INCLUSION OF CO2 TRANSCRITICAL HEAT-PUMP AND POWER CYCLES IN A MASSIVE ELECTRICITY STORAGE SYSTEM

1st Eur. Seminar on Supercritical CO2 Power Systems | F. Ayachi[a], **N. Tauveron**[a,], T. Tartière[b], D. Nguyen[c], H. Davarzani[d], E. Macchi[e]

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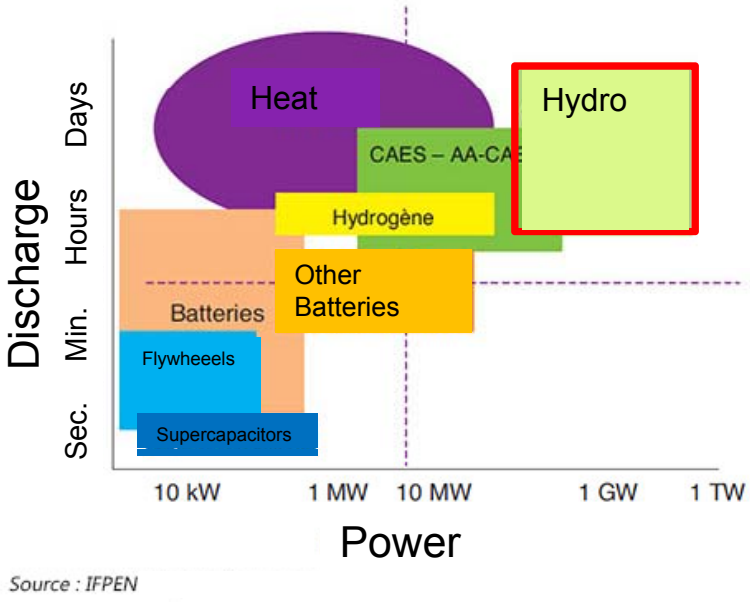
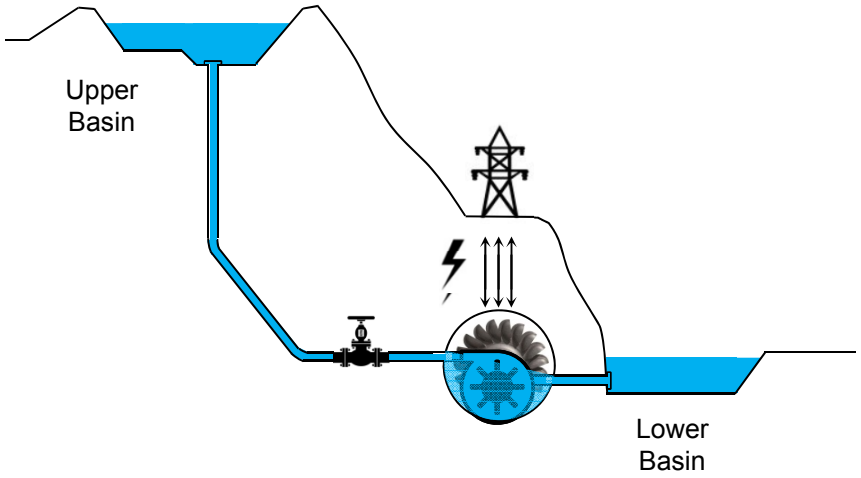
SCOPE OF THE PRESENTATION

- State of the art
- SELECO2 Concept
- Thermodynamic Simulations
- Architecture discussion
- Preliminary modeling of the hot storage ground heat exchangers
- Preliminary Ground Storage Model & Transient Coupling with Thermodynamic Cycles
- Conclusion

Electricity storage: State of the art (1)

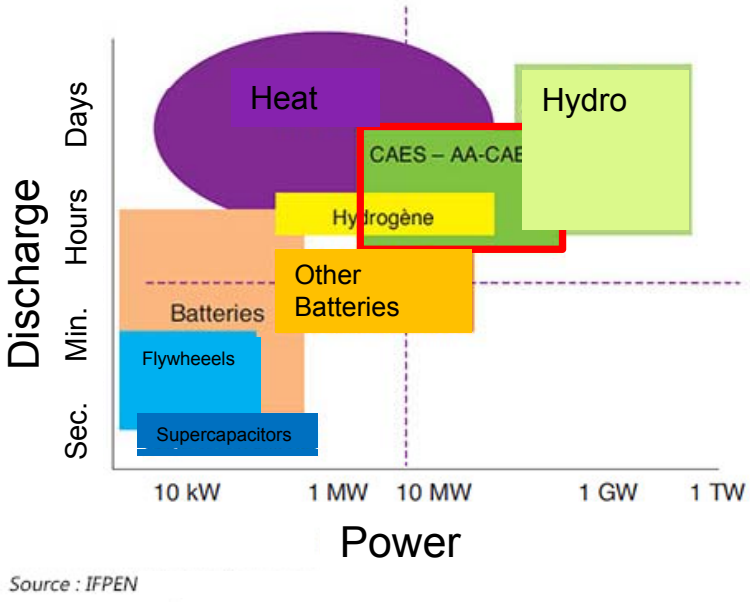


Source : IFPEN



Maturity	Mature (< 1890's)
Deploiement	200 sites (140 GW)
Efficiency	> 80%
Scale	500 MW – 3 GW // 1 – 100 GWh
Discharge	Few hours – Few days
Expected Life	40 years

Electricity storage: State of the art (2)



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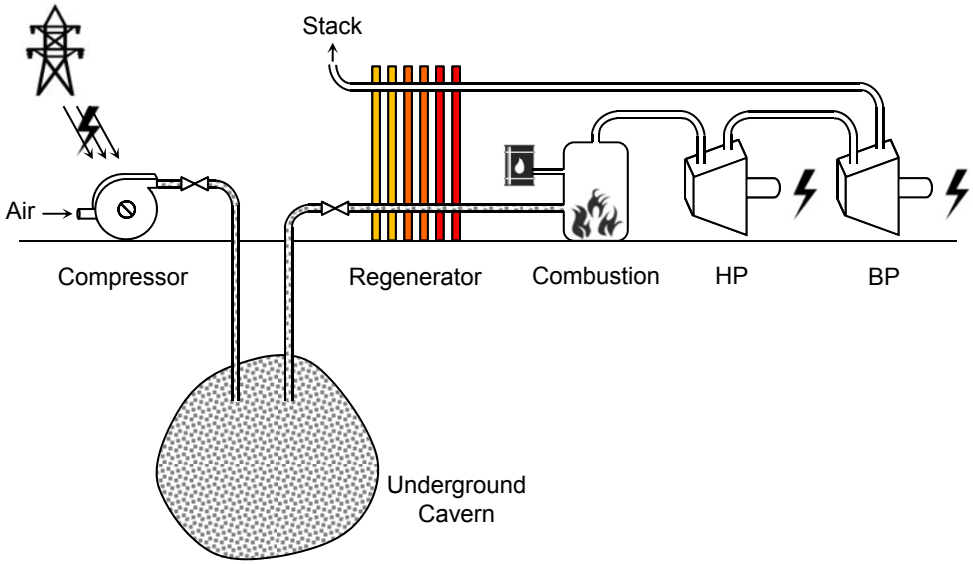
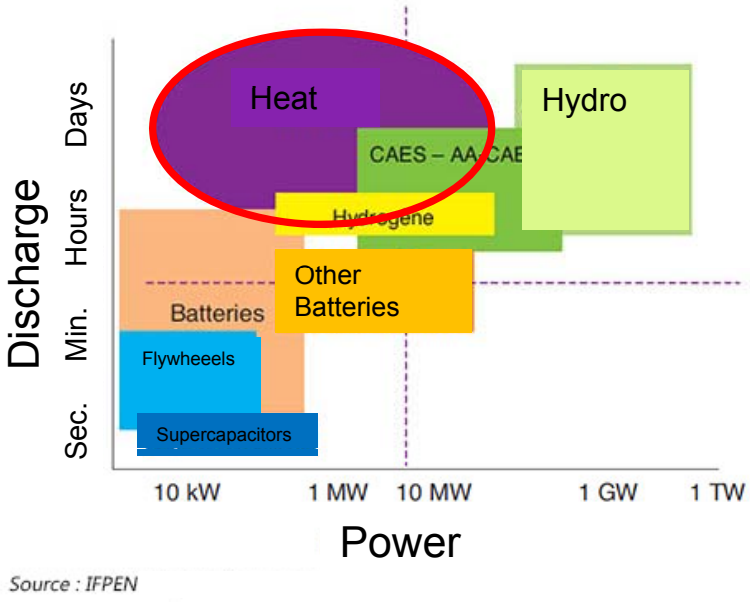


Maturity	Commercialised
Deploiement	2 sites (USA) { 290 MW – 2h / 110 MW – 26h > 12 projects
Efficiency	~ 50-55%
Scale	10 – 400 MW // 0,5 – 20 GWh
Discharge	1 – 26 hours
Expected Life	30 years

Electricity storage: State of the art (3)



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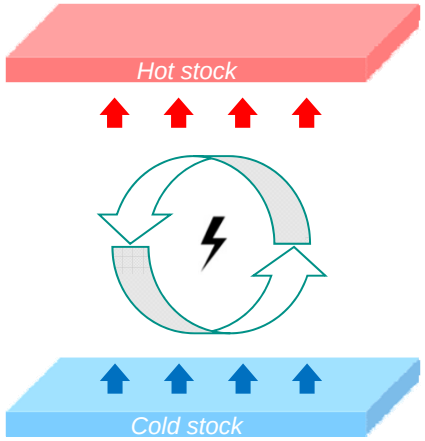

Maturity	**Several R&D projects** Various fluids and cycles (Ar, CO_2, …)
Deploiement	No installed capacity
Efficiency	> 40%
Scale	< 100 MW
Discharge	Few hours – Few days
Expected Life	25 years

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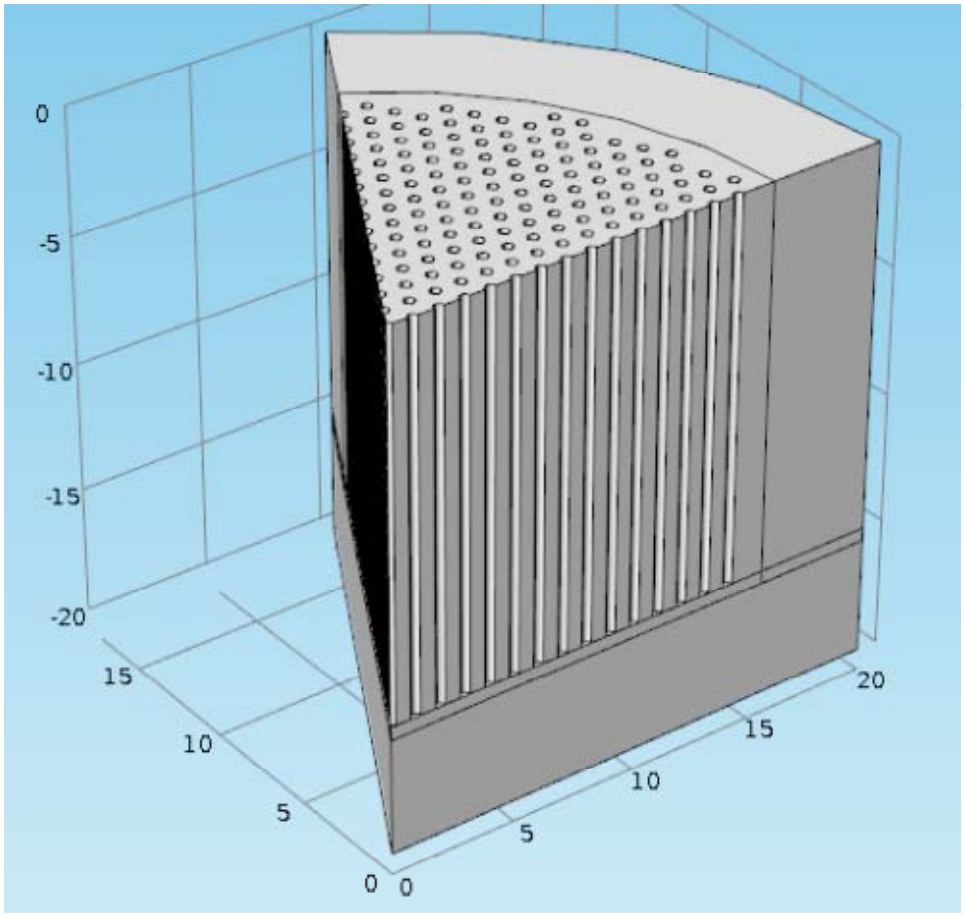
ANR Project – SELECO$_2$

Project website: http://seleco2.free.fr/

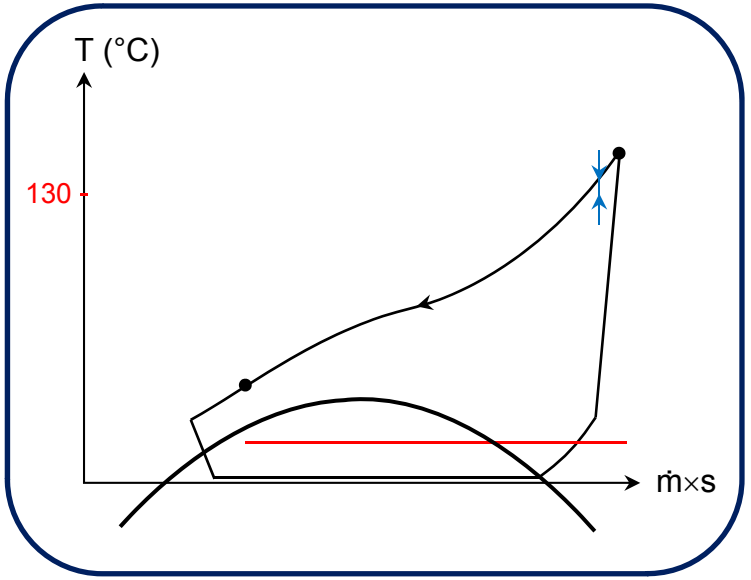
SELECO$_2$ Concept (1)



$\varnothing_{column}$ ~ 1 m / column , T_{max} ~130°C

Rock conductivity =3,4 W/m.K

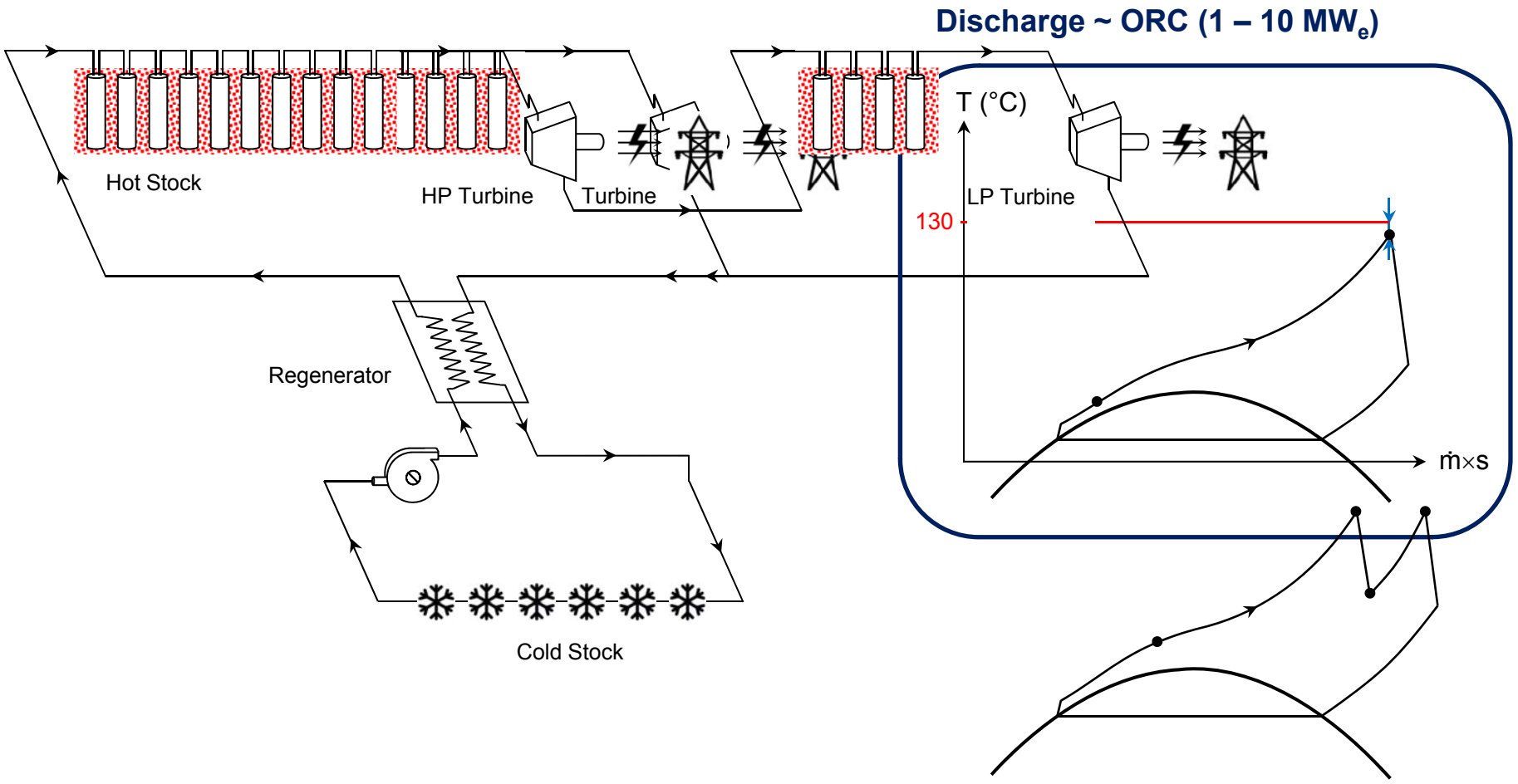
Charge : Heat-Pump cycle (≥ 8 hours)



1st characteristics : Hot storage medium: in situ rock (granite)

2nd characteristics : CO_2 supercritical

SELECO$_2$ Concept (2)



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Parametric studies & results (1)

$$\eta_{sys} = \frac{\dot{W}_{el}'}{\dot{W}_{el} + \dot{W}_{el}''}$$

Code :

Architecture : single stage

Net Power: 1 MW_e

Rock Temp : $T_{rock\_max} = 130°C$

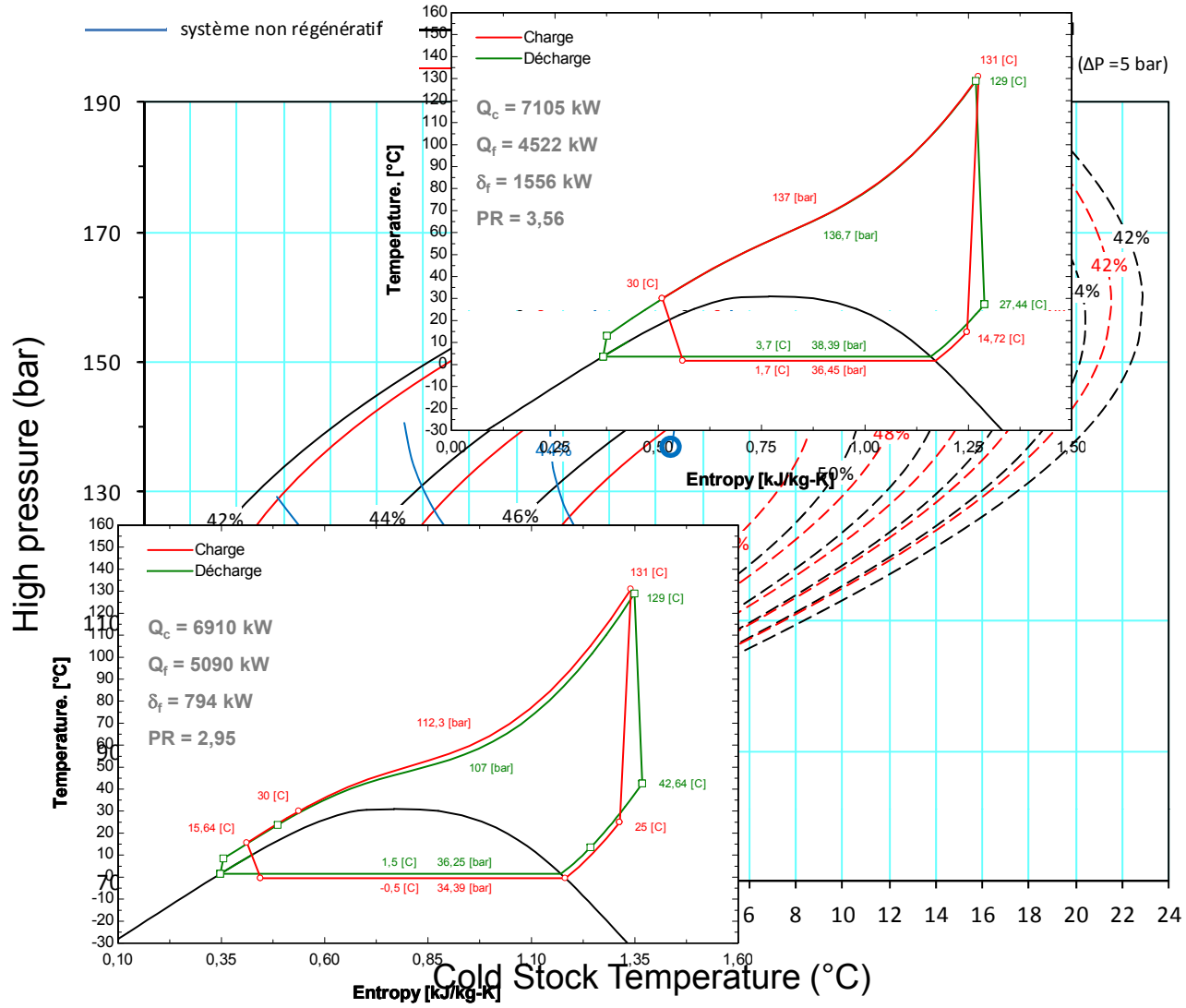
« Pinch » : upper limit

$$\Delta T_{min} = \left| T_{CO_2} - T_{rock} \right|_{min} = 1K$$

Double regenerated

1- Global efficiency ↗
2- High pressure ↘
3- Pressure ratio ↘
4- Hot stock power ↘
5- Chiller contribution ↘

⇒ Cost ↘



non-regenerative — regenerative discharge — regenerative dicharge (ΔP_{reg} = 5 bar)

– – – – regenerative charge & discharge – – – – regenerative charge & discharge (ΔP_{reg} = 5 bar)

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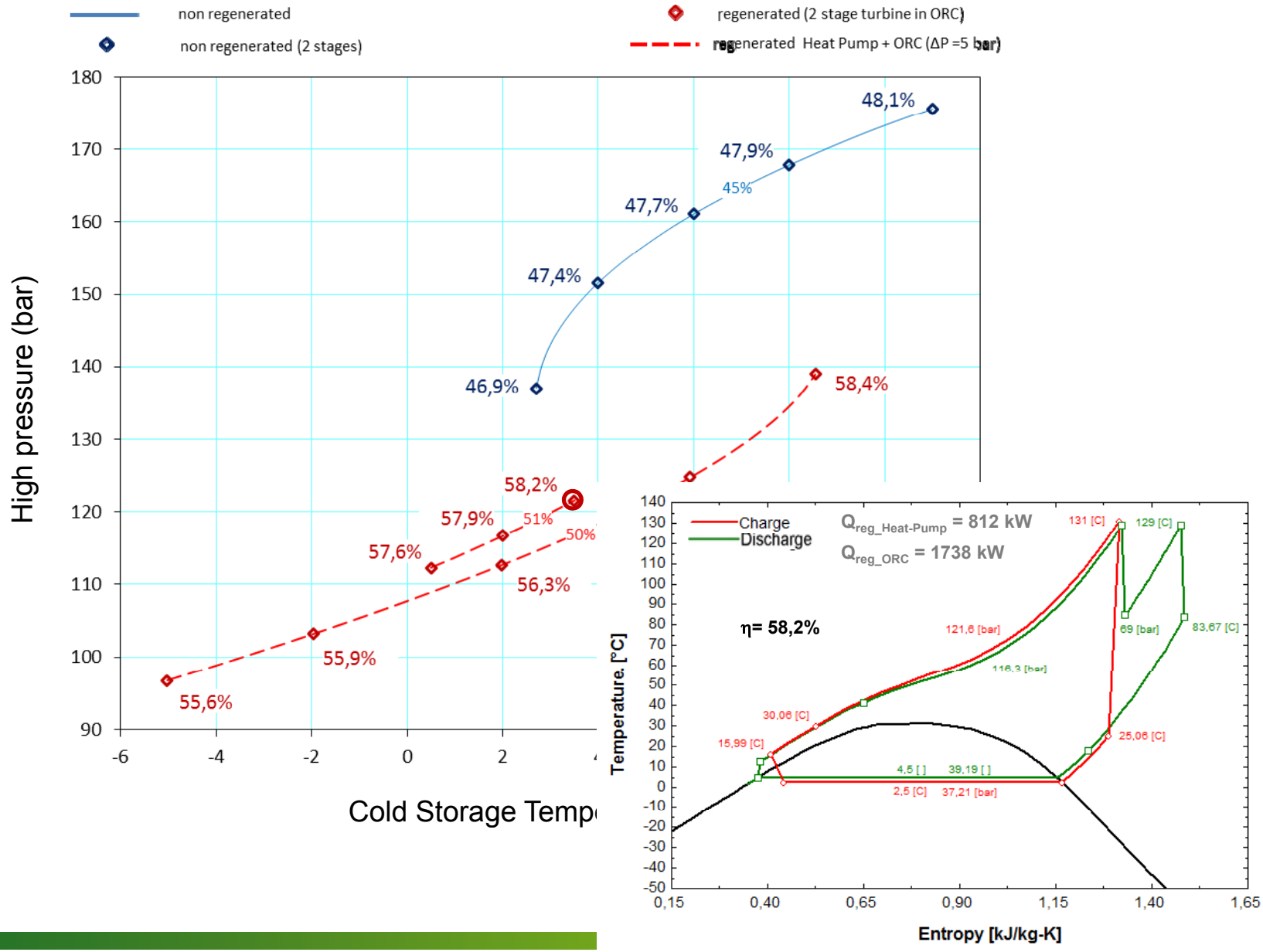
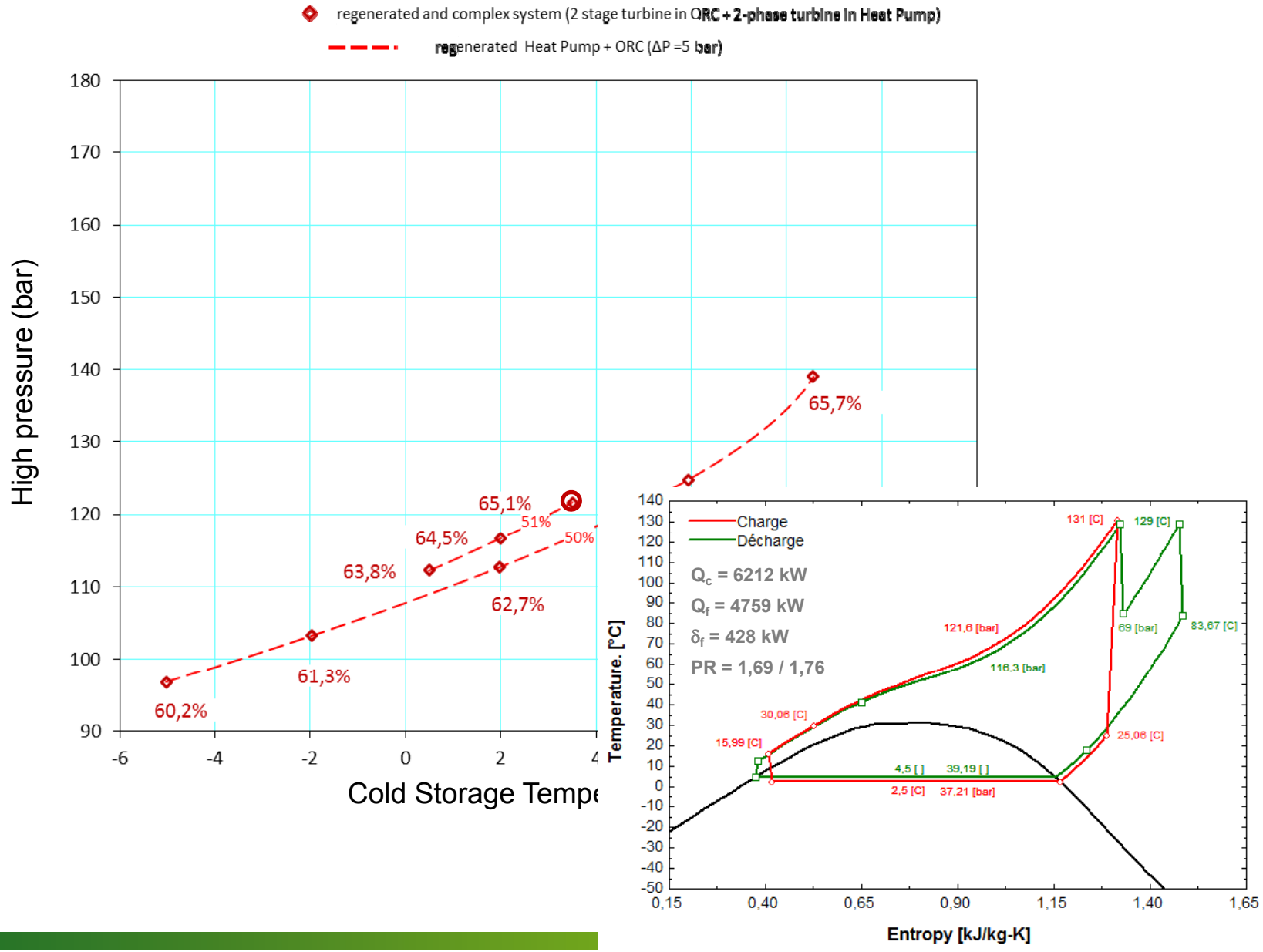
Parametric studies & results: architecture discussion (1)



Parametric studies & results: architecture discussion (2)



Architecture discussion (3)

- **2-stage ORC system**

  ⇒ **Favorable impact on global efficiency:** $\eta_g \nearrow$ **58,2%**

  ⇒ **Default ?** $Q_{reg\_ORC} \times 2$

- **2-phase turbine in Heat-Pump**

  ✓ **Isentropic efficiency = 75% ?**

  ⇒ **Favorable impact on global efficiency:** $\eta_g \nearrow$ **57%** & $\eta_g \nearrow$ **58,2%→65 %**

  ⇒ **Default ? Maturity and life of turbine component**

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Preliminary modeling of the hot storage ground heat exchangers

Code :

Model : 1D

Convection : forced

Configuration: vertical

Correlations : **supercritical** CO_2

Shitsman (1959)

$$Nu[i] = 0{,}023\ Re^{0,8}[i]\ Pr^{0,8}[i]$$

Jackson (1975)

$$Nu[i] = 0{,}0183\ Re^{0,82}[i]\ Pr^{0,5}[i] \left(\frac{\rho[i]}{\rho_w[i]}\right)^{-0,3}$$

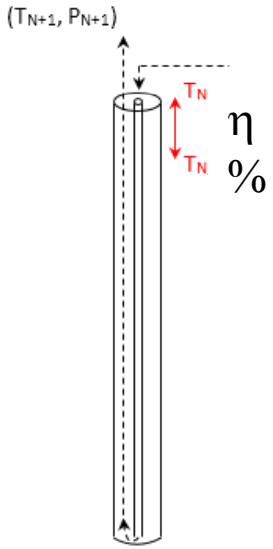
Flux per serie : $\dot{Q}_{serie} = \sum_{i=1}^{N} \dot{Q}_{unit}[i]$

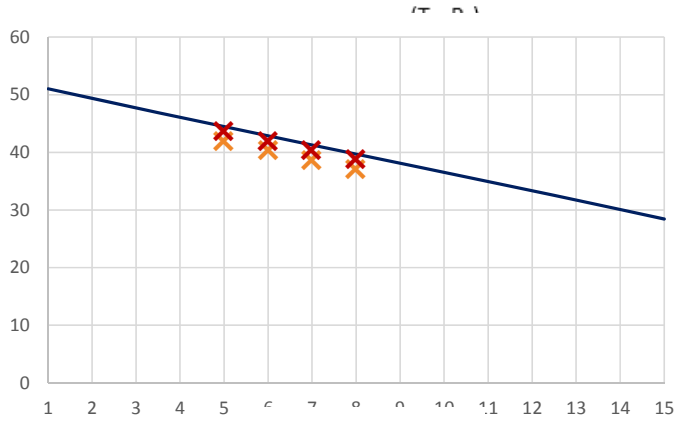
Column height: 15 m

∅ **column :** 0,4 m

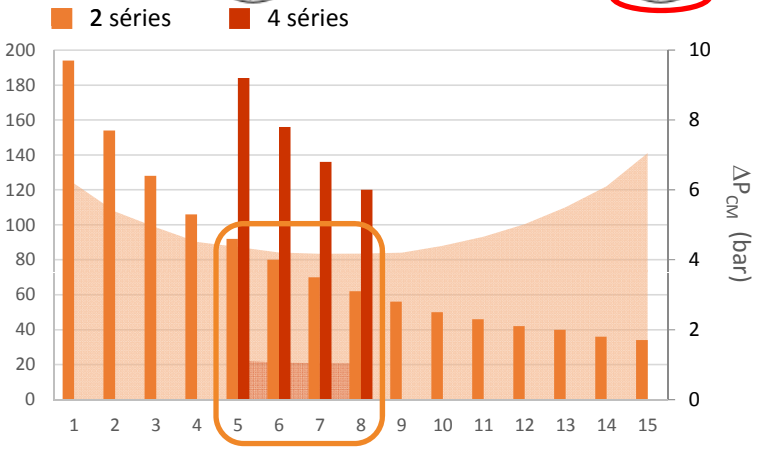
∅ **central pipe:** 0,2 m

Nb of Col per MWel





Pinch



Γrock [1]

Pinch

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Preliminary Ground Storage Model & Transient Coupling with Thermodynamic Cycles - 1

Code :

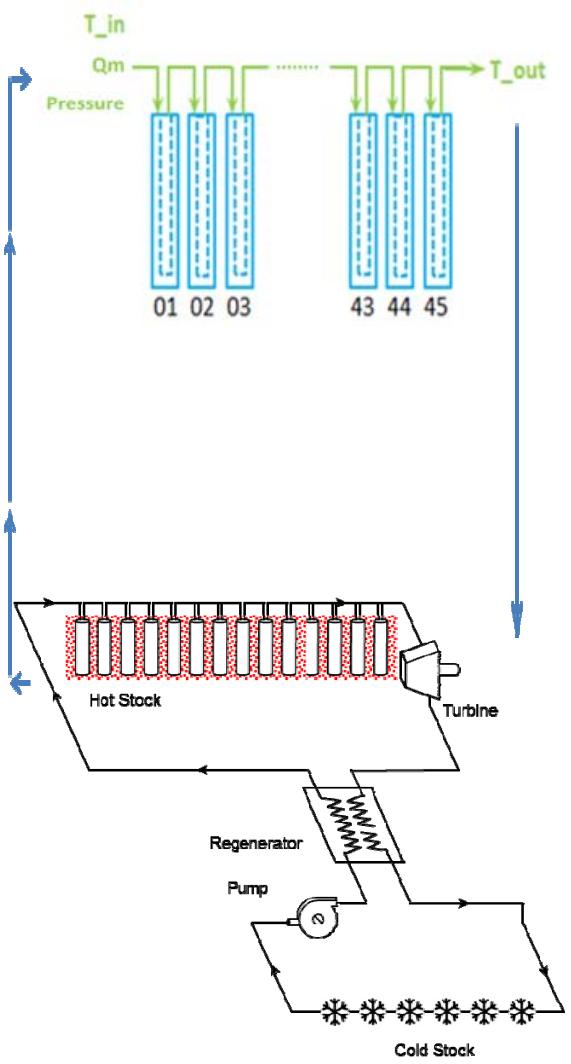
COMSOL MULTIPHYSICS

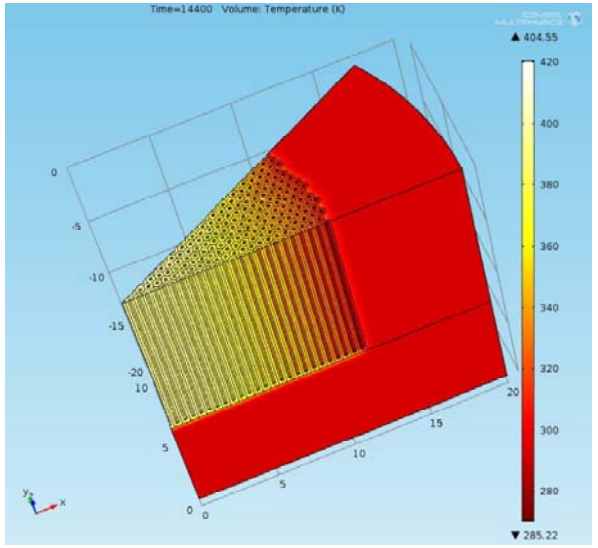
Module : Heat Transfer in Solid

Model : 1D Fluid – 3D Solid

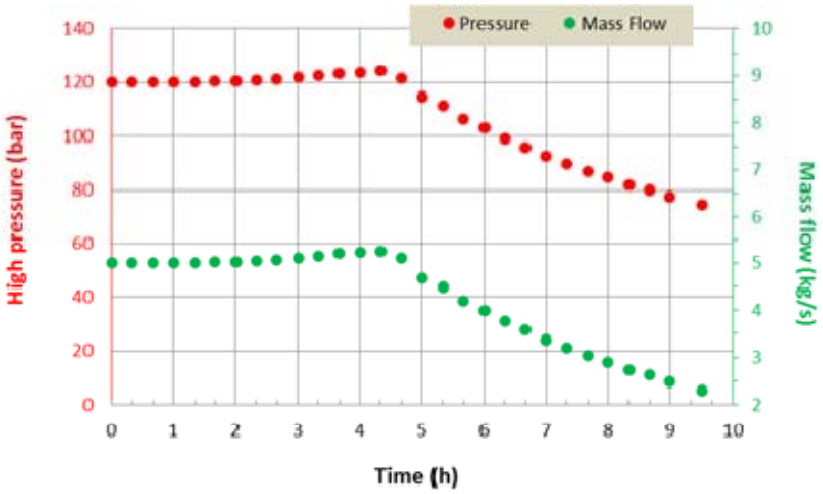
Code :

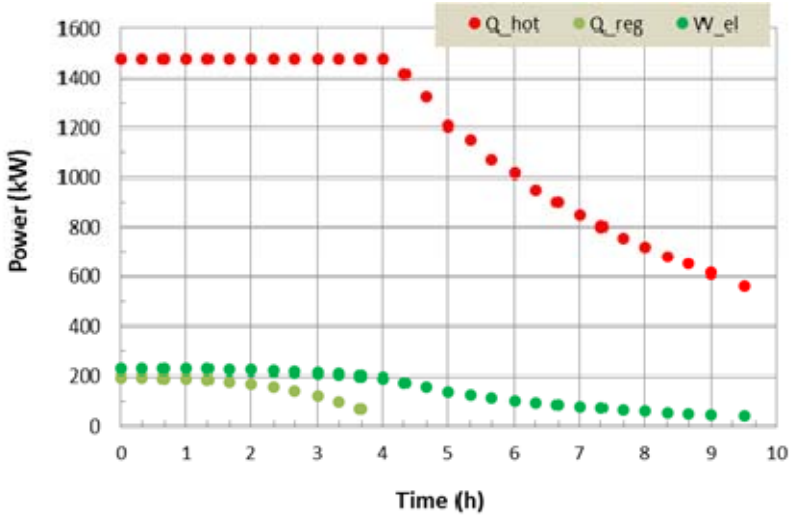
EES

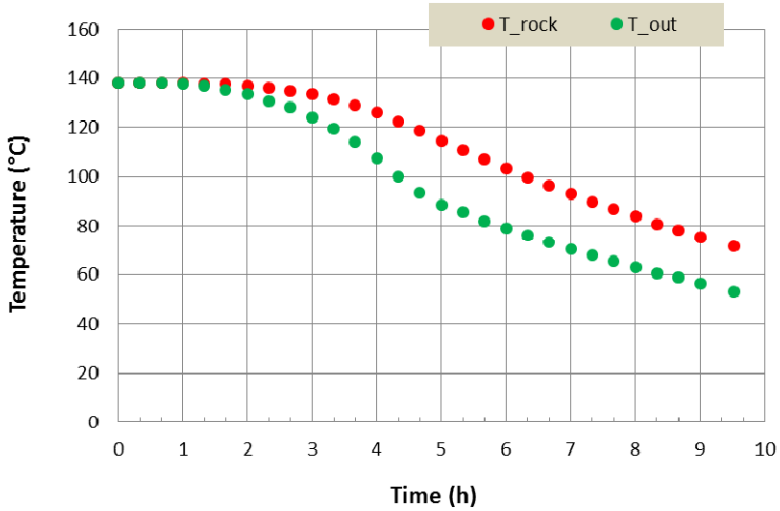




Preliminary Ground Storage Model & Transient Coupling with Thermodynamic Cycles - 2







High CPU cost
Cross-comparison with Macchi et al.

CONCLUSION

- **Parametric studies at steady-state**

- **A 1D steady state model of hot storage**
  - Taking into account pressure losses
  - Parametric study of pinch value

  ⇒ **Unfavorable impact on global efficiency**

- **Architecture discussion** ⇒ **Favorable impact on global efficiency**

- **Off-design simulations & Transient multi-D coupling**

  ⇒ **Study to be continued**

- **Other important tasks**
  - Turbomachinery design
  - Experimental validation ⇒ **1/10 device**
  - Economy

Acknowledgments

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Preliminary modeling of the hot storage ground heat exchangers

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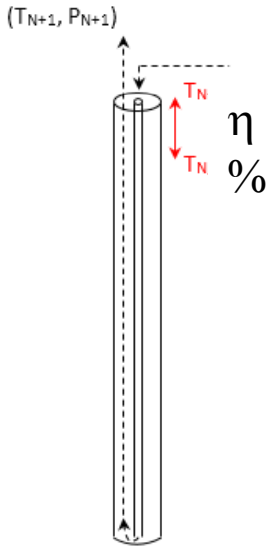
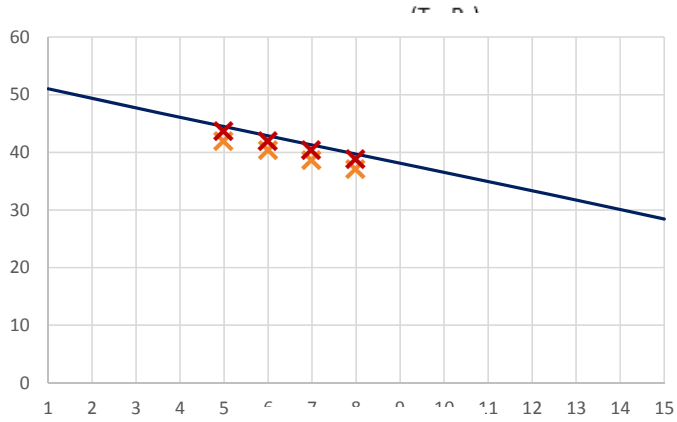
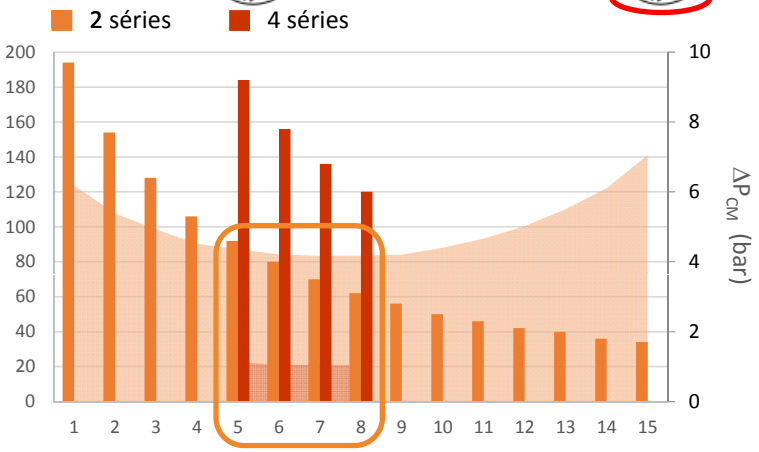




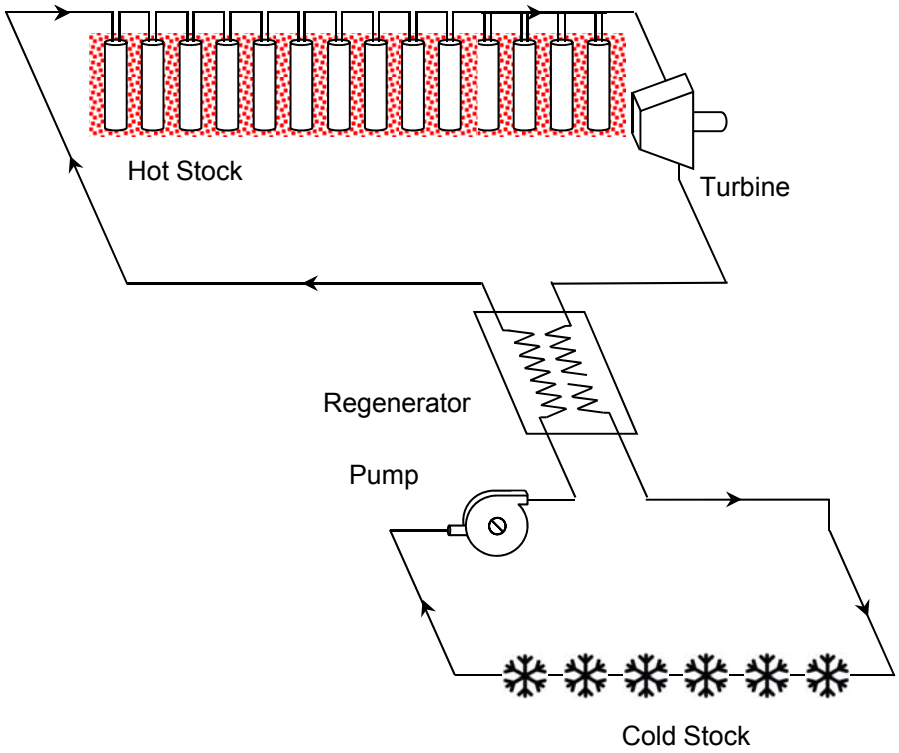
Pinch



Γrock [1]

Pinch

SELECO$_2$ Concept (2)



SELECO$_2$ Concept (2)