Performance Untapped Modulation for Power and Heat via Energy Accumulation Technologies

PUMP-HEAT project

Flexible Combined Cycles for the future RES-based Energy Market

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RINA Consulting SpA - University of Genoa, Italy

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Start Date: 1st September 2017
End Date: 31st August 2021

This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 764706

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PUMP HEAT Main Challenge

Combined Cycle Gas Turbine (CCGT) are facing **highly demanding efficiency and flexibility requirements** and often they are not profitable enough to avoid mothballing or closure

Heat pump integration in CCGT is as an opportunity to make CCGT the **bridging technology to a decarbonized economy** but they must win the following main challenges:

- Enhance the **plant flexibility** and **overall efficiency**
- Be **techno-thermo-economically viable** compared to already known solutions

1. Power only CCGT

2. Combined heat and power CHP

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PUMP-HEAT in a nutshell

THE NEED: Gas Turbine (GT) OEMs and energy utilities look for power flexibility especially for CHP Combined Cycles (CC), constrained by thermal demand, hence providing limited grid services.

THE IDEA: PUMP-HEAT proposes an innovative concept based on the coupling of CCs with a fast-cycling highly efficient **Heat Pump** (HP) equipped with **Thermal Energy Storage** (TES).

The integrated system features an **advanced control** concept for smart scheduling:

- the HP modulates power to cope with the CC reserve market constraints;
- the *high temperature heat* can be exploited in the district heating network (DHN);
- the *low temperature cooling* can be used for gas turbine inlet cooling.

The CC integration with a HP and a cold/hot TES brings to a reduction of the Minimum Environmental Load (MEL) and to an increase in power ramp rates, while enabling power augmentation at full load and increasing electrical grid resilience and flexibility.

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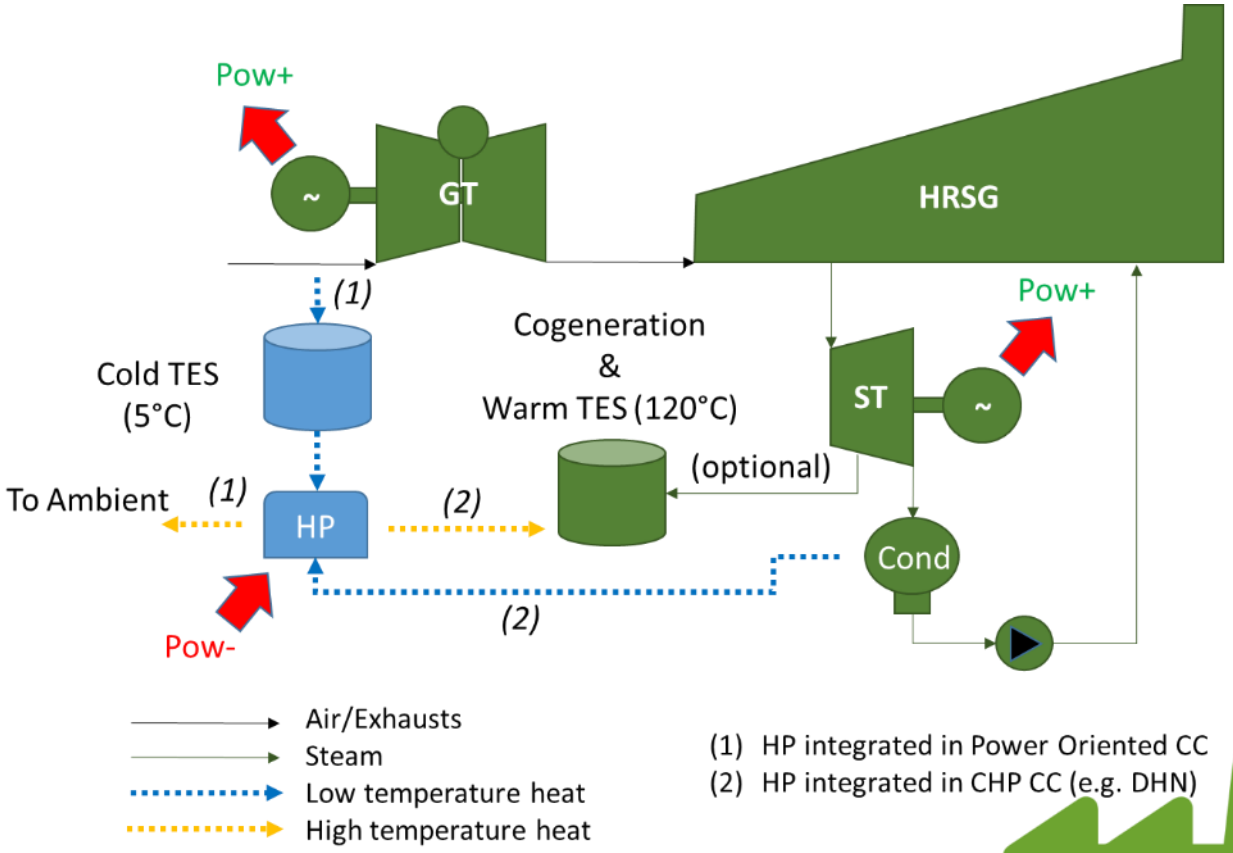
PUMP-HEAT concept overview

- Heat Pump (HP) as a *smart electrical load*
- HP may allow CC to sell grid services also when the CC is off
- HP will impact on the GT inlet air, reducing P_min and augmenting P_max as required
- HP can produce useful heat for DHN, displacing auxiliary boilers
- HP will also increase the CC average annual efficiency



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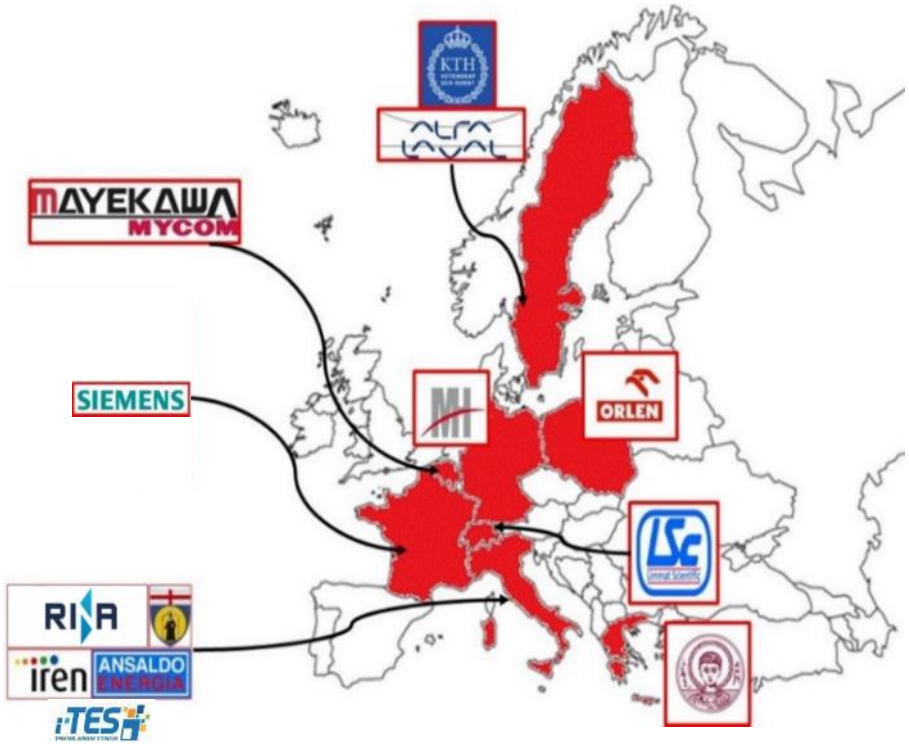
PUMP-HEAT Consortium



PUMP-HEAT

an Industry-driven Consortium

This guarantees:

- Industrial and Market interest to project outcomes
- Involvment of wide range of stakeholders
- Strong commitment to PHCC realization
- A common «project business» to be pursued made by «different actors' business»
- Ability to overcome contingencies

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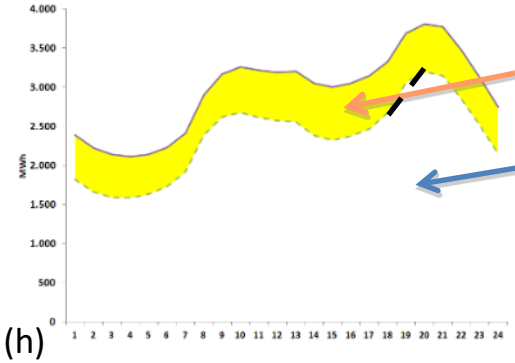
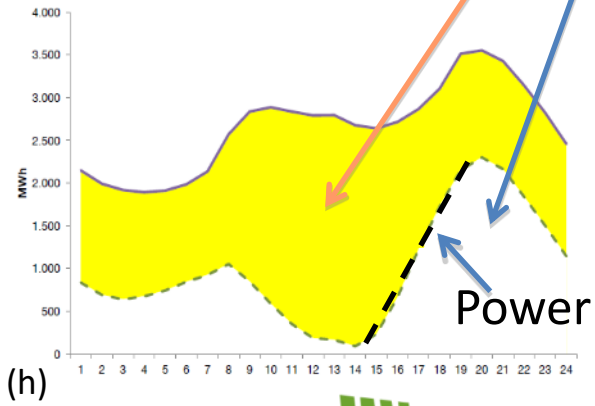
Why use a Heat Pump for CC flexibility?

March 2010 – working day



March 2017 – working day



PV and Wind

Dispatchable power

Power Ramp

Renewable share increase

- ✓ Increase of Renewable production increased low (or negative) electricity price period
- ✓ To store or to use excess of Renewable production is mandatory
- ✓ Heat Pump integrated with Thermal Energy Storage can take advantage of this trough a **PowerToHeat approach**
- ✓ The Thermal Energy Storage allows to use the heat when is most beneficial to CC profitability

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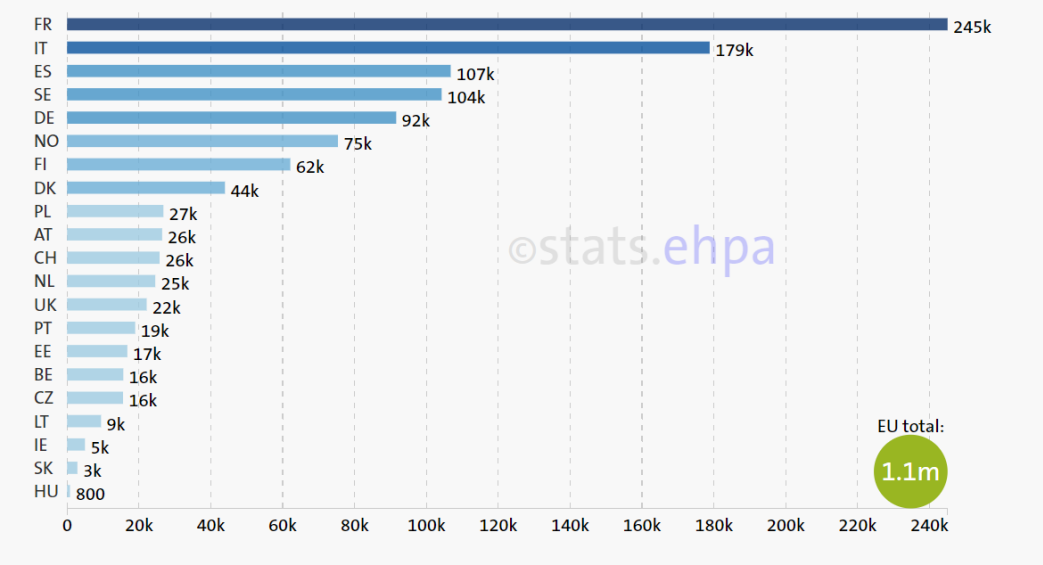
Why use a Heat Pump for CC flexibility?

- ✓ To store or to use excess of Renewable production is mandatory in <u>every energy market</u>
  Heat pumps enable the **PowerToHeat approach**
- ✓ The Thermal Energy Storage allows to use the heat when is most beneficial to CC profitability
- ✓ In cogenerative applications, the Heat Pump may displace fossil-fuelled auxiliary boilers
- ✓ <u>France and Italy</u> are the largest EU markets for heat pumps



Heat pumps sales in 2019 [EHPA, 2020]

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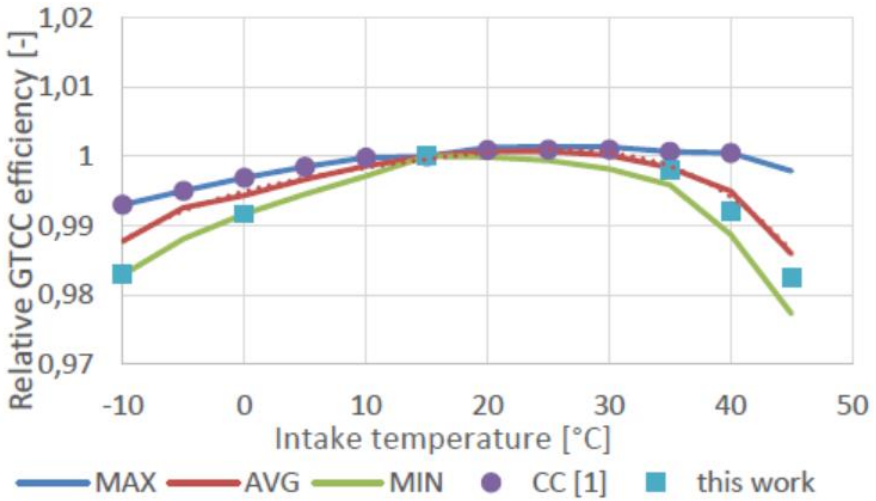
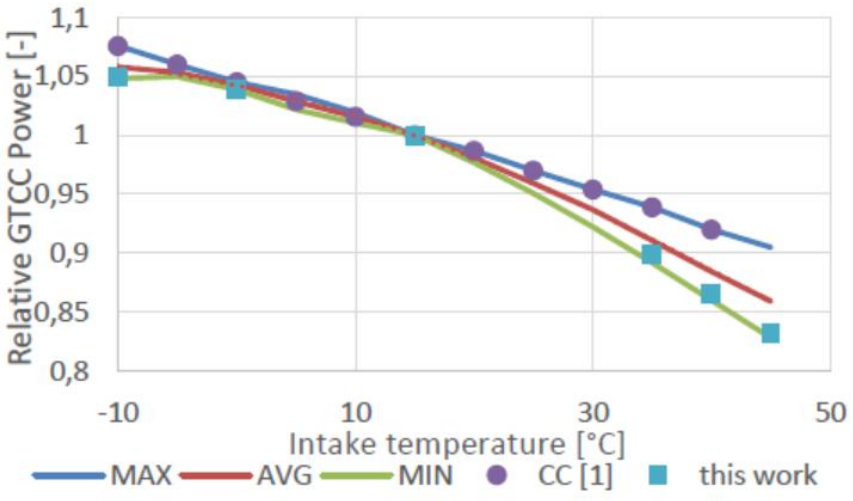
Why use a Heat Pump for CC flexibility?

CCGT Efficiency



CCGT Power



Open literature curves and Authors' calculations were compared with the Combined Cycle correction curves on temperatures for the OEM F Class GT frames (e.g. AE94.3A, GE9F, SGT5 4000F such as simple cycles and AEGT26 such as reheat cycles), extracted by the GT PRO.

Analysis of a Combined Cycle Exploiting Inlet Conditioning Technologies for Power Modulation, ASME TurboExpo 2019, ASME paper GT2019-91541

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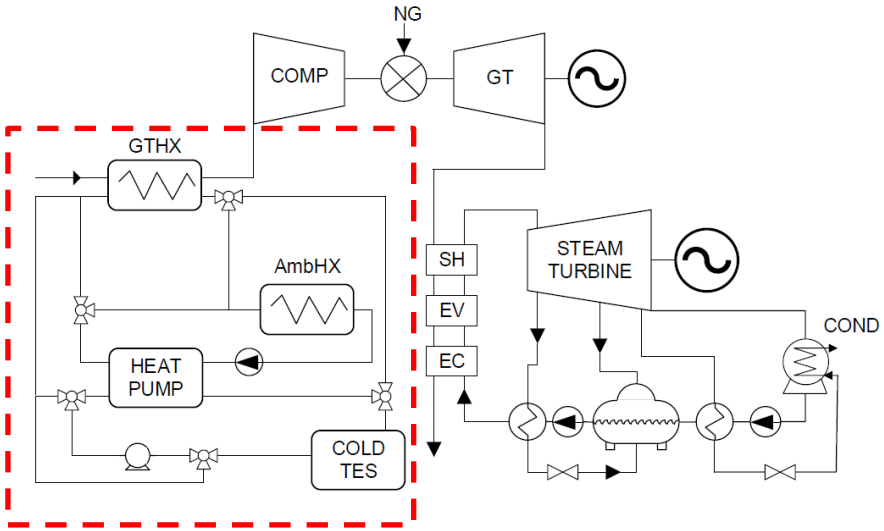
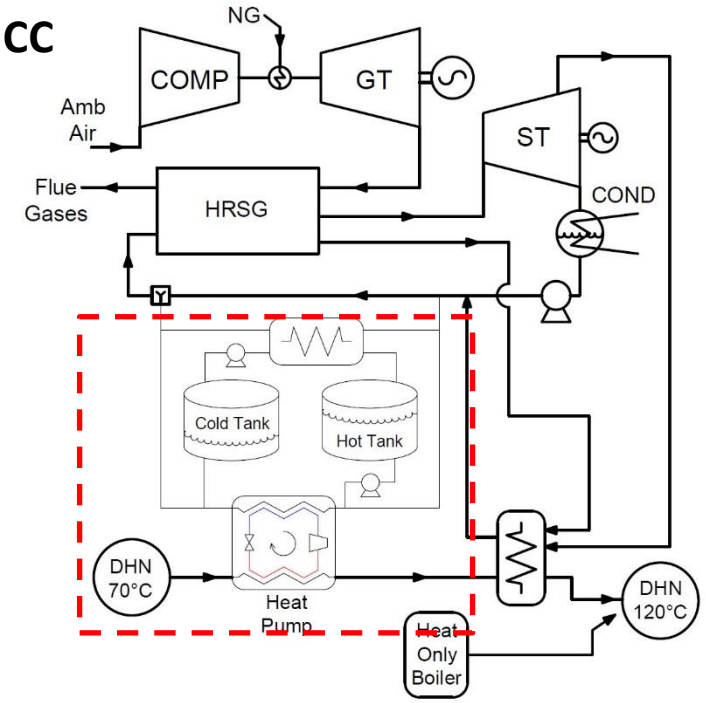
Two Cycle Layouts: Power Oriented and CHP Combined Cycles

Power Oriented CC



CHP CC



Different role of HP+TES System – different role/flexibility offered on the electric market.

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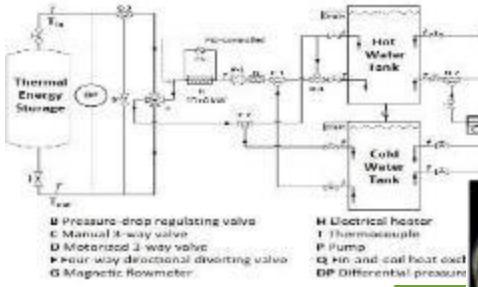
A *demonstration-to-market approach*, as excellence for Research Innovation Actions

Demonstration at IREN Moncalieri CHP CC (+District Heating)

Validation at UNIGE

PO layout

…and KTH labs



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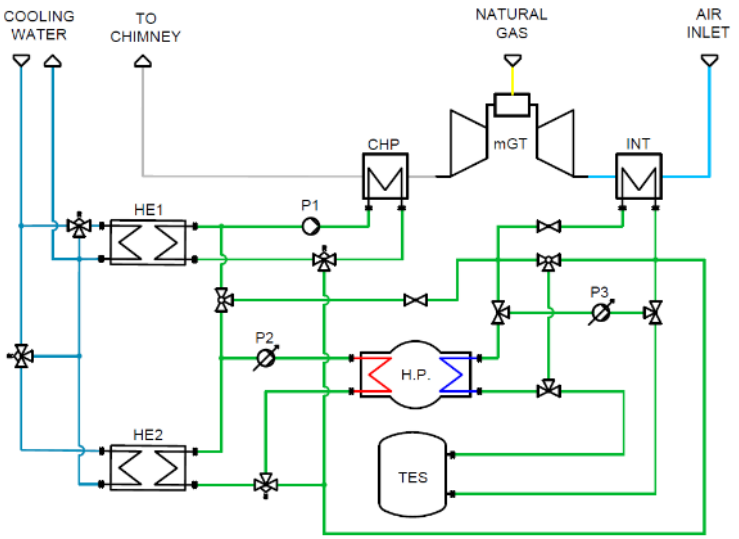
PUMP HEAT Validation site @ UNIGE



- Project Validation site, placed within Tirreno Power power plant, Savona (Italy)
- 100 kW_e micro gas turbine
- Fast response HP, 10 kW_e
- Cold thermal storage, 100 kWh, T range -5°C to +5°C

Università di Genova

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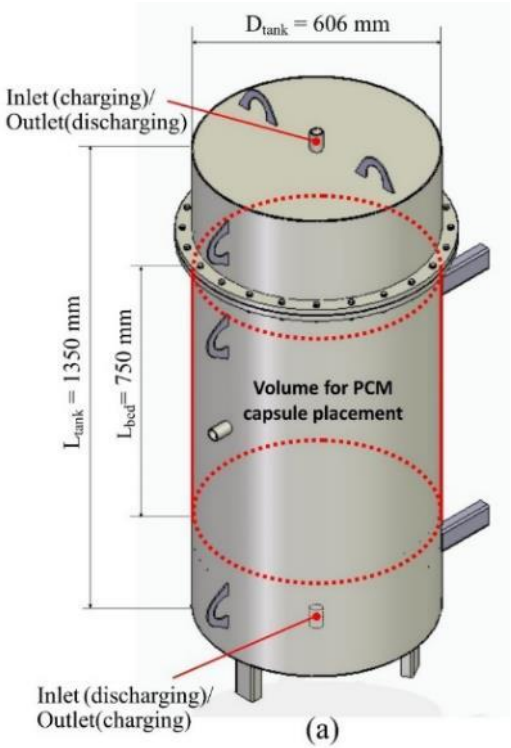
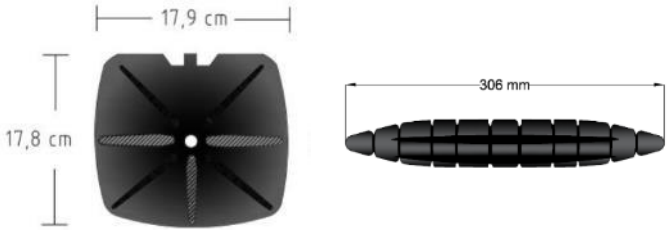
PUMP HEAT Validation site - Lab Scale Warm Thermal Storage @ KTH



- Two thermal storage configurations:
  - Shell-and-tube heat exchanger
  - Macro-encapsulation
- Volume of tank chamber=0.2 m3



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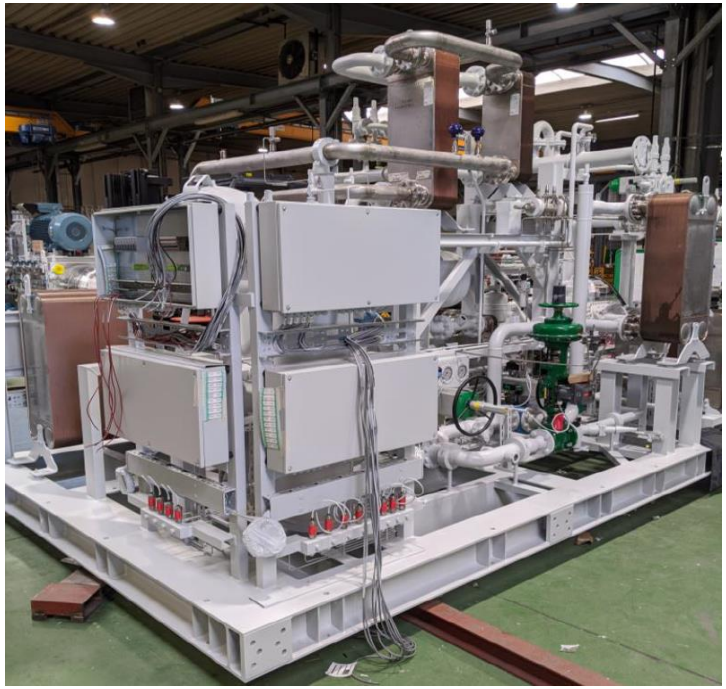
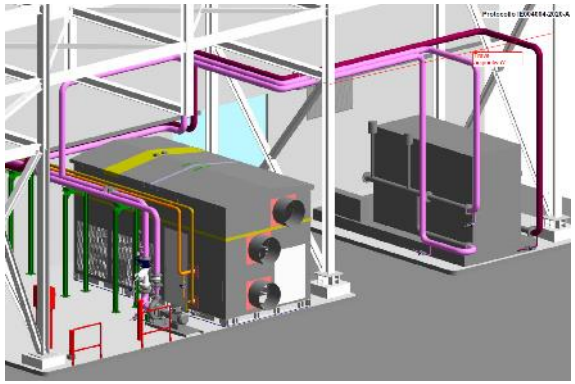
PUMP HEAT Demonstration site @IREN





- Project Demosite is settled within an IREN facility in Moncalieri power plant (Italy), a 400 MW_e CHP
- Fast response HP, 150 kW_e
- Warm Thermal storage, 360 kWh, temperatures up to 120 °C

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A *demonstration-to-market approach*, as excellence for Research Innovation Actions

Key Exploitable Results	TRL
HOT TES	8
COLD TES	4
Steam HP	4
Hot Water HP	4
INNOVATIVE TURBOEXPANDER	4
CONTROLLER	4
HEAT EXCHANGER	5
PHCC LAYOUT	3

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Key Exploitable Results	TRL
HOT TES	9
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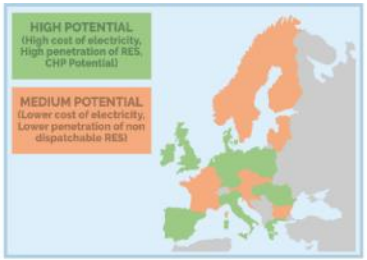
CONTROLLER	8
HEAT EXCHANGER	8
PHCC LAYOUT	8



MAIN APPLICATIONS:

Combined Cycle (CHP or Power Only)

MARKET DRIVERS:

- De-Moothballing of Combined Cycle
- Increasing of RES penetration
- Need for an Increased Back-Up Capacity of Flexible Power Plants
- Increase of CHP penetration for process industries

PROJECT STARTS 2017 — 2019 — 2020 (TRL 6) — 2021 (TRL 8) — 2023 (TRL 9)

Project Starts

Project Drivers

- Flexibilization of Natural Gas Based Power Plants to increase their role in electrical market
- Fast-Response Back-up Capacity for fluctuating RES
- Increase the efficiency and the performances at minimum and part load of the plants
- Demonstrate a "Thermal Equivalent" Electrical Storage
- Use of HP as Smart Load for the Electrical market and increase their efficiency

Intermediate Achievements

Demonstration at Moncalieri IREN CHP Power Plant

Standards and norms definition	• Heat exchangers and containers fro PCM storages and the coupling with HPs need to be standardized in terms of geometry and size according to the stored energy capacity • Definition of rules for the installation of the PUMP-HEAT upgrade • Overcoming normative barriers for what concerns the interaction with the electrical grid • Standardization of control systems protocol
Manufacturing	• Upscale the production capacity of PCM and Hot water/steam HP with consequent reduction of the costs due to economy of scale • Development of high temperature and steam hot pumps • Full integration of the turboexpander in commercial heat pumps
Further demonstrations	• Demonstration of the concept at full scale • Application in other countries (environmental and electrical market contexts)
Marketing	• Start to promote the coupling of heat pumps with CC and GT plants • Selection of the first entry markets • Assessment of the final business model for the commercial exploitation of the concept • Advertising and awareness campaigns for increasing the promotion of the PHCC layout

ADDITIONAL MARKETS:

Integrated Industrial CHP Plants

Large Size DHN CHP Plants

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Power Oriented CCGT

Be technically feasible:

- **Heat Pump with R600 (Butane) as a working media**: advanced technology HP can lead to high COPs thus better impact on all thermo-economic indexes.
- **TES size/technology and costs**: recent studies demonstrate how TES is a key enabler for HP successful integration into PO CCGTs
- **Plant operation scheduler optimizer** is a must to properly manage the operation modes (TES charging/discharging, continuos cooling/heating) in todays and future complex market scenarios

Be thermo-economically viable:

- The thermo-economic analysis is a challenging task due to the **unpredictability of the Ancillary Service Market** (ASM). To increase profitability from ASM:
  - **Reduce Minimum Environmental Load** (MEL) to increase turn down period and availability for ASM
- Reduce emissions and O&M costs:
  - **Reduction of intraday shutdown/startup**: a hot pressurized start-up has a costs of ca 24,2 keur and > 100 tons of CO2 and can be economically replaced by a turn-down period
  - **Reduce components life consumption** due to shutdown/startup

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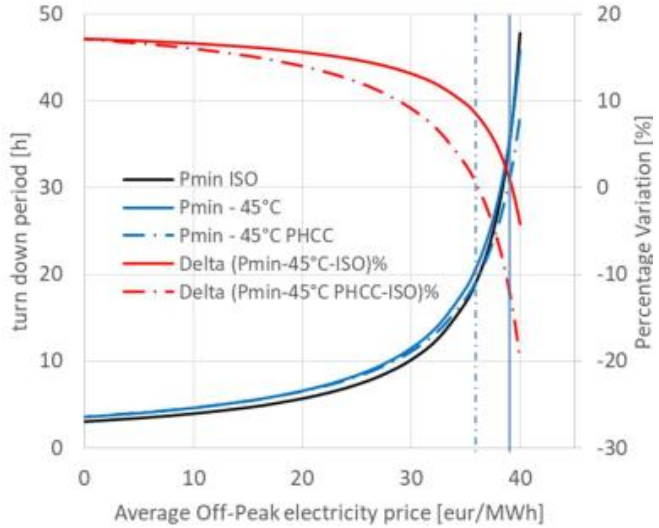
Power Oriented CCGT

Minimum Environmental Load (MEL) reduction enhances the profitability:

- Remain available for Ancillary Service Markey (ASM) thanks to increased turn down period

Parameter	Unit	Δ	Δ%
Inlet Temperature	[K]	30	10,4
Gross Power	[MW]	-30,1	-15,9
Gross Efficiency	[pt%]	-0,75	-1,50
Net Power	[MW]	-32,7	-17,3
Net Efficiency	[pt%]	-1,55	-3,10
Thermal Input (Fuel)	[MW]	-55,6	-14,7
CO2 Emission	[tonCO2/h]	-11,2	-14,7
Net Specific CO2 Emission	[kg CO2/MWh]	13,0	3,20

Adopting the HP increases the turn down duration even at lower el. price [eur/MWh] compared to existing solutions



- Avoid the emission related to start up procedure the start-up impact over component aging

pollutant	u.m.	Hot P SU	Hot SU	Warm SU	Cold SU	SD
CO2	ton	78,6	108,0	127,7	196,4	19,5
NOx	kg	49	68	127	254	18
CO	kg	528	726	794	998	68

For each avoided SU/SD procedure is possible to avoid ca 98 tons of CO2, ca 67 kg of NOx and ca 596 kg Carbon Monoxide

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Combined Heat and Power (CHP)

Be technically feasible:

- **Retrofit** applications constraints **limit the performance** enhancement of the HP concept
  - Minimum steam flow rate for the LPT (we cannot extract too much steam).
  - Minimum exhaust temperature at stack to keep sufficient buoyancy effect to increase pollutant dispersion
  - Avoid exhaust gas condensation (acid condensate)
- **New unit**: best performance enhancement with **flue gas condensation**
  - Imposes a particular layout configuration
  - Reheating of flue gas must be considered after the latent heat exploitation to guarantee minimum stack Temp
  - Flue gas condensing system is a technical challenge itself

Be thermo-economically viable:

- The key enabler is the capability to **uncouple GT load and thermal energy** production
- **High capital expenditure** for large size heat pump (ca. 10 times more than HOB) restricts the market conditions under which the value of the investment is positive.
- ASM participation is the best scenario for HP integration profitability. Strong presence of renewable generators will bring HP integration NPV much higher than today.

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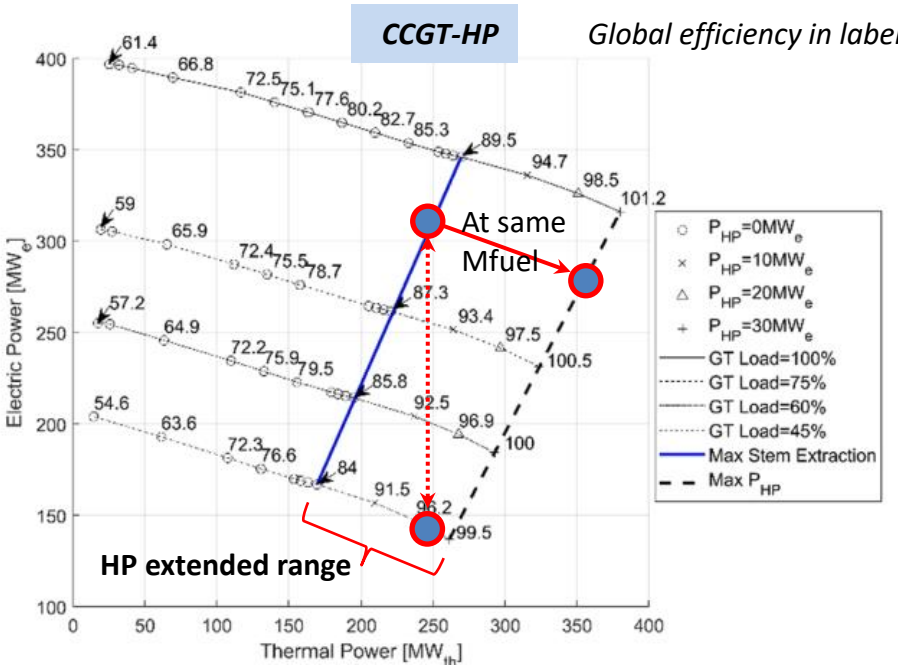
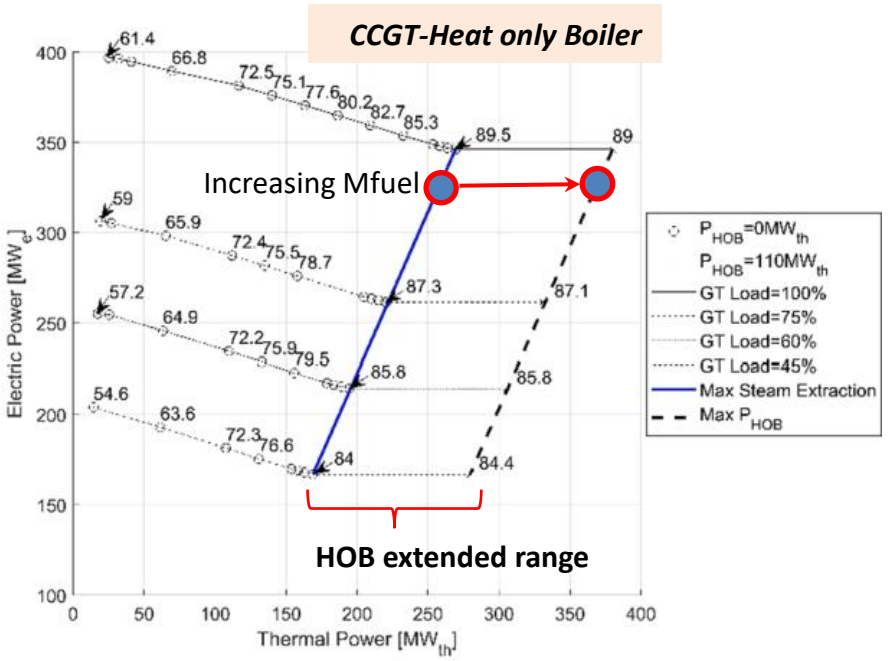
Combined Heat and Power (CHP): Uncoupling GT load and thermal energy production





The CCGT-HP allows to provide the same **additional heat without increasing the fuel consumption**

Increased global efficiency

Reduced emissions

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A *demonstration-to-market approach: interacting with stakeholders is crucial!*

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PUMPHEAT Project

PUMP-HEAT WP6 ACTIVITIES

- Interaction with stakeholders via web surveys and "key bilateral interviews" with plant manager
- Replication studies
- Setup of a Techno-economic Roadmap to TRL9 also identifying most relevant EU markets where CCGT-CHP are active and where **ancillary services market** is remunerative and RES penetration is high

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Ancillary Service Profitability

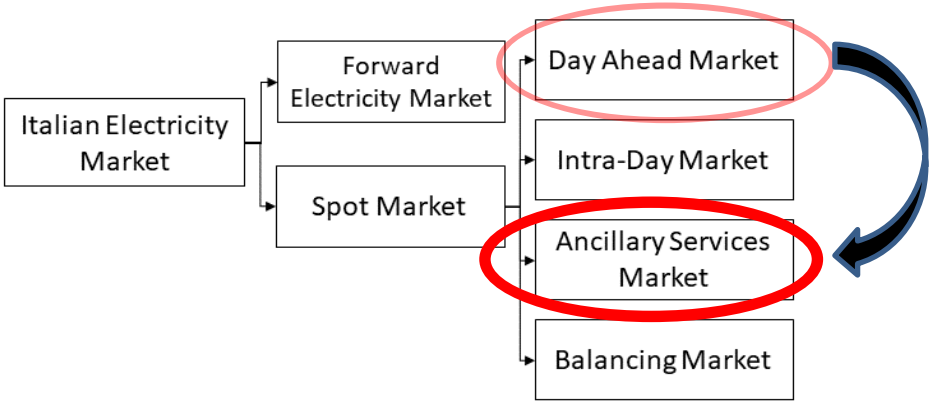
Non-programmable generators spread

Lack of profitability for CCGTs on the Day-Ahaed-Market

Increase in **demand for ancillary services** to the grid

AS provision is a source of income no longer neglectable

Italian Electricity Market



Shift of profits opportunities

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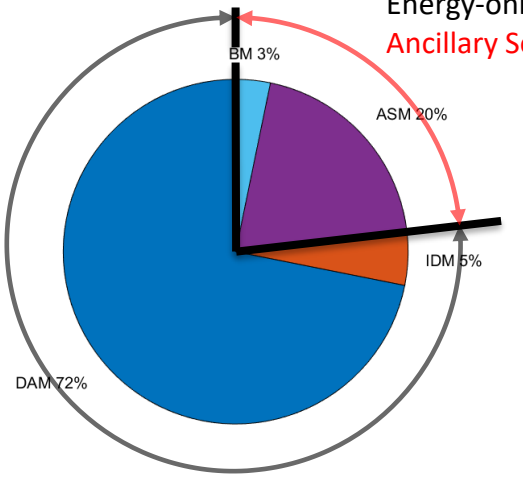
Ancillary Service Profitability

Revenues

(not including costs)

Energy-only markets 77%

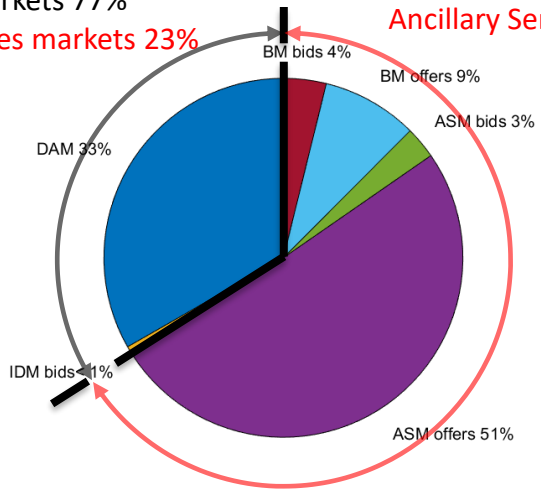
Ancillary Services markets 23%



Net Profits

Energy-only markets 33%

Ancillary Services markets 67%



Ancillary Services Market (ASM)
Is a relevant source of profits for modern CCGTs

However

The opportunities on the ASM are strongly depended on the location within the grid

Analysis carried out on 45 Italian power-oriented CCGTs considering 2018 and 2019

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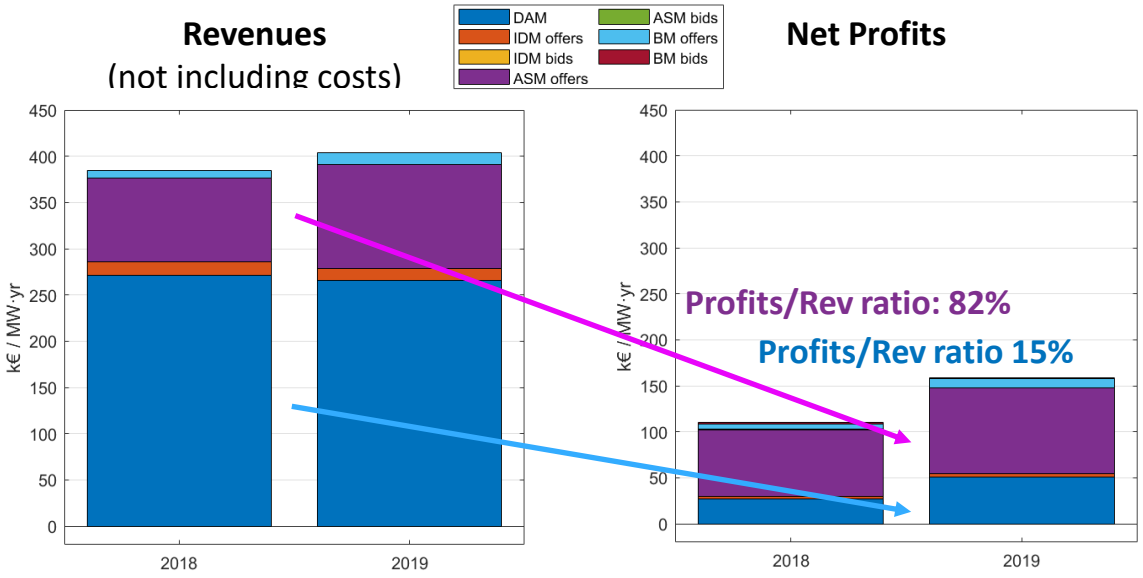
South-Centre Italy Focus

Within the **Centre-South Italy** (high RES penetration) **ASM** accounts up to **63% of profits**

Revenues
(not including costs)



Net Profits

Low Rev/Profits ratio on the DAM

- CCGTs accept **low economic margin on DAM**, even negative, to be able to participate on the ASM
- Considerable Profits/Rev ratio **on the ASM: higher prices for energy**

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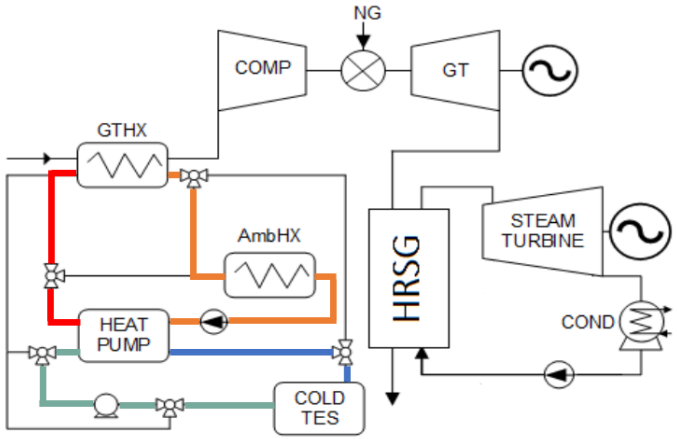
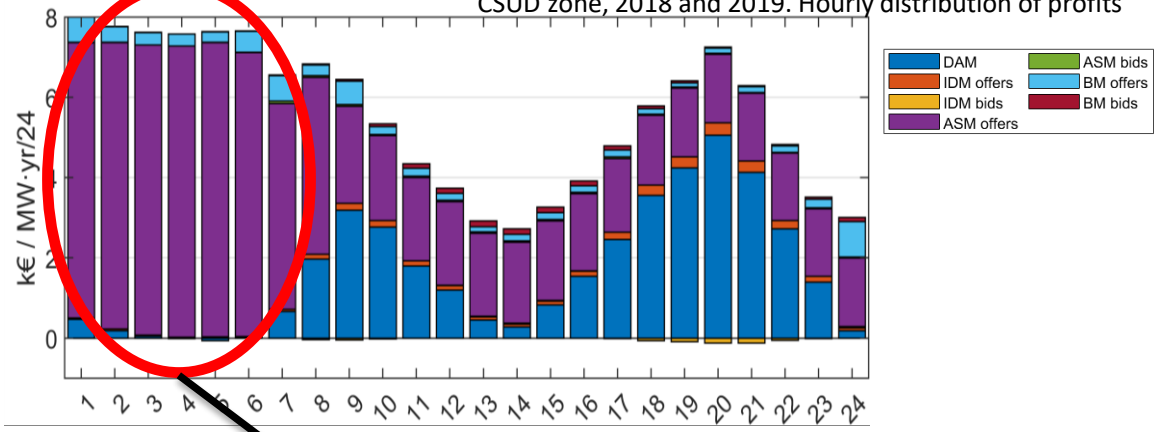
PUMP-HEAT PO LAYOUT IN THE ANCILLARY SERVICES MARKET

The PUMP-HEAT concept allows to **low the minimum load** by means of **GT inlet heating**



CSUD zone, 2018 and 2019. Hourly distribution of profits



A low minimum load allow to save fuel, making viable to keep the power plant operating waiting for opportunity of profits on the ASM

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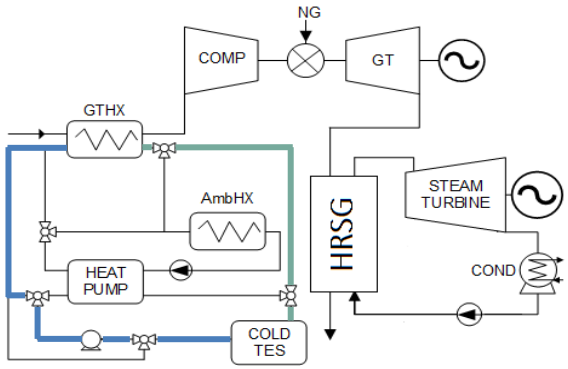
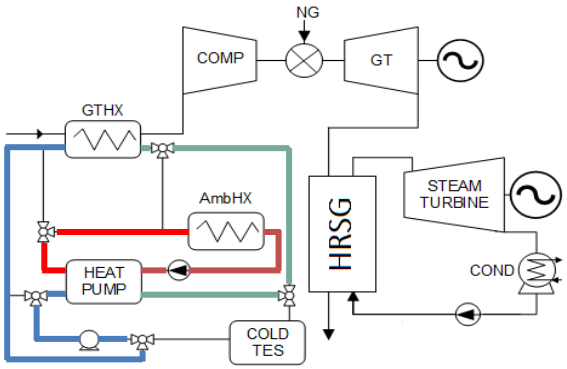
PUMP-HEAT CHP LAYOUT IN THE ANCILLARY SERVICES MARKET

The PUMP-HEAT concept allows to **increase the maximum power output** by means of **GT inlet cooling**



TES discharging



Continuous cooling

A PH-CCGT has extra power to sell on the ASM at higher prices

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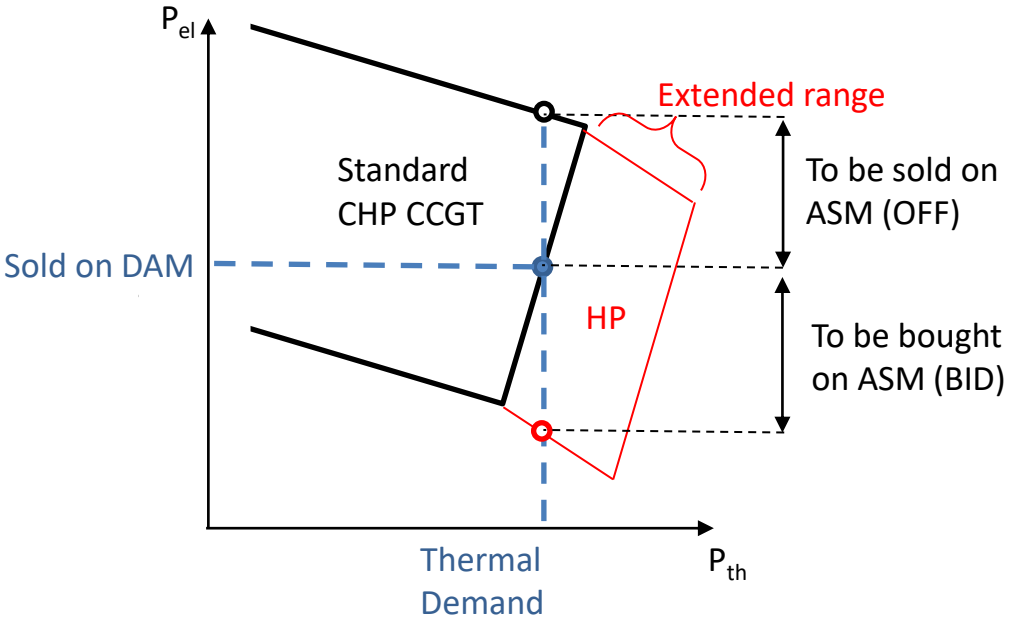
PUMP-HEAT CHP LAYOUT IN THE ANCILLARY SERVICES MARKET



- **CHP must fulfil the local thermal demand**
- Whit high thermal demand the minimum power output increases
- So is the **ability in providing Ancillary Services is limited**
- **HP** operative-range extension allows to **decrease the minimum power output**
- **The TES gives extra-flexibility** mitigating the thermal demand peak

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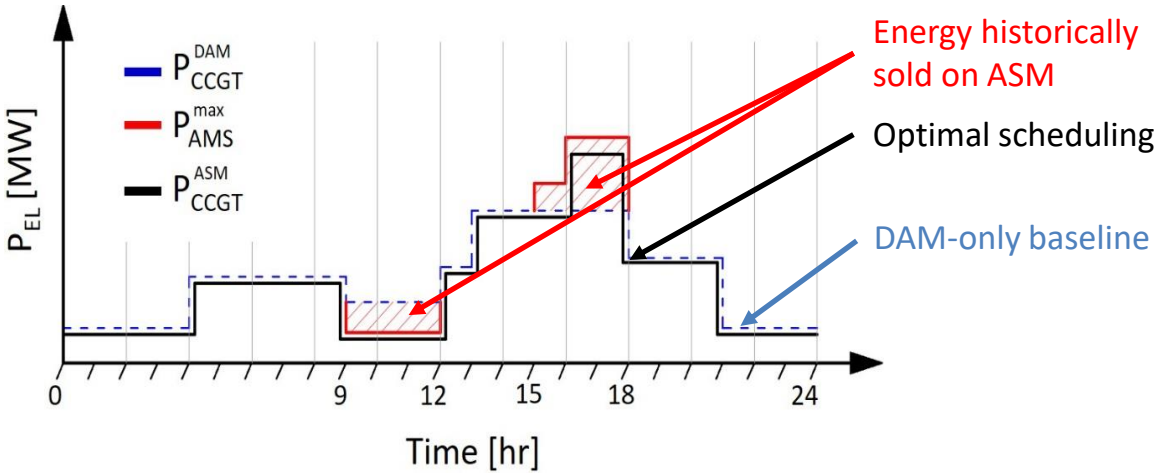
Economic Impact Assessment of PUMP-HEAT PO layout

Data-driven model of **optimal dispatch on the ASM**



- 400 MW Power Oriented CCGT
- F-Class Gas Turbine
- Northen Italy grid zone
- 2018 data

+3% in profits with the PUMP-HEAT concept

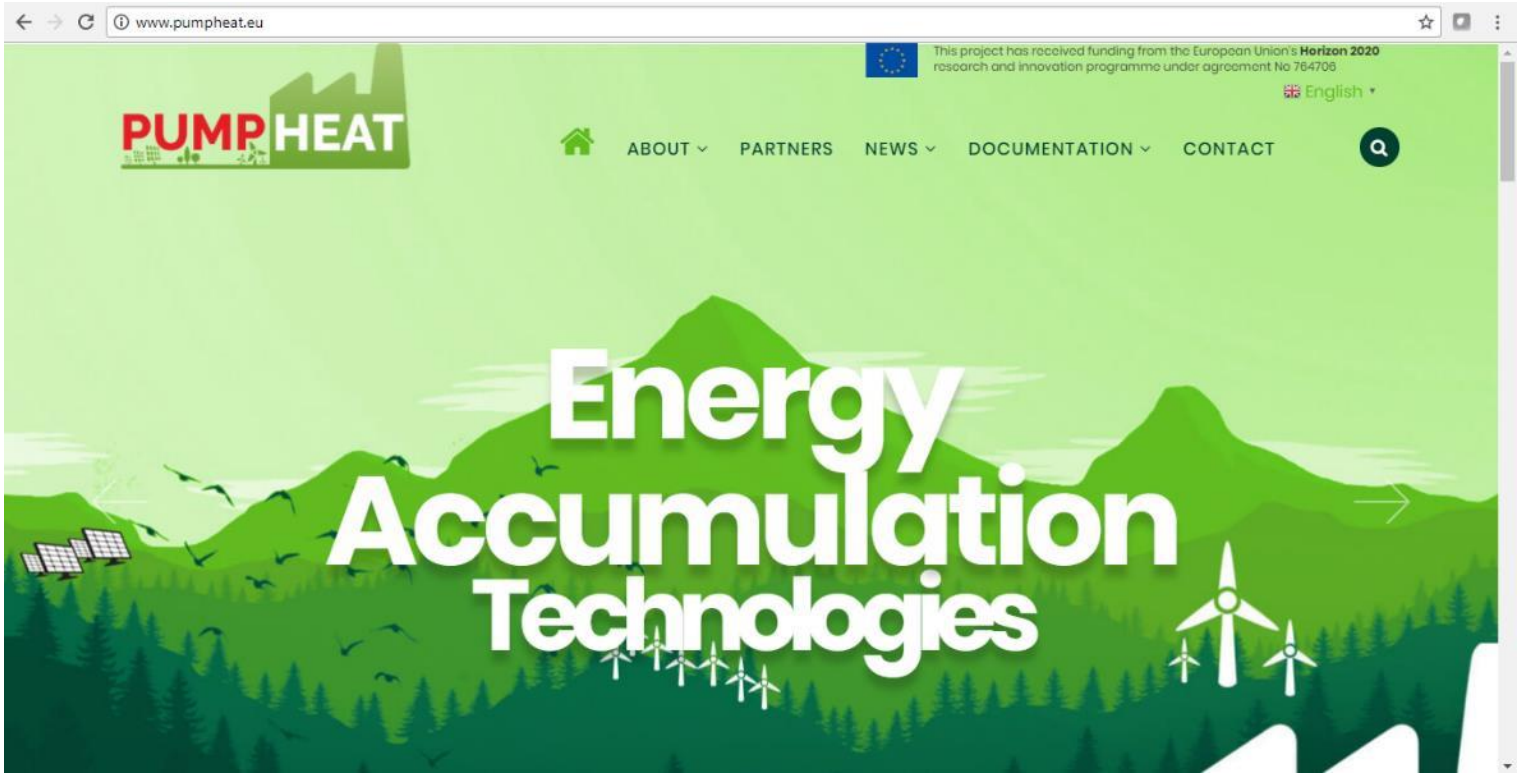
PUMP-HEAT power-oriented retrofit KPIs:

- NPV=1.42M€*
- PBP=12.9yr*

*Interest rate 5%

This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 764706

Would you like to support PUMP-HEAT?



www.pumpheat.eu

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THANKS FOR YOUR TIME

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