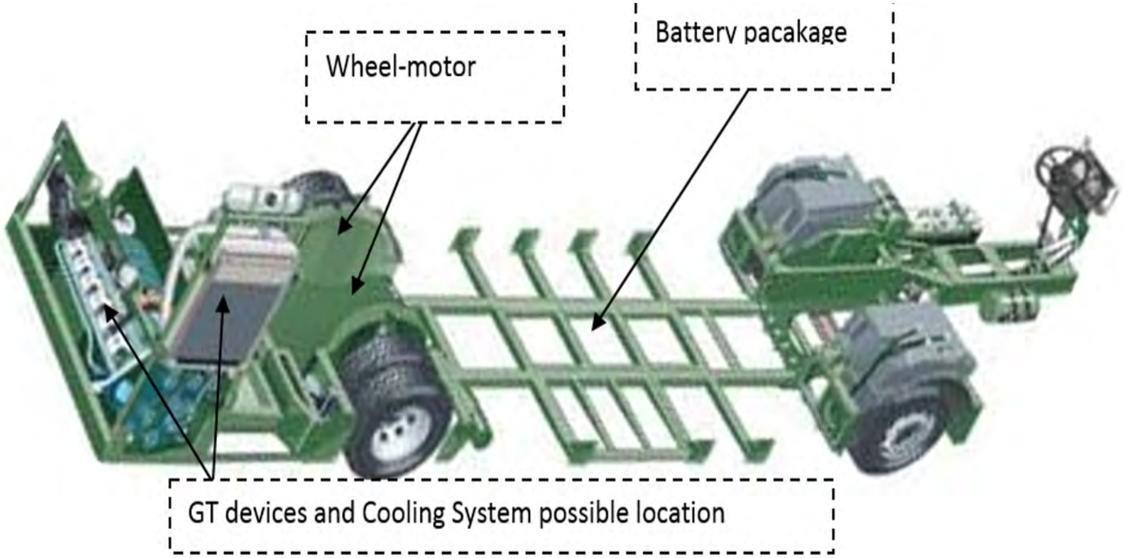




CYC_ECE
speed (km/h)
elevation (meters)
key on
speed
elevation
time (sec)
Speed/Elevation vs. Time
Description
Statistics
Percentage (%)
Speed (km/h)
time: 195 s
distance: 0.99 km
max speed: 50 km/h
avg speed: 18.26 km/h
max accel: 1.06 m/s^2
max decel: -0.83 m/s^2
avg accel: 0.64 m/s^2
avg decel: -0.75 m/s^2
idle time: 64 s
no. of stops: 3
max up grade: 0 %
avg up grade: 0 %
max dn grade: 0 %
avg dn grade: 0 %
Drive Cycle
Trip Builder
Time Step 1
# of cycles 70
SOC Correction
Cycle Filter
Initial Conditions
Constant Road Grade
Interactive Simulat...
Multiple Cycles
none
Test Procedure
TEST_CITY_HWY
Acceleration Test
Accel Options
Gradeability Test
Grade Options
Parametric Study
# of variables
Variable 1
Low
High
Pts
veh_mass 15940 16340 3
Variable 2
veh_CD 0.79 0.99 3
Variable 3
veh_FA 8.0516 10.0516 3
Save Runs
Prefix cp
Dir: C:\Users\Carlo\Des
Elec. Aux. Loads
Load Sim. Setup
Optimize cs vars
Save
Help
Back
RUN



Electric motor
LPG tank
181 kg
187 kg
Battery package
Gas turbine
VMU
inverter

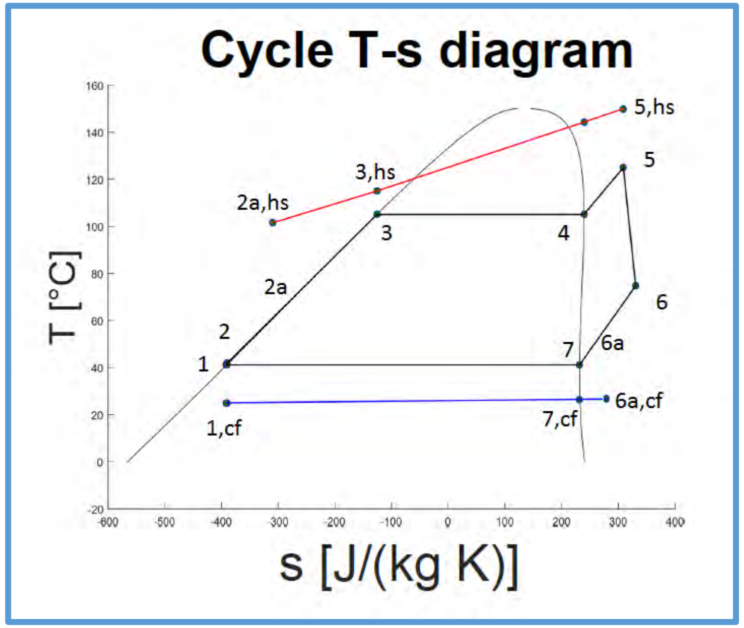


Wheel-motor
Battery pacakage
GT devices and Cooling System possible location

Turbomachinery – 4 & 5

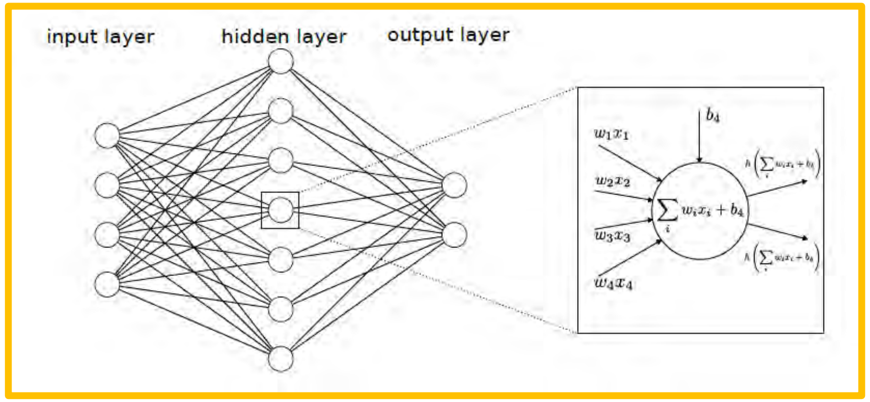
iv. As an alternative to the LETHE concept, a system is being studied to **recover the exhaust thermal power of a Diesel engine via an Organic Rankine Cycle** installed on board, directly downstream of the engine and upstream of the exhaust plenum. Since the temperature of the exhaust gas varies between 300 (turbocharged diesels) and 600 (air breathing diesel), and both values are quite well standardized, two configurations were considered. The first is based on a synthetic fluid operating in a Rankine cycle (whence the name ORC) that is boiled by the 300°C gas in a HRSG, expanded in a turbine, condensed in an additional radiator and compressed by a pump before being reinjected into the boiler. The second cycle is similar, but uses water as a working medium, because of the higher boiling temperatures. Both cycles have a relatively low efficiency (7-10% the low-T version and about 25% the high-T one), but the net gain in power output justifies their implementation. At present, three possible applications are being studied: one for a **British diesel train (nominal output 1000 kW, recovered power about 150 kW); a second one for a turbocharged commercial truck (nominal power 500 kW, recovered power about 35 kW), and one for a city taxi (nominal power 100 kW, recovered average power about 10 kW).** For all configurations, a feasibility study has been performed, and a **prototype system for the train** is being built by the sponsor (Entropea Lab, London) in their facilities in Baltimore. UDR1 has participated by designing the turbine.
The study is being funded by an external sponsor.

v. Another related study is underway: the application of an **ORC to a standalone microturbogas** (nominal power 100 kW, recovered power about 25 kW). This system -in a variant that comprises an additional absorption heat pump- has been proposed to the **Sapienza University for installation on the roof of the Aula Magna**. The design is being carried out completely by our group.
This study is being sponsored -via the spinoff CAESAR- by an external Company.
Participants: R.Capata, R.Masci, E.Sciubba, L.Tocci, C.Toro, other external co-authors

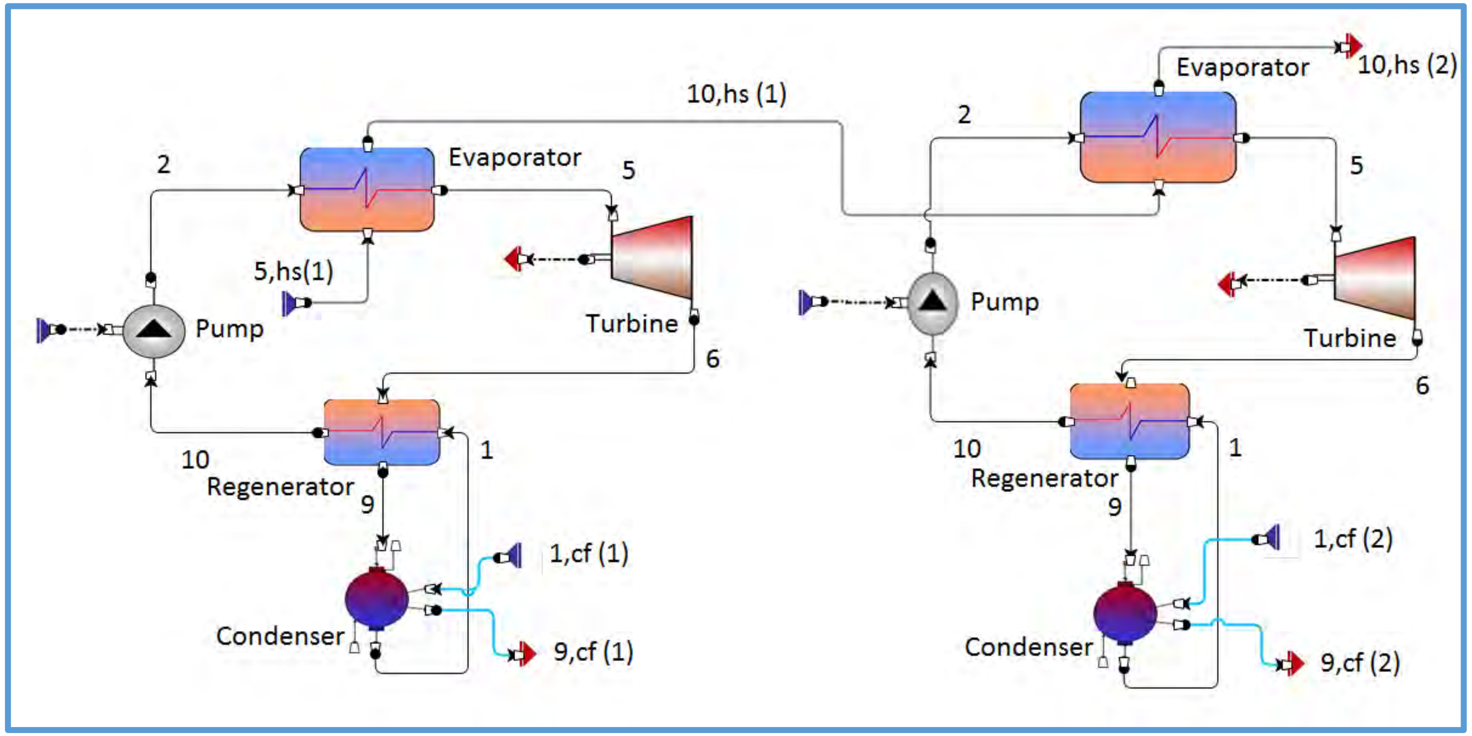


Thermodynamic modelling

Optimization using Neural Networks

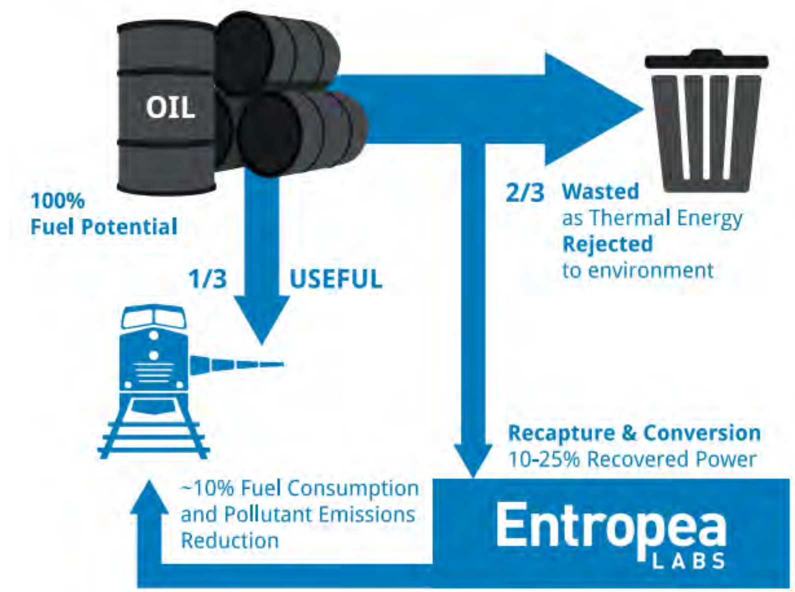


Plant layout

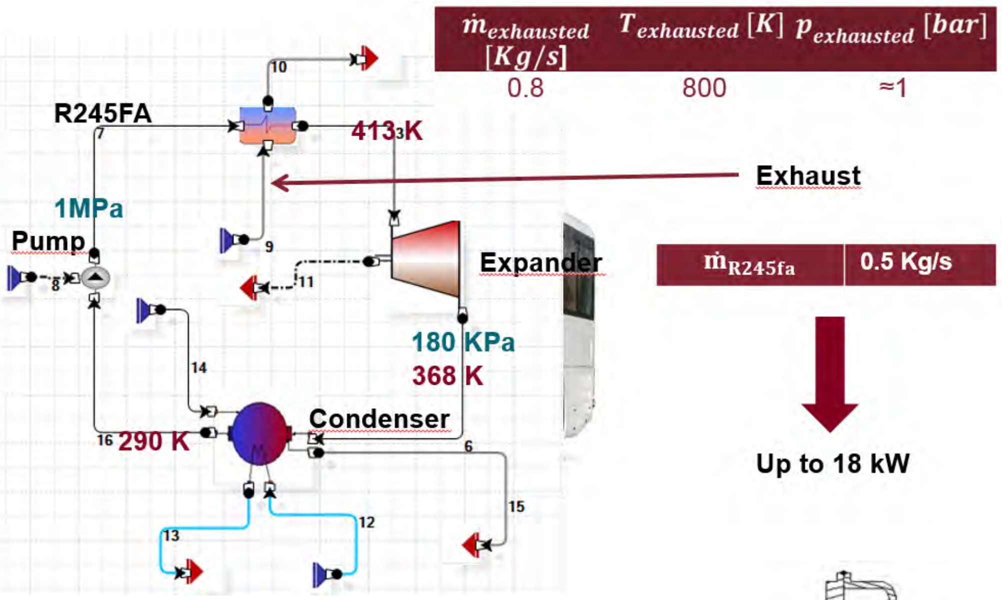


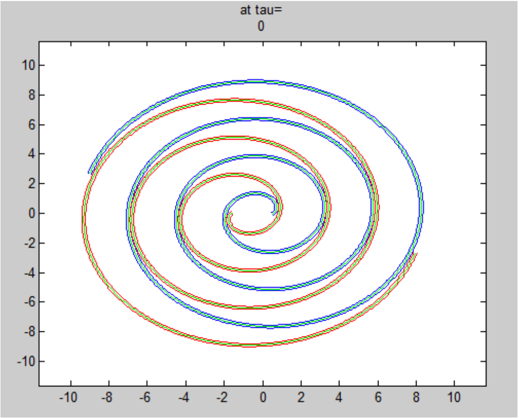
Small scale ORC optimization

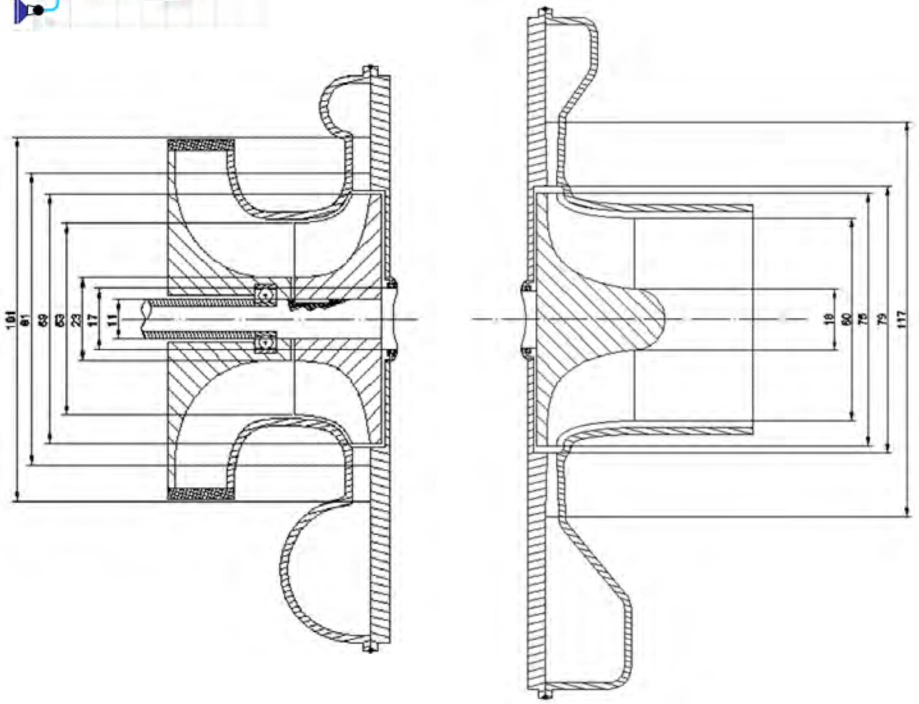
- Optimization of the ORC thermodynamic cycle
- Design and manufacturing of the ORC components in the small scale range (20 – 100 kWe)
- Testing facilities and labs for experimental validation

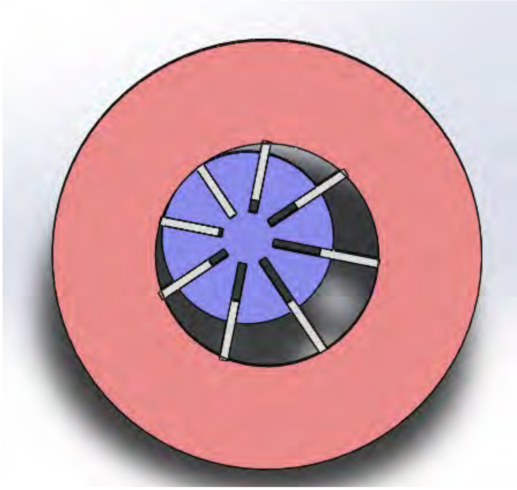


Fluid Machinery for ORC







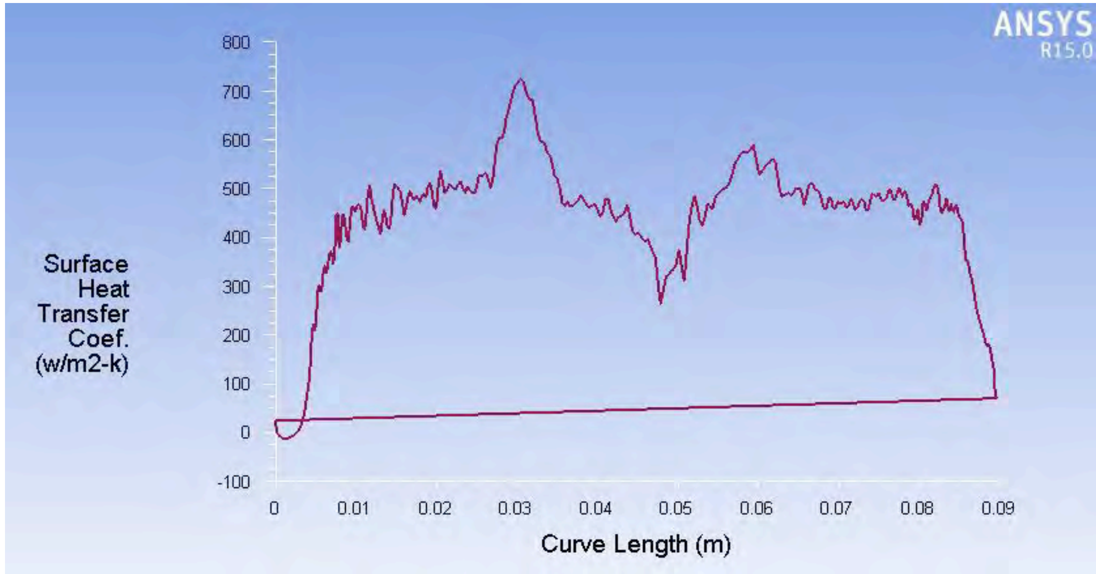


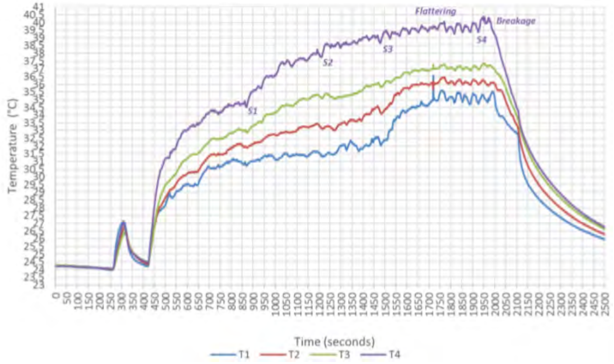
Turbomachinery – 6 & 7

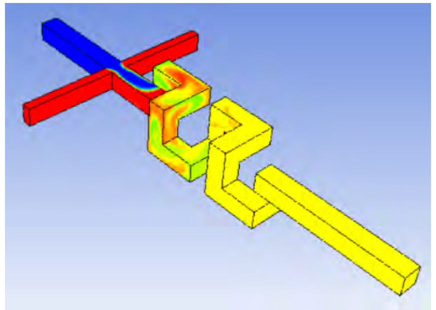
vi. CFD of turbomachinery components: viscous adiabatic turbulent flows in rotoric & statoric channels, both axial & radial. Accurate RANS ans LES simulations allow for a better identification the flow phenomenology: blade cooling, porous coating, entropy generation as a design decision parameter, heat recovered combustion chamber, modular super-compact heat exchangers for gas and organic fluid microturbines.

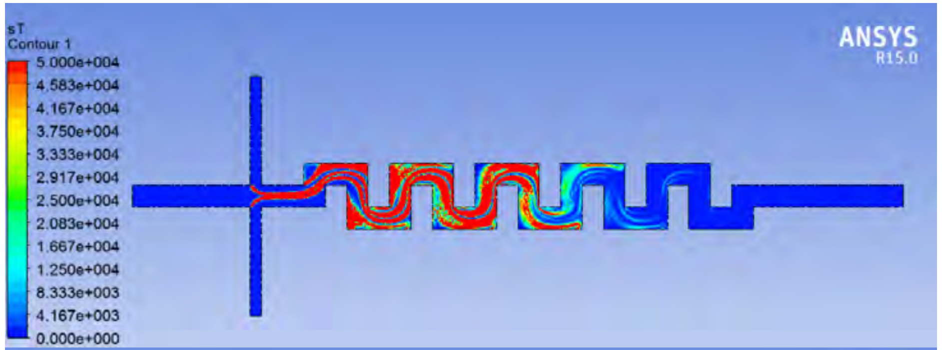
vi. Design and construction of an axial rotoric turbine blade in TiAl: conception, 3D simulation, structural analysis, advanced manufacturing, centrifugal melting of two generations of prototypes.

Participants: R.Capata, R.Masci, E.Sciubba, other external co-authors









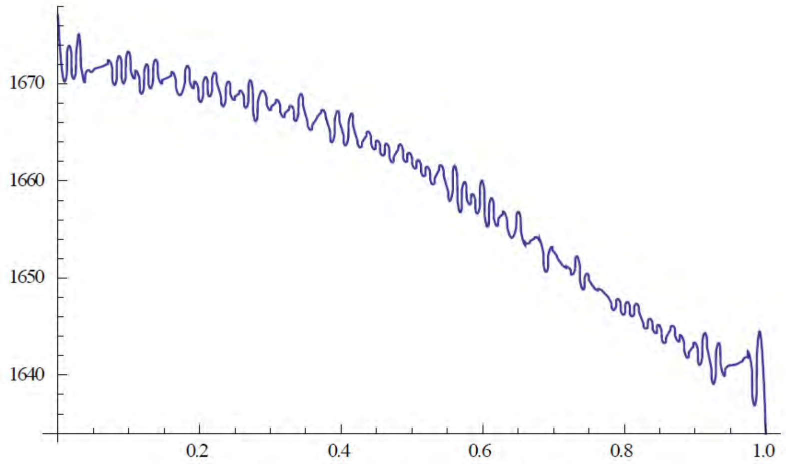
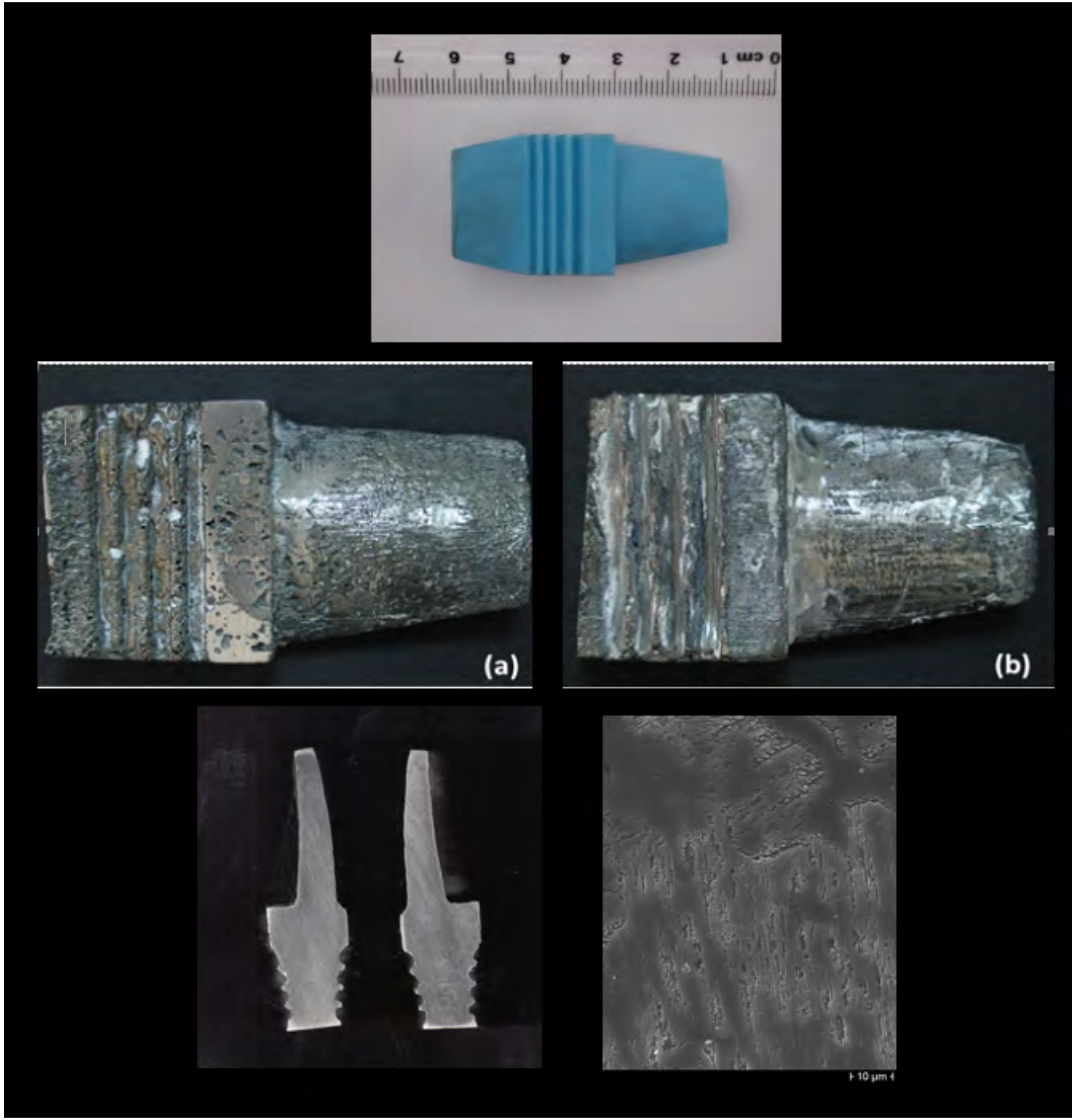
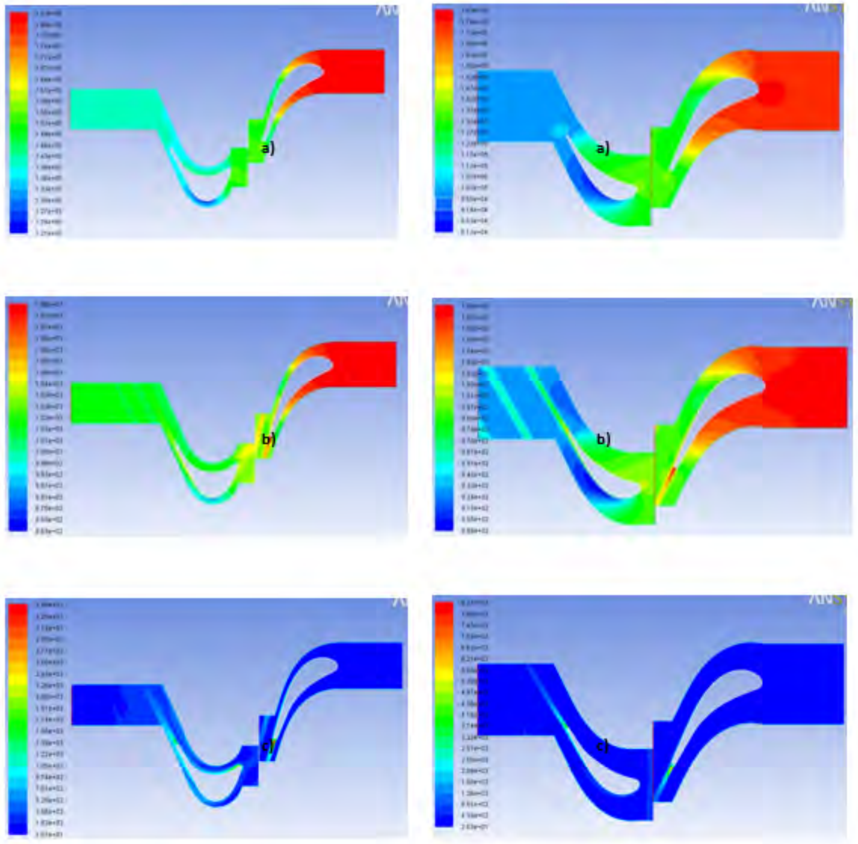
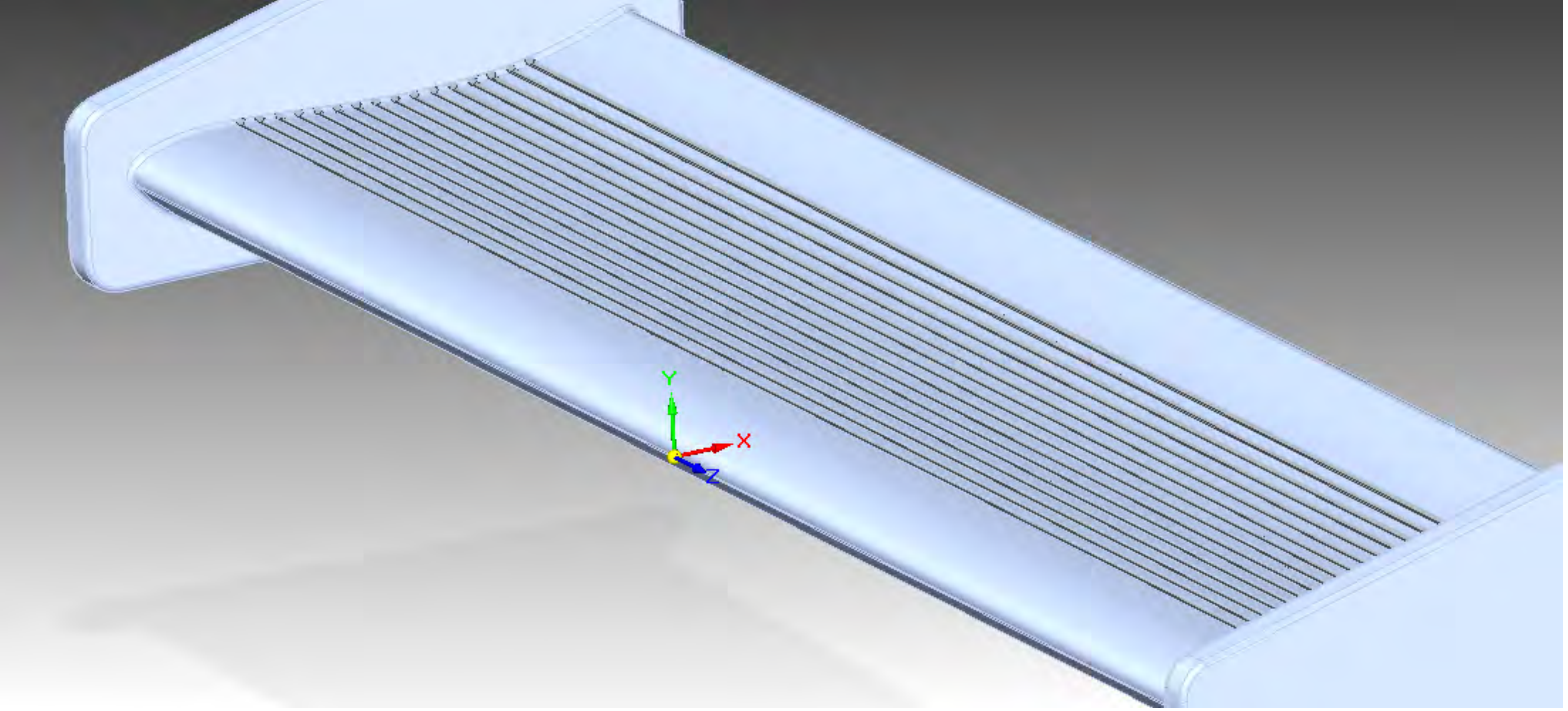
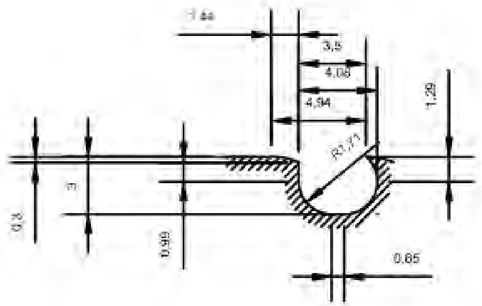


Figura 12. Temperatura pala con St (Mathematica)


(a)
(b)
10 µm

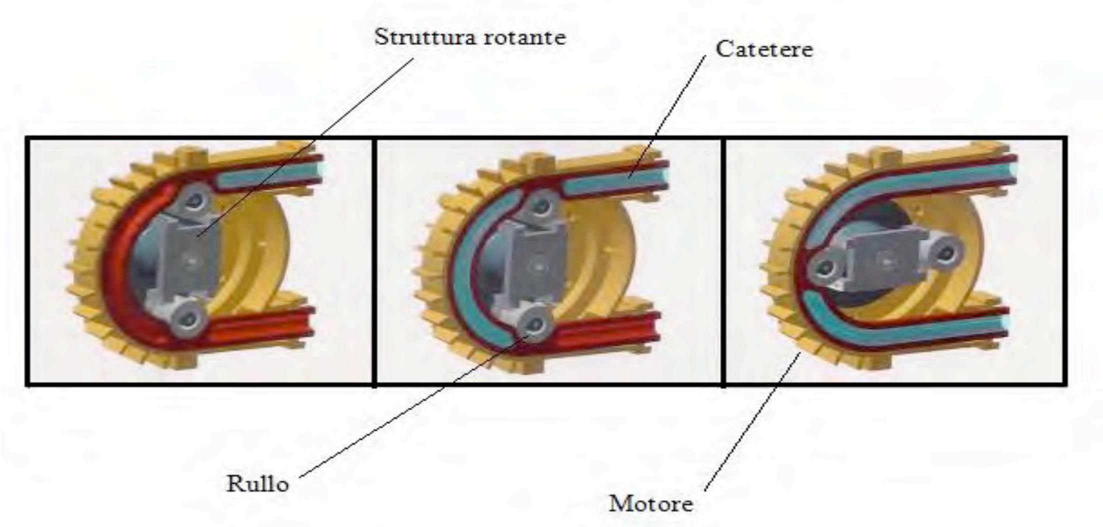

a)
a)
b)
b)
c)
c)

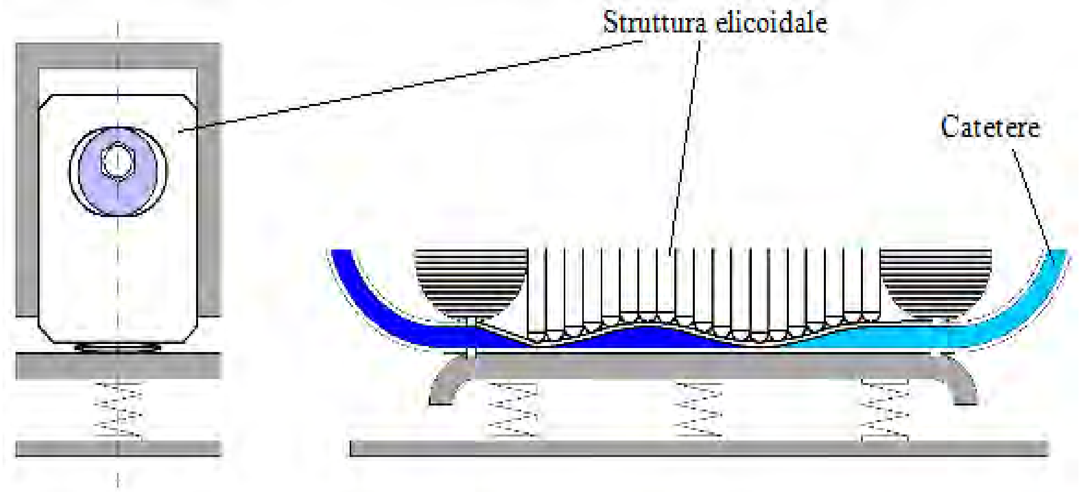

Y
X
Z

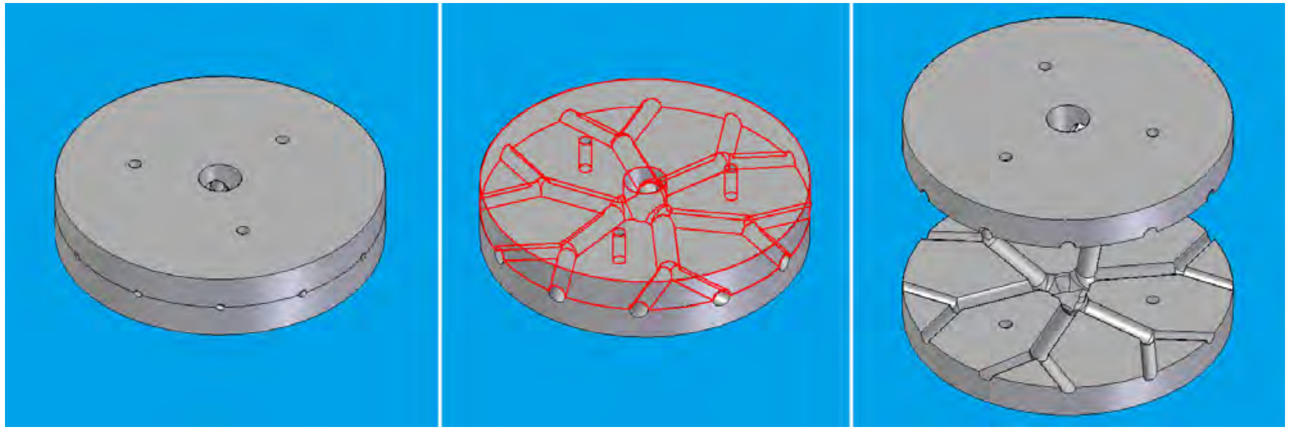

3,5
4,08
4,94
1,29
R1,71
0,3
3
0,99
0,65

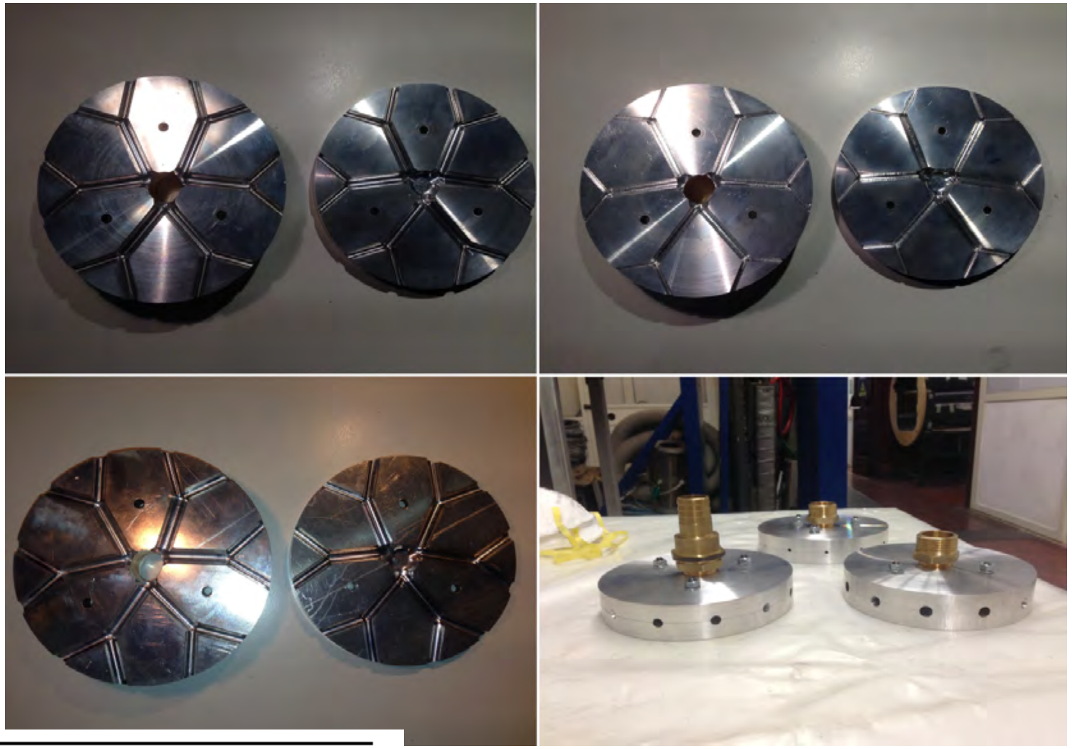
PERISTALTIC PUMPS IN DIALYSIS (R.Capata)

1. Allowable shear on blood cells vs. pumping head: parametric evaluation
2. Blood flow limiting capability, fluid behaviour evaluation
3. Rotary and/or reciprocating geometry analysis









“Constructal” heat exchangers: theoretical analysis, validation of design concept & testing of 3 prototypes.
R.Capata, E.Sciubba & other external co-authors

Water													
Configuration A													
$\dot{m} = 2\ l/min$													
T_{in}	T_{ex}	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
33	47	38,5	38,8	38,6	38,7	38,6	38,5	38,7	38,6	38,7	38,6	38,5	38,7
$\dot{m} = 4\ l/min$													
T_{in}	T_{ex}	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
38	45,8	40,3	40,4	40,4	40,3	40,5	40,4	40,5	40,6	40,4	40,5	40,4	40,5
$\dot{m} = 10\ l/min$													
T_{in}	T_{ex}	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
41	42	41,8	41,8	41,9	41,8	41,8	41,7	41,8	41,8	41,7	41,7	41,8	41,8

Turbomachinery – 8

viii. Conceptual definition, implementation and prototyping of an Expert System for the automatic preliminary design of turbomachinery (incompressible & compressible, axial and radial, single and multi-stage). A first-order design (type and structure, velocity triangles for each stage, specific work, efficiency and cost) is performed by an «intelligent expert system» consisting of a knowledge base of qualitative and quantitative design rules and of a multi-level inference engine that includes fuzzy decision rules.

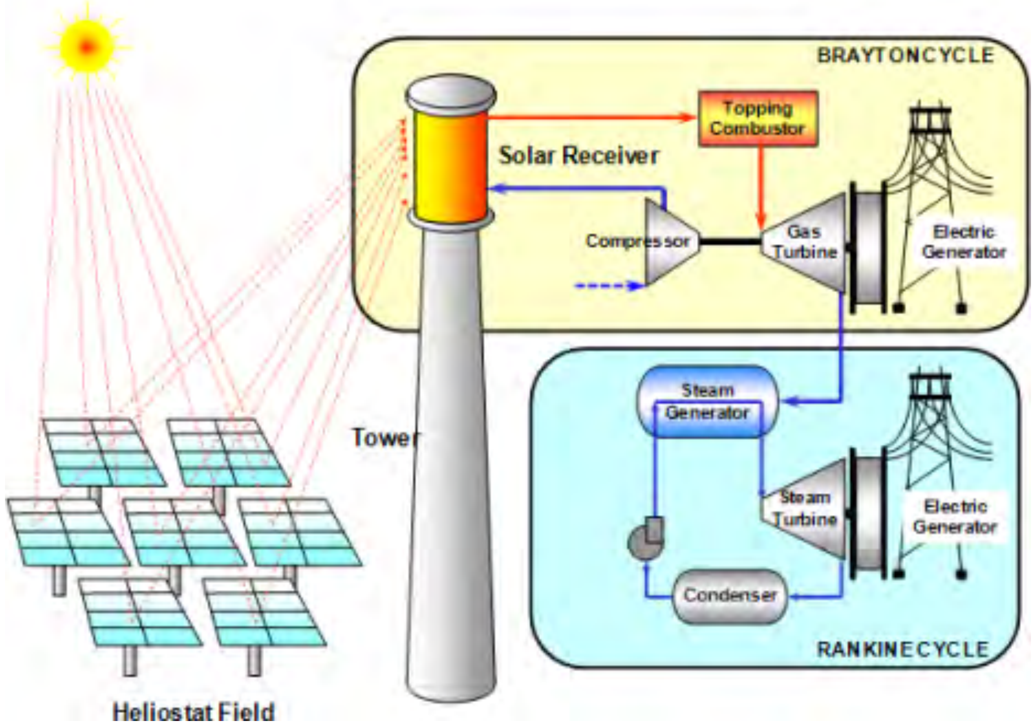
Theoretical & Applied Thermodynamics 1

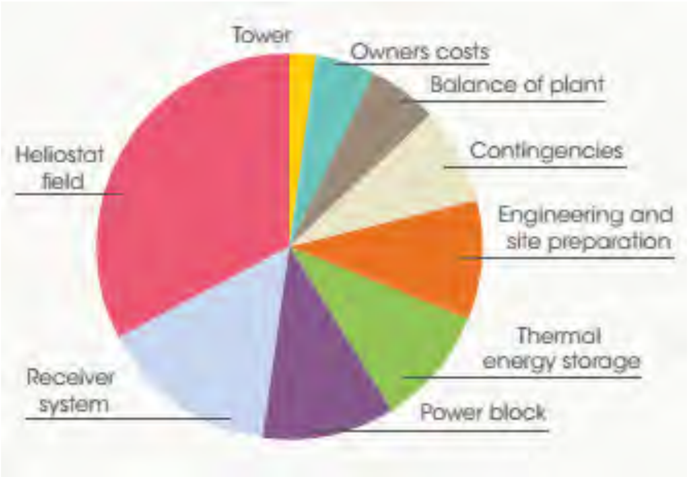
- Exergy-based analysis of energy conversion systems
- Thermo-Economic evaluations of the feasibility of different system configurations

A concept study: solar driven gas turbine

- GTCC hybridization with a **solar tower power plant**
- **Thermodynamic** and **thermo-economic analysis** of different plant configurations (Base-load/peaker designed power plant)
- **Plant simulations** at **different operating conditions** (linked to sunlight daily and short-term variations in cloudy days)
- Qualitative and quantitative assessment of **fuel savings**, **CO_2 emission reductions**

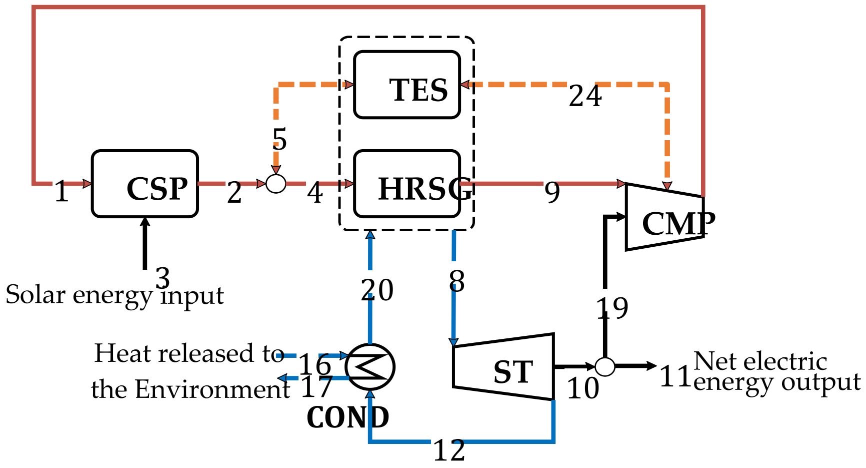
Participants: R.Masci, C.Toro, FBK Trento

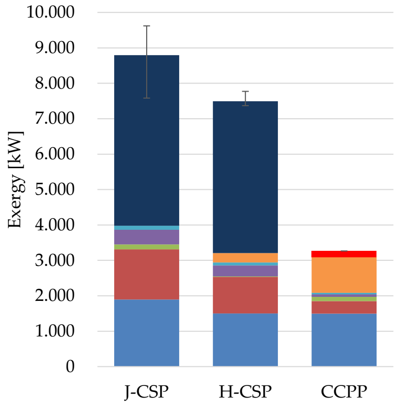


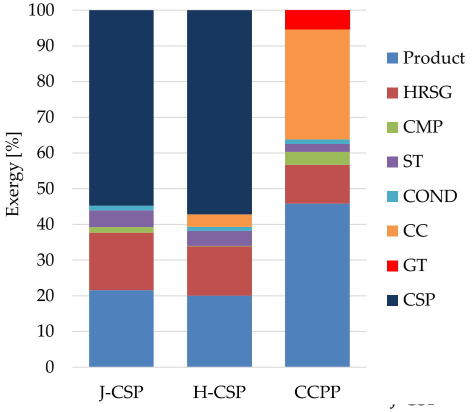


Solar tower **installation costs** breakdown

Thermo-Economic analysis of
High-T Concentrated Solar process using air as heat transfer fluid



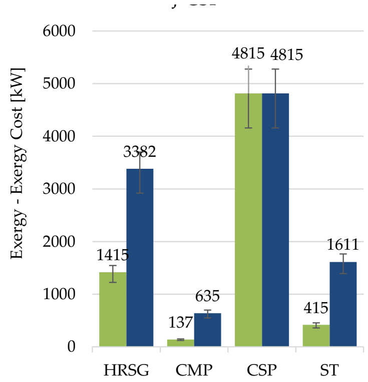


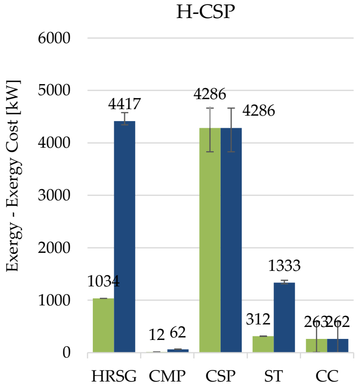


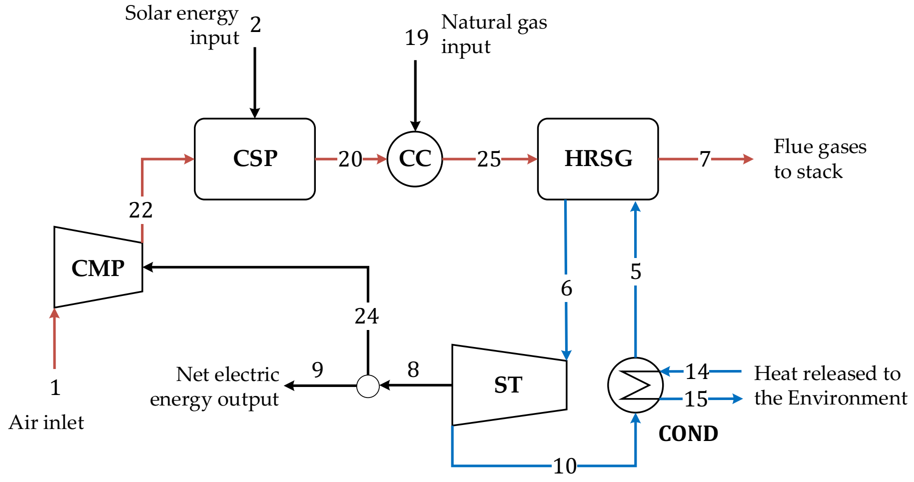
- Exergy Analysis

The Julich (J-CSP) CSP plant with thermal energy storage has been compared with a Hybrid plant (H-CSP) using air as working fluid

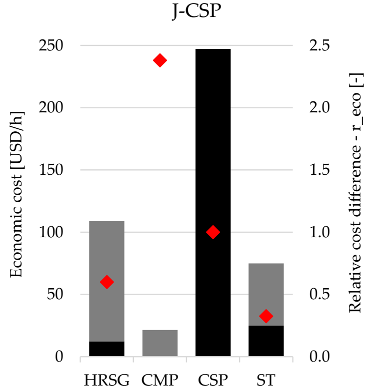
- Exergy Cost Analysis

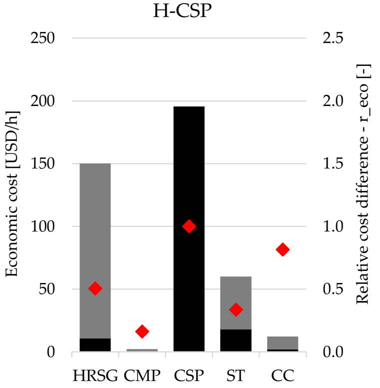




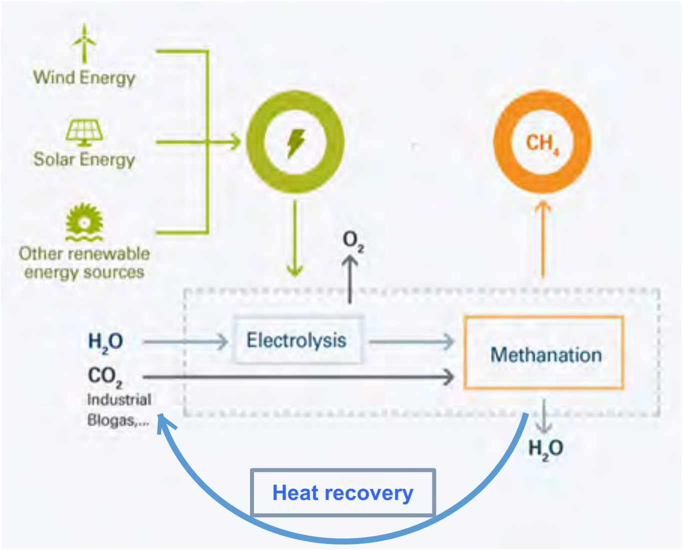


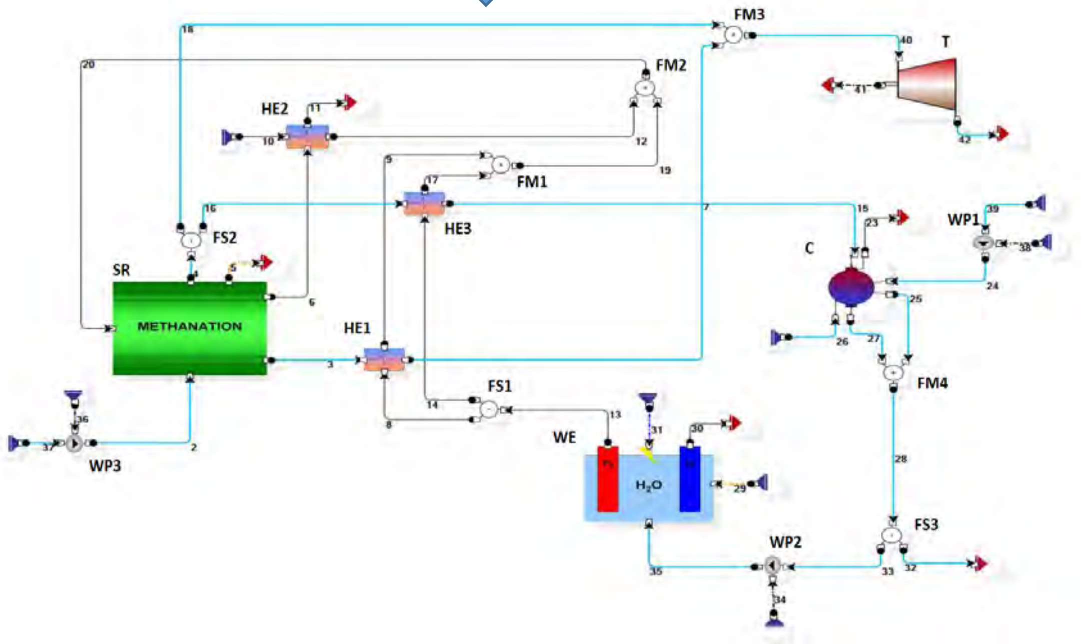
- Economic Cost

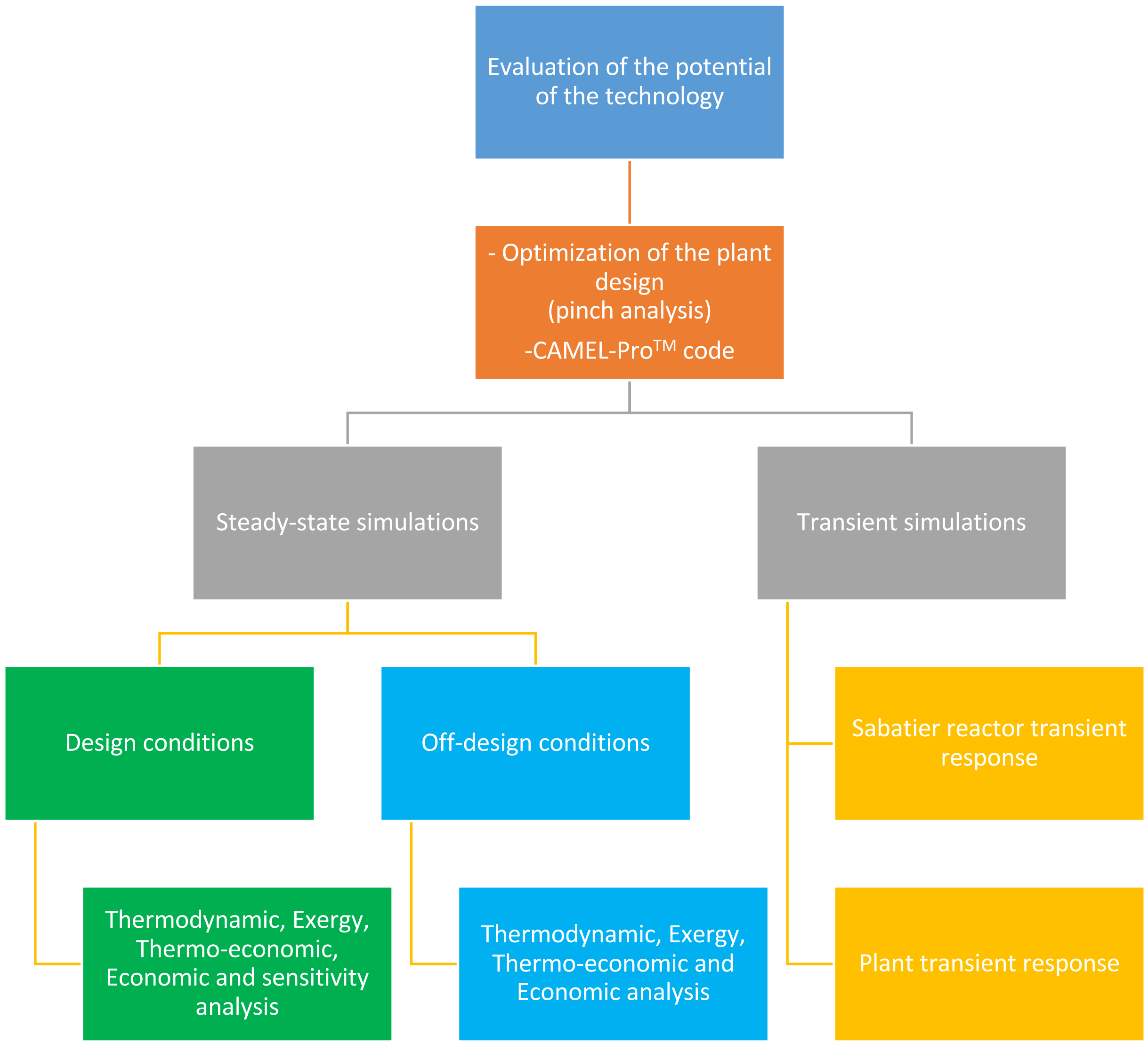




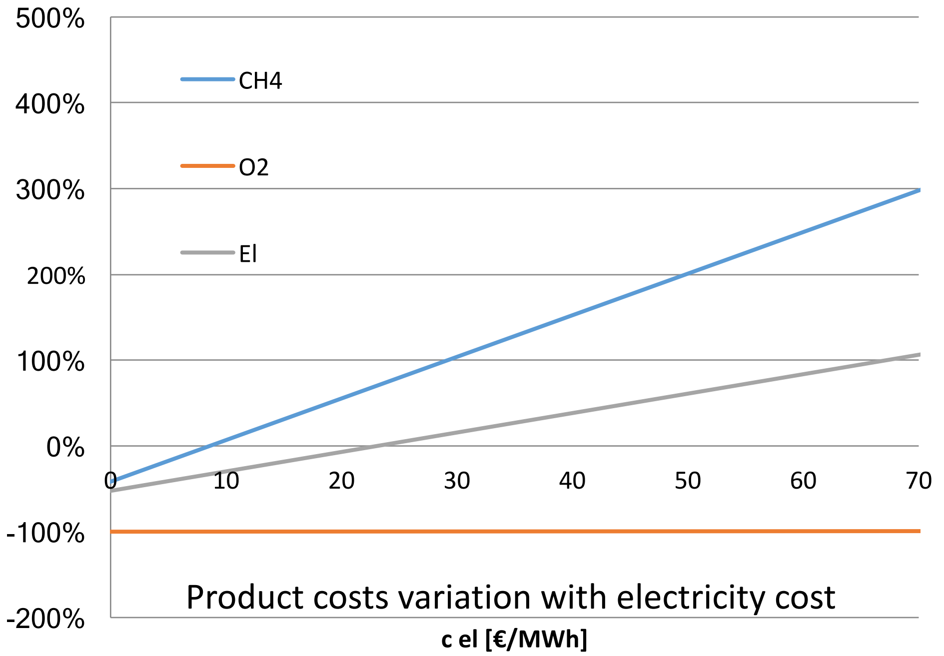
"Sabatier" CO_2 methanation

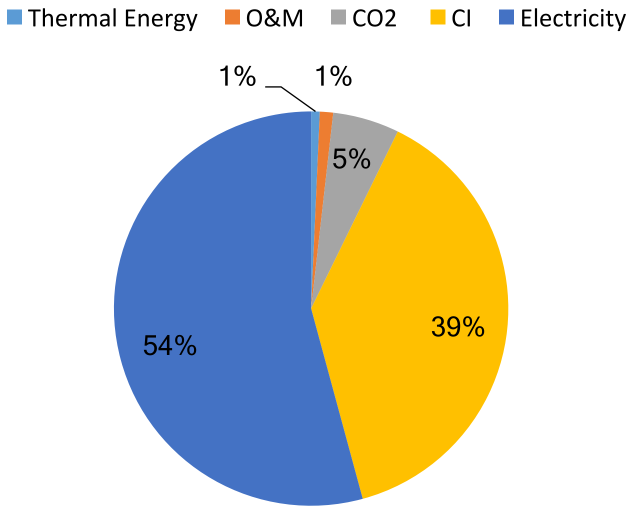


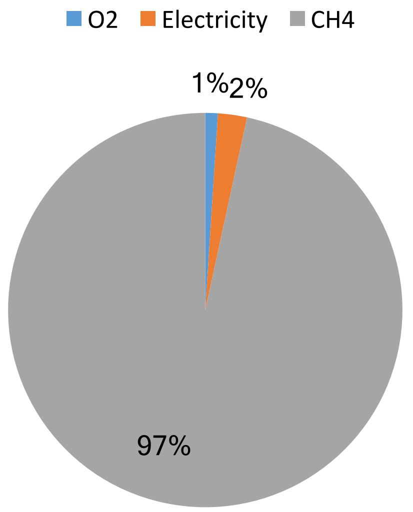




Sabatier based cycle for CO_2 methanation







Share of product costs

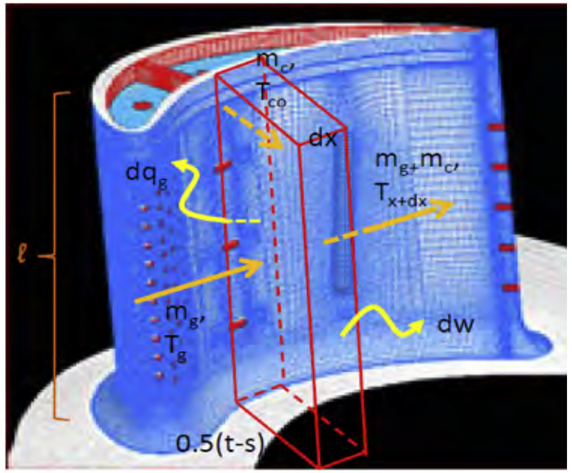
Cost assumptions	
Electricity cost [€/MWh]	20
CO_2 sequestration [€/t_{CO2}]	25
CO_2 emission trades [€/t_{CO2}]	9
Thermal energy [€/MWh]	31
Operation hours [h/year]	7008

Products Cost	
CH_4 cost [€/smc]	0,47
O_2 cost [€/smc]	0,003
Electricity cost [€/MWh]	50,44

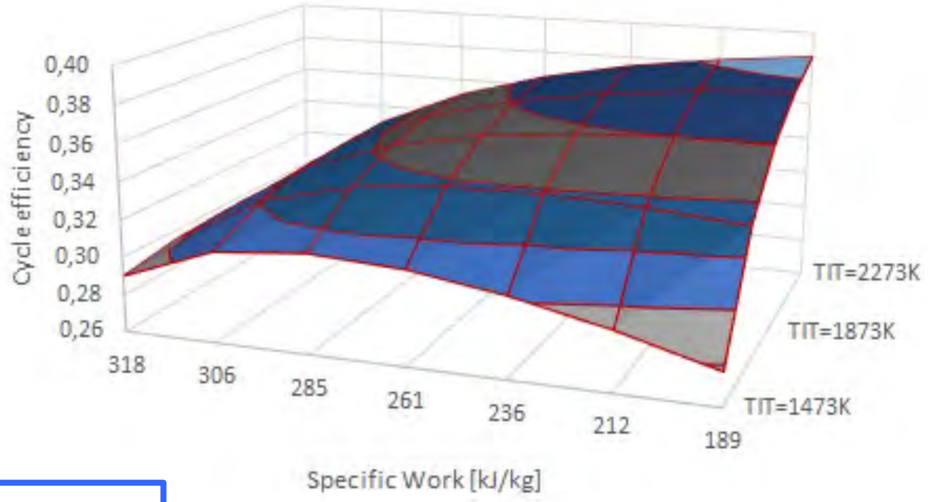
Participants
R.Masci, E.Sciubba, C.Toro

Air-cooled gas turbine cycles: simulation of first-stage cooling effects on gas turbine cycle performance

A lumped thermodynamic model of blade cooling

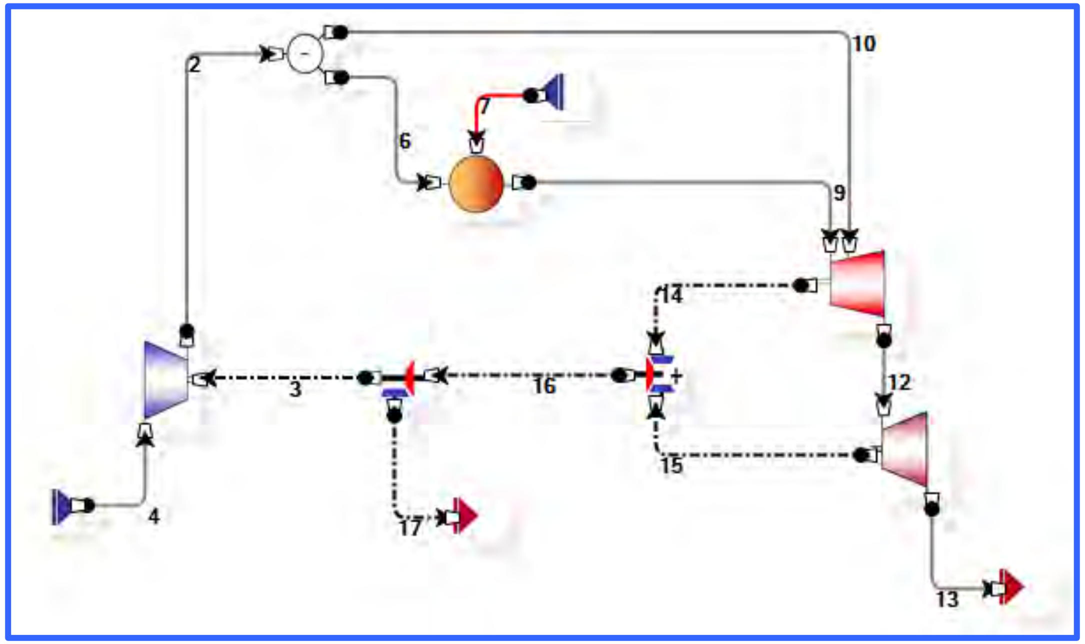


At a given PR, a **maximum** in **thermal efficiency** is likely to be reached below stoichiometric conditions, imposed by the **large amounts of cooling air** required



First-stage cooling requirements

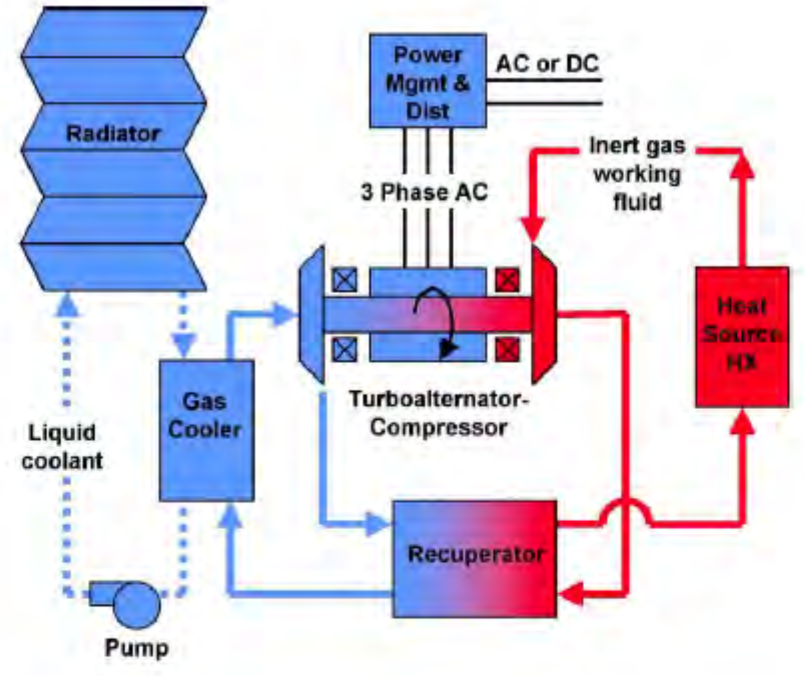
CAMEL-Pro™ GT Power Plant

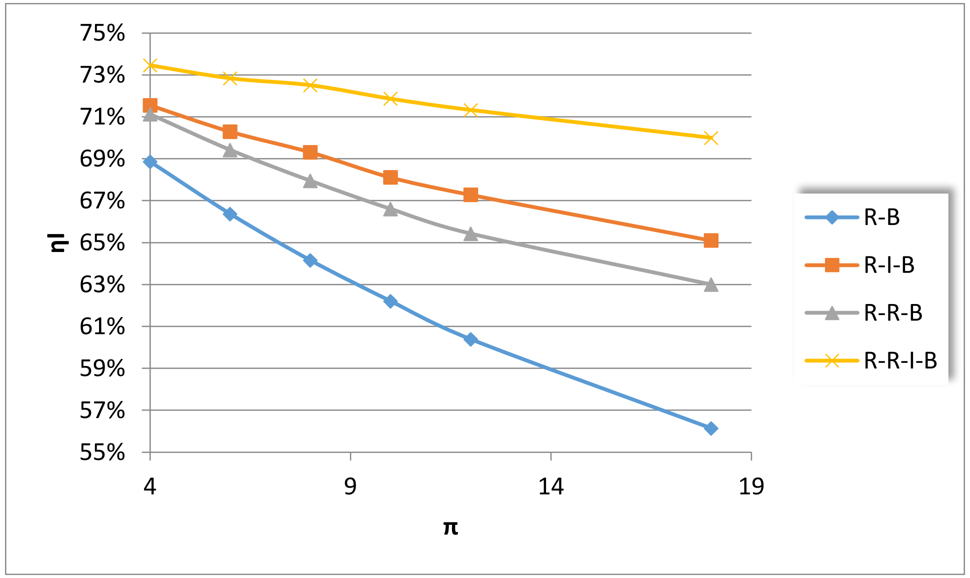


Thermodynamic analysis

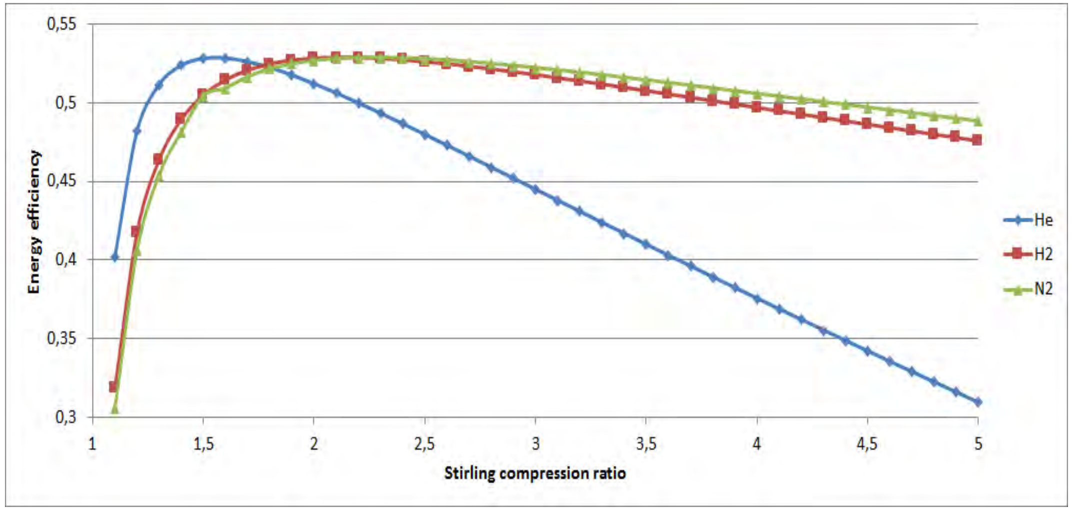
Participants
R.Masci, E.Sciubba

Analysis and comparison of solar-heat driven Stirling, Brayton and Rankine cycles for space power generation





Comparison of thermal efficiency of Brayton cycles with different configurations



Stirling cycle thermal efficiency comparison for different working fluids (T_H=1500K, T_L=200K, ε_r =0.85)

Participants

C.Toro, other external co-authors

Rankine and Brayton cycles results

(R-B Regenerative Bryton; R-R Regenerative Rankine; R-R-R Regenerative-Reheated-Rankine; R-R-B Regenerative-Reheated-Brayton; R-I-B Regenerative-Intercooled-Brayton; R-R-I-B Regenerative-Reheated-Intercooled-Brayton)

	R-B			R-R		R-R-R		R-R-B	R-I-B	R-R-I-B
Cycle parameter	H_2	N_2	$50\%_{vol}N_2$ $50\%_{vol}H_2$	Ar	N_2	N_2	Ar	N_2	N_2	N_2
p_L [bar]	1	1	1	0.75	0.15	0.75	0.15	1	1	1
T_L [K]	200	200	200	84	64	65	85	200	200	200
π/	10	10	10	200	1000	1000	200	10	10	10
TIT	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
η_{I} [%]	61.7	62.2	67	77.87	84.25	88.9	84.28	66.6	68.1	71.8
ε [%]	61.8	62.36	70.5	78.3	84.63	89.34	84.8	70.11	71.68	75.65
ψ [kW/m²]	0.8344	0.847	1.062	0.01413	0.00797	0.0117	0.02115	1.037	0.479	0.575

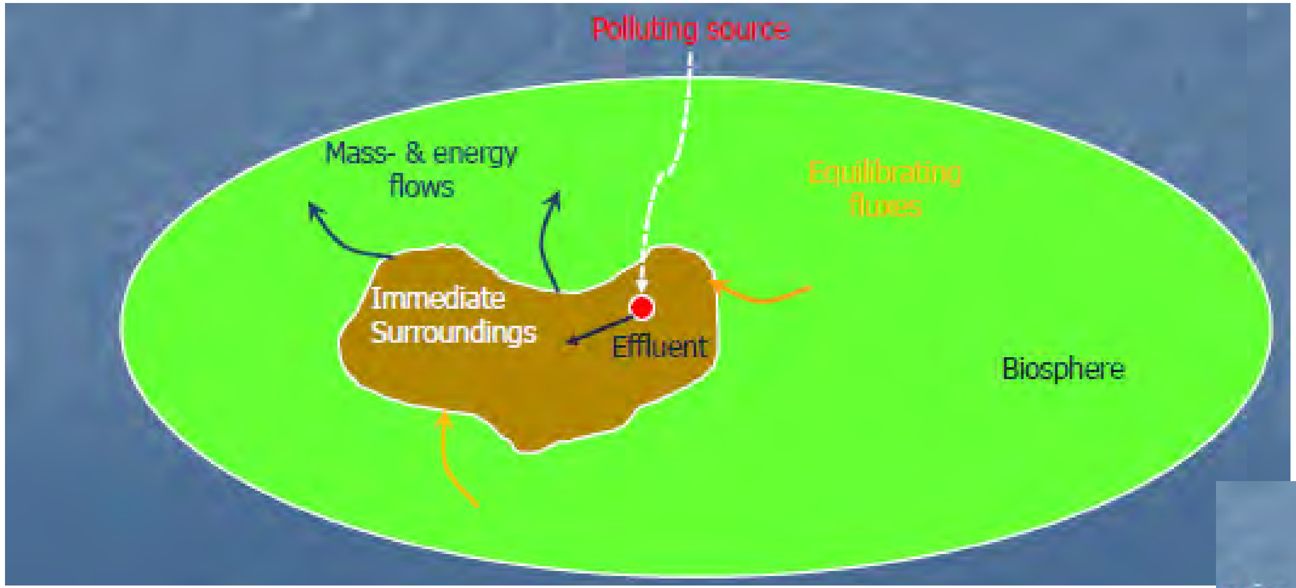
Stirling cycles results

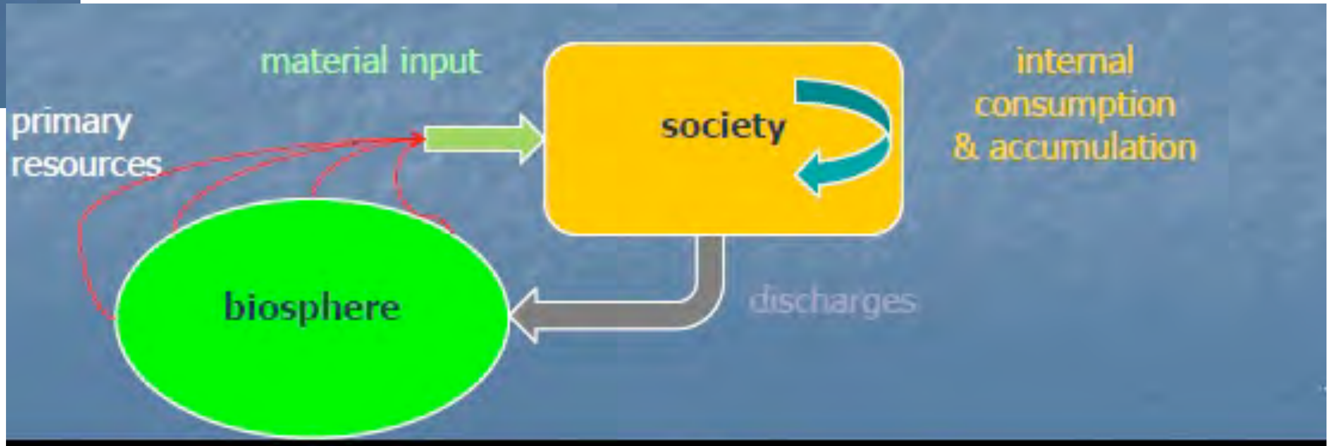
Cycle working fluid		H_2			N_2		
Stirling working fluid		H_2	N_2	He	H_2	N_2	He
p_L [bar]		1	1	1	1	1	1
T_L [K]		200	200	200	200	200	200
rv		2.15	2.3	1.55	2.15	2.3	1.55
T_H		1500	1500	1500	1500	1500	1500
$m_{wf,hs}$ [kg/s]		0.060	0.060	0.060	0.78	0.78	0.78
$m_{wf,cs}$ [kg/s]		0.011	0.011	0.011	0.16	0.16	0.16
$\eta_{Stirling}$ [%]		62.2	62.2	62.2	62.2	62.2	62.2
η_{I} [%]		52.8	52.8	52.8	52.8	52.8	52.8
ε [%]		64.8	64,8	63.3	64.8	64,8	63.3
ψ [kW/m²]		0.483	0.483	0.483	0.483	0.483	0.483

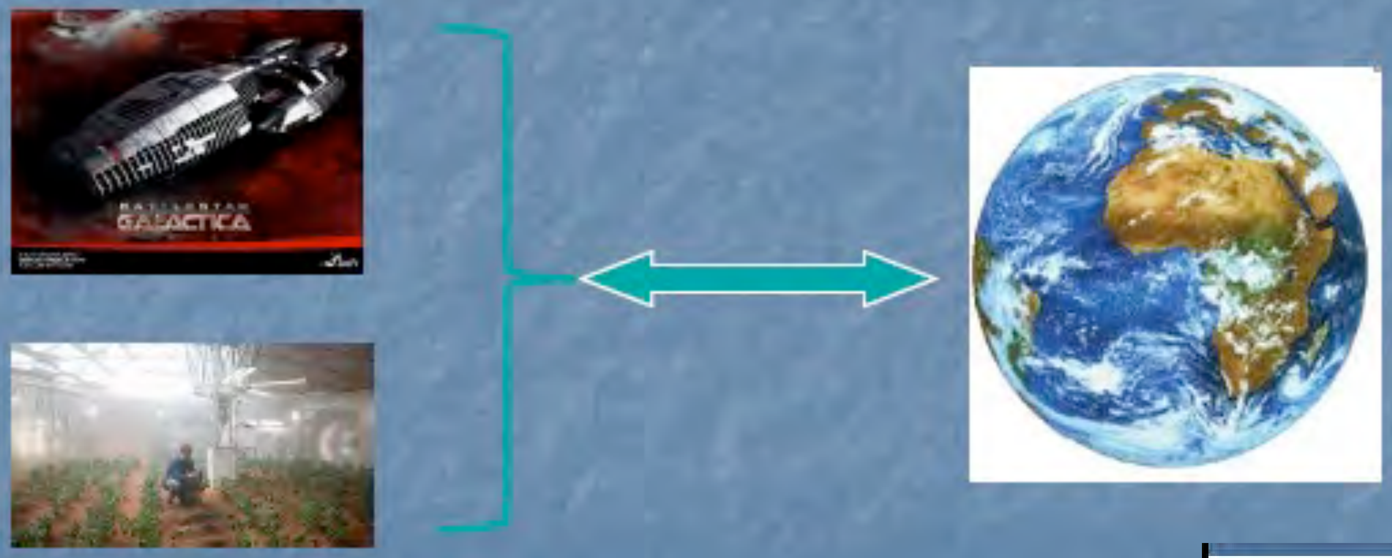
Theoretical & Applied Thermodynamics 2

Extended Exergy Analysis: a rigorously thermodynamic-based method for the identification of the exergy footprint of a society.

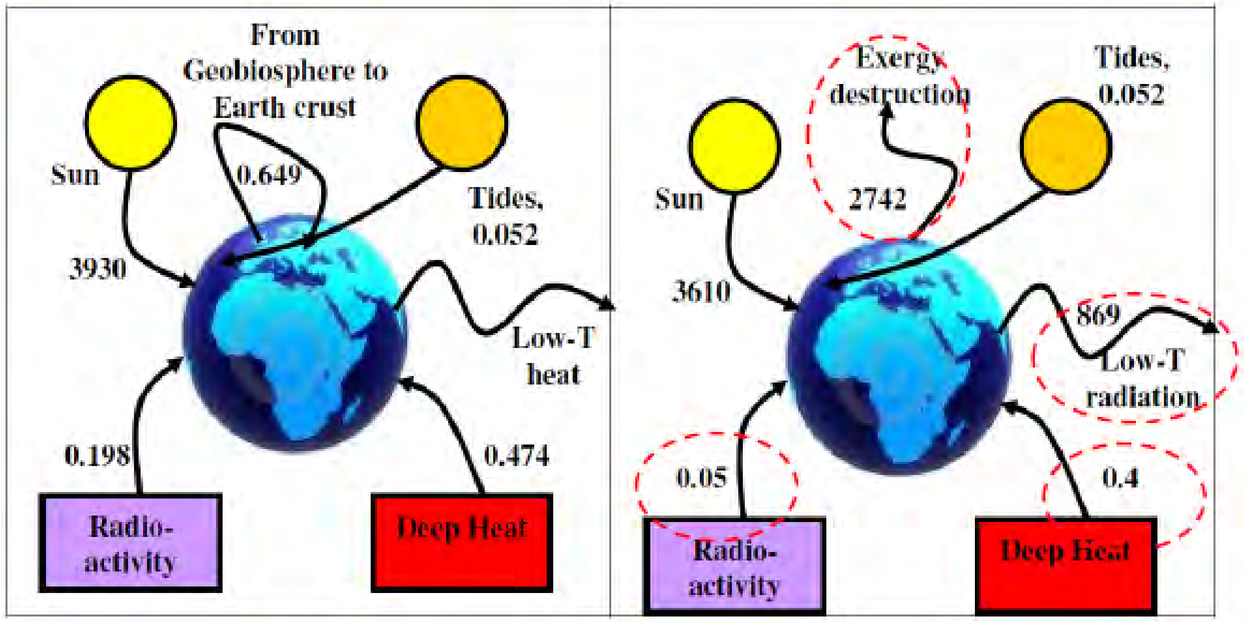
E.Sciubba







…the analogy is transparent!

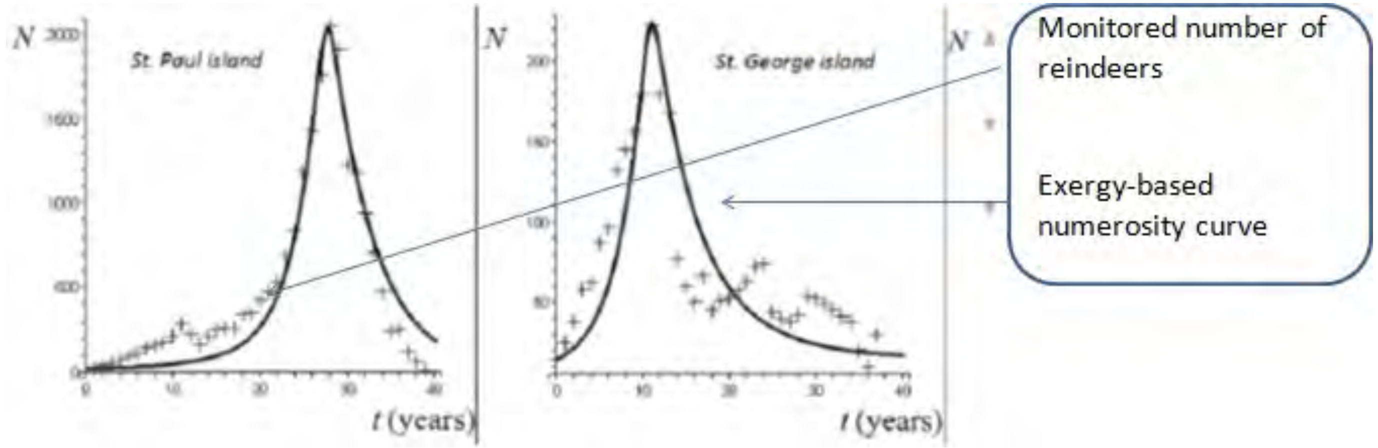


The Earth's budget according to the EMA (left) and EXA (right)
All flows in YJ

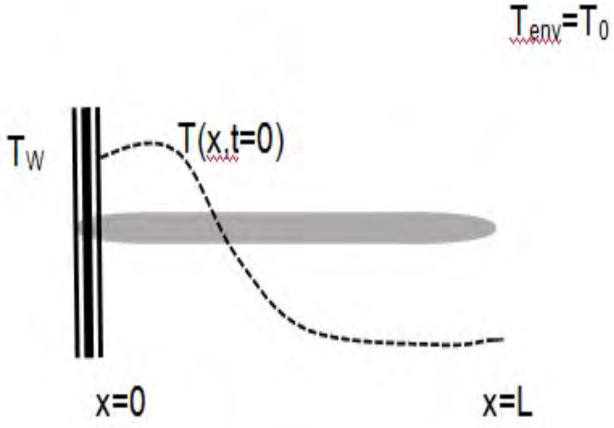
Theoretical & Applied Thermodynamics 1

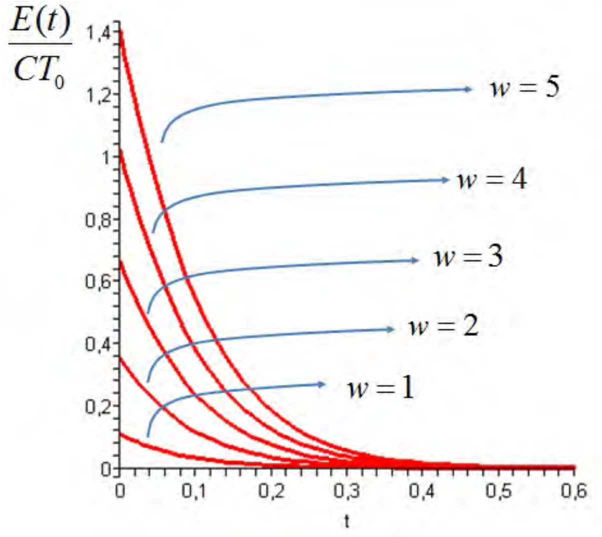
Analisi exergetiche dei sistemi di conversione dell'energia e approfondimenti di termoeconomia per la valutazione di fattibilità di diversi sistemi, anche a fonti rinnovabili.

•Modelli di dinamica delle popolazioni e sostenibilità che includono principi termodinamici

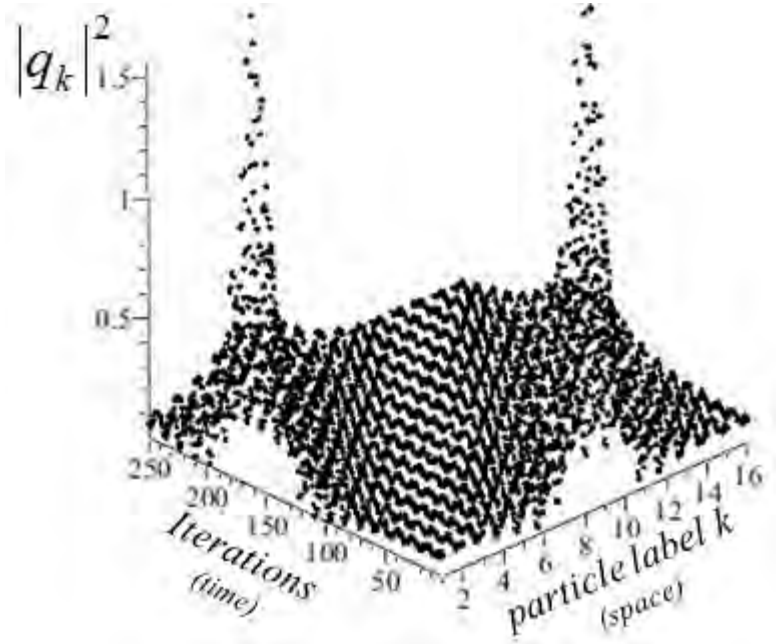


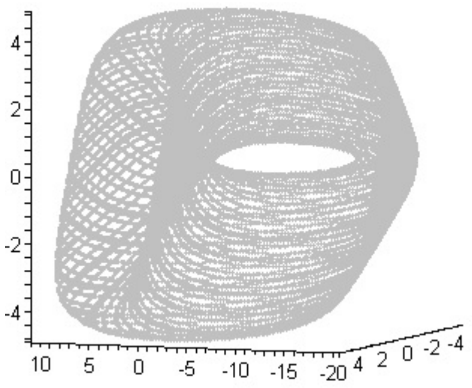
•Studio di processi termodinamici di non-equilibrio

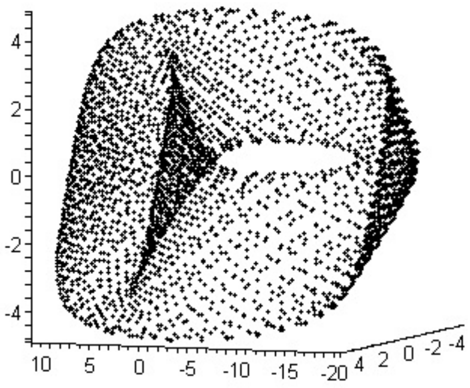




•Discretizzazione di sistemi integrabili (con applicazioni in analisi numerica) tramite trasformazioni di Backlund







•Studio di funzioni automorfe e loro rappresentazioni e studio delle funzioni di Painlevé, in particolare per le loro applicazioni in:

✓Fisica del plasma, onde non lineari (resonant oscillations in shallow water, convective flows with viscous dissipation, Görtler vortices in boundary layers, Hele-shaw problems).

✓Problemi di conduzione del segnale in fibre ottiche con risposta non-lineare.

Theoretical & Applied Thermodynamics 1

Diagnostica e Prognostica di Impianti
Sviluppo di programmi per la classificazione e previsione
di catene di guasto per impianti per la produzione di energia
con l'utilizzo di metodologie intelligenti open source

Sviluppo di codici per l'ottimizzazione di reti di scambiatori di calore
applicata a impianti di liquefazione gas, impianti industriali

Progettazione di impianti di dissalazione

Sviluppo di programmi per l'analisi della diffusione in relazione alle condizioni ambientali
di sostanze inquinanti e nocive quale supporto ai gruppi di primo intervento