THE POTENTIAL OF sCO_2 CYCLES AS BOTTOMING CYCLES FOR GAS TURBINE

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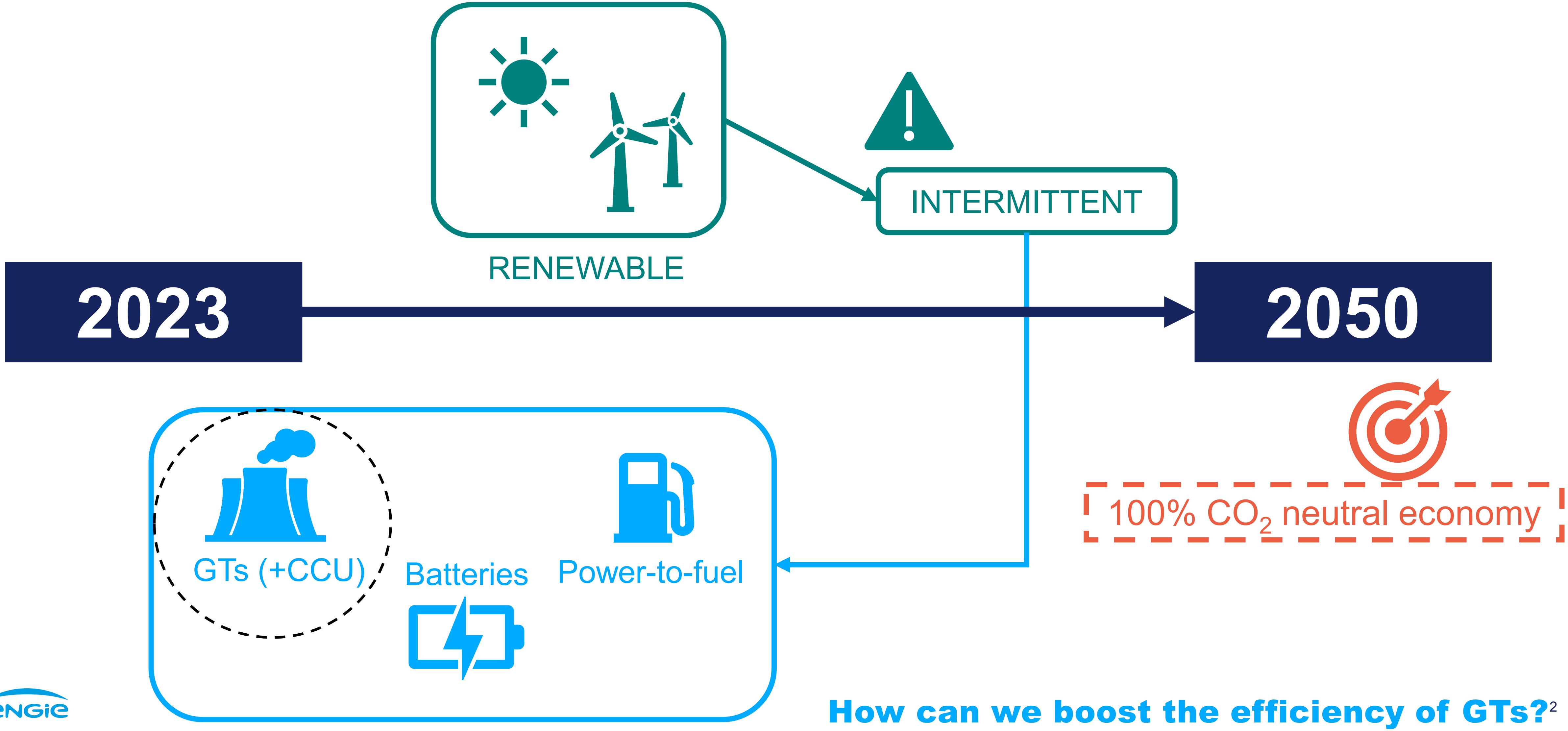
The use of gas turbines is ineluctable on the road to carbon neutrality!



How can we boost the efficiency of GTs?

Are steam and organic Rankine cycles the most suitable technologies?

Drawbacks of steam cycles:

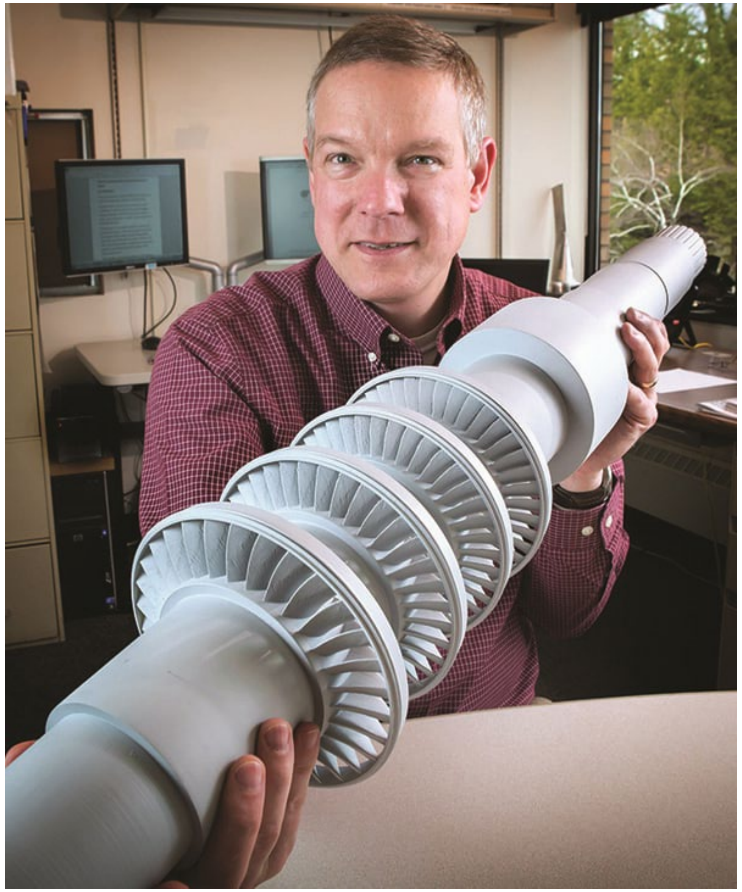
- Water treatment and quality
- Low density of steam
- Sub-atmospheric pressure
- Steam quality and droplets on the blades
- Unsuitable below T_{flue} < 350 °C

Drawbacks of organic cycles:

- Cost of the organic fluids
- Thermal stability
- Flammability
- Toxic
- Possible Global Warming Potential (GWP)

Is there an alternative fluid?

sCO_2 an interesting challenger to conventional working fluid!



16 MWe gross power at your fingertips
credits: STEP

sCO_2 presents many benefits for power cycles:

- supercritical state combining the high density of the liquid with the expandability of the gas
- critical point near ambient temperature and easily reachable (31 °C - 73.8 bar)
- non-polluting
- non-flammable
- GWP = 1
- grid flexibility
- low-cost installations (if economy of scale)

Outline

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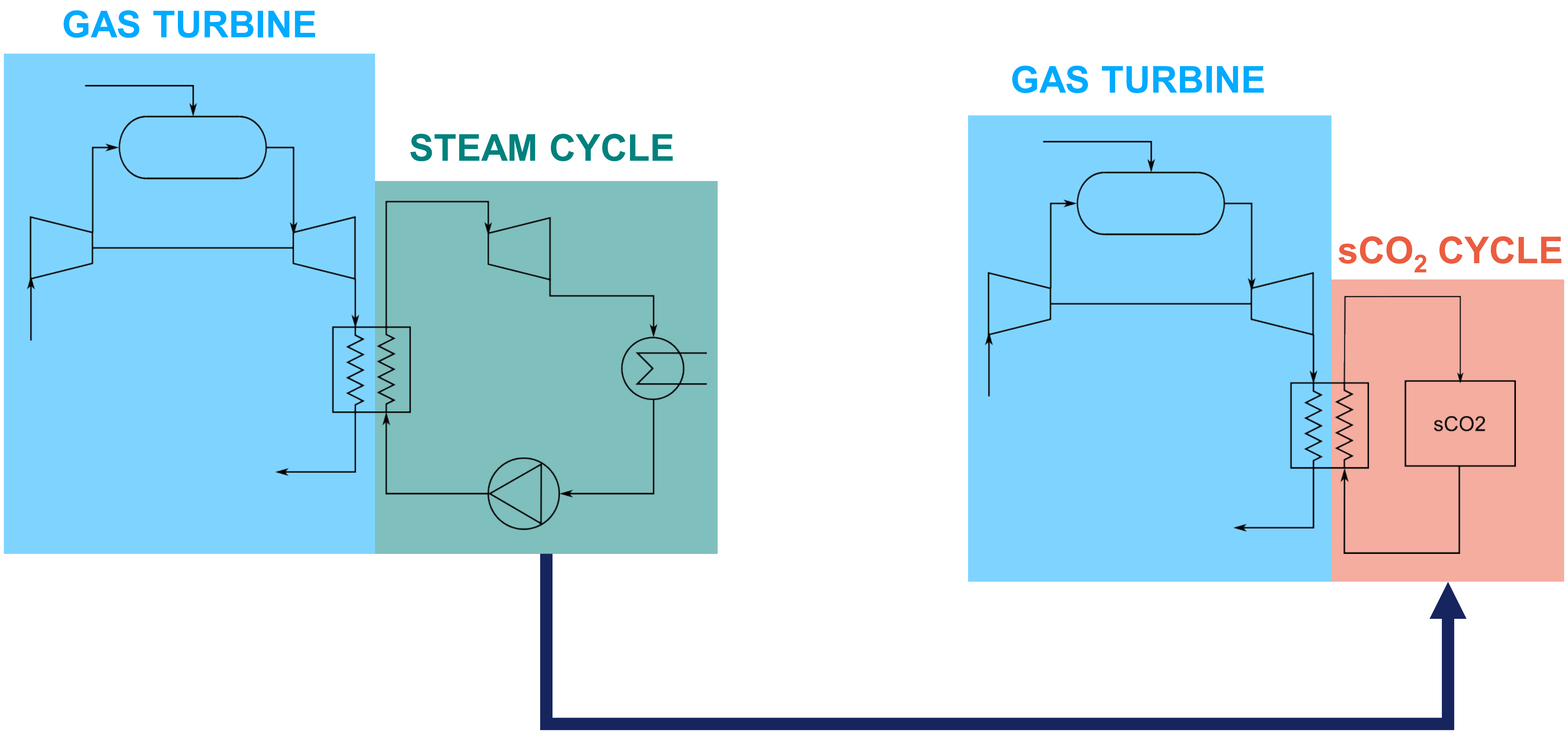
Outline

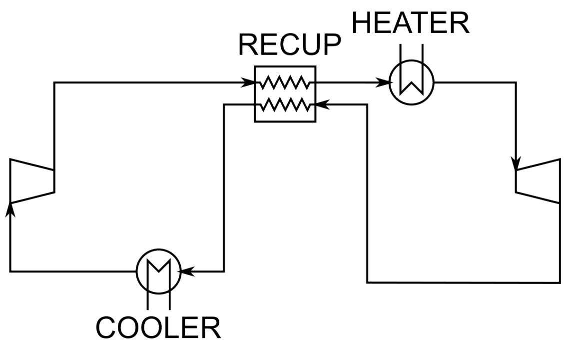
Performance maps
What can we expect from supercritical cycles? **01**

Let’s replace the steam cycle with sCO_2 cycles!

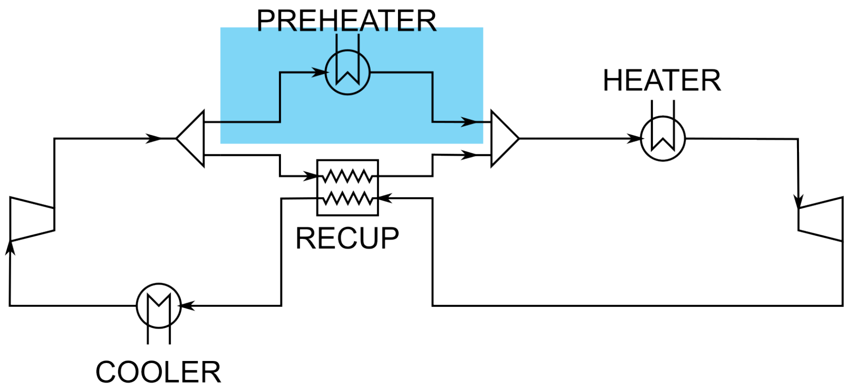


Which cycles are we going to use?

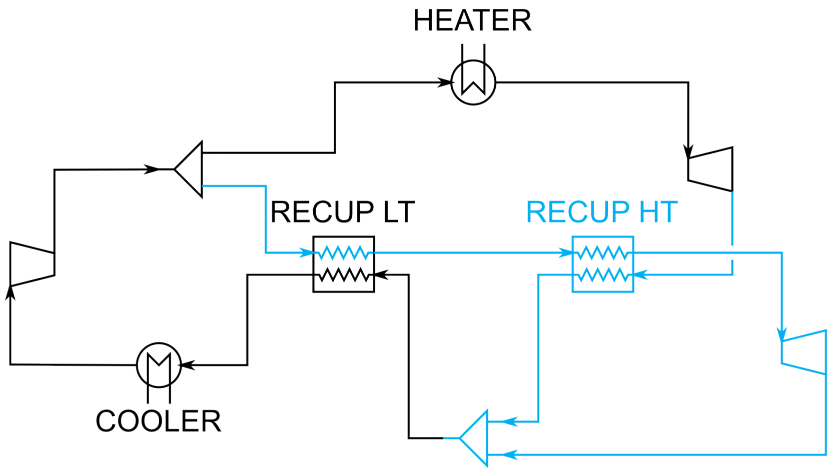
Four sCO_2 cycles are promising for bottoming application!



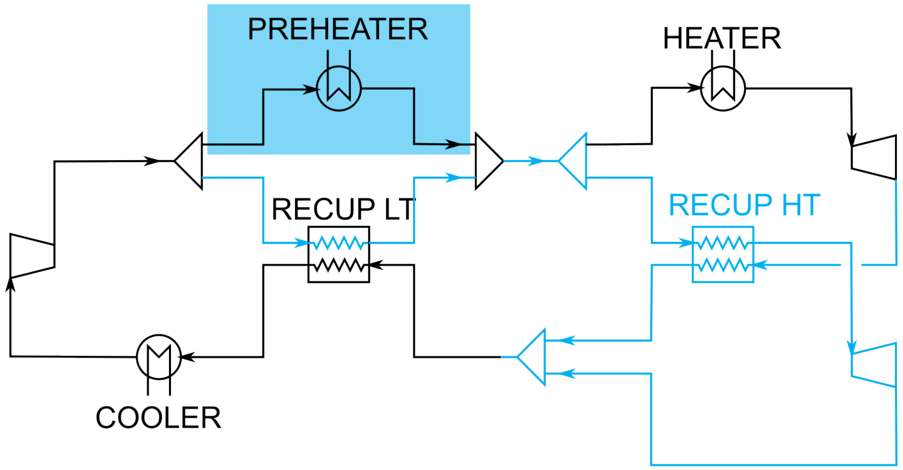
1 - Simple Recuperative Brayton Cycle



13 - Preheating Cycle



20 - Single Heated Cascade Cycle



27 - Dual Heated and Split Cascade Cycle

Credits: Crespi, F., et al. (2017). Applied energy, 195, 152-183.

Which hypothesis are used to simulate the cycles?

Standard conditions are applied to simulate the cycles!

Thermodynamic properties:

RefProp via AspenPlus V12

Economical computations:

Weiland, N. T., et al. (2019, June). In *Turbo Expo GT2019-90493*. ASME.

Exhaust gases composition:

Components		%vol
Nitrogen	N_2	73.72
Oxygen	O_2	10.53
Carbon dioxide	CO_2	4.65
Water	H_2O	10.21
Argon	Ar	0.89

Characteristics of the components:

Item	Value	Unit
Compressor isentropic efficiency	80	%
Turbine isentropic efficiency	85	%
Minimal recuperator temperature pinch	10	°C
Minimal heater temperature pinch	30	°C
Cooler outlet temperature	33	°C
Configuration of the heat exchangers	Counterflow	-
Minimal pressure	85	bar
Maximal pressure	280	bar

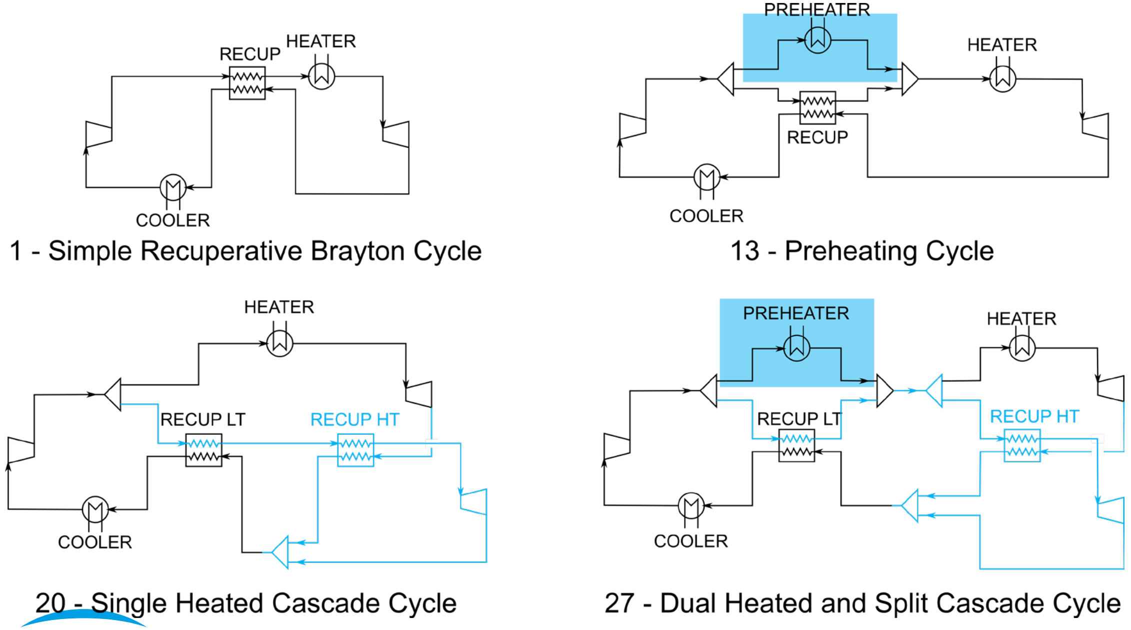
What are their potentials?

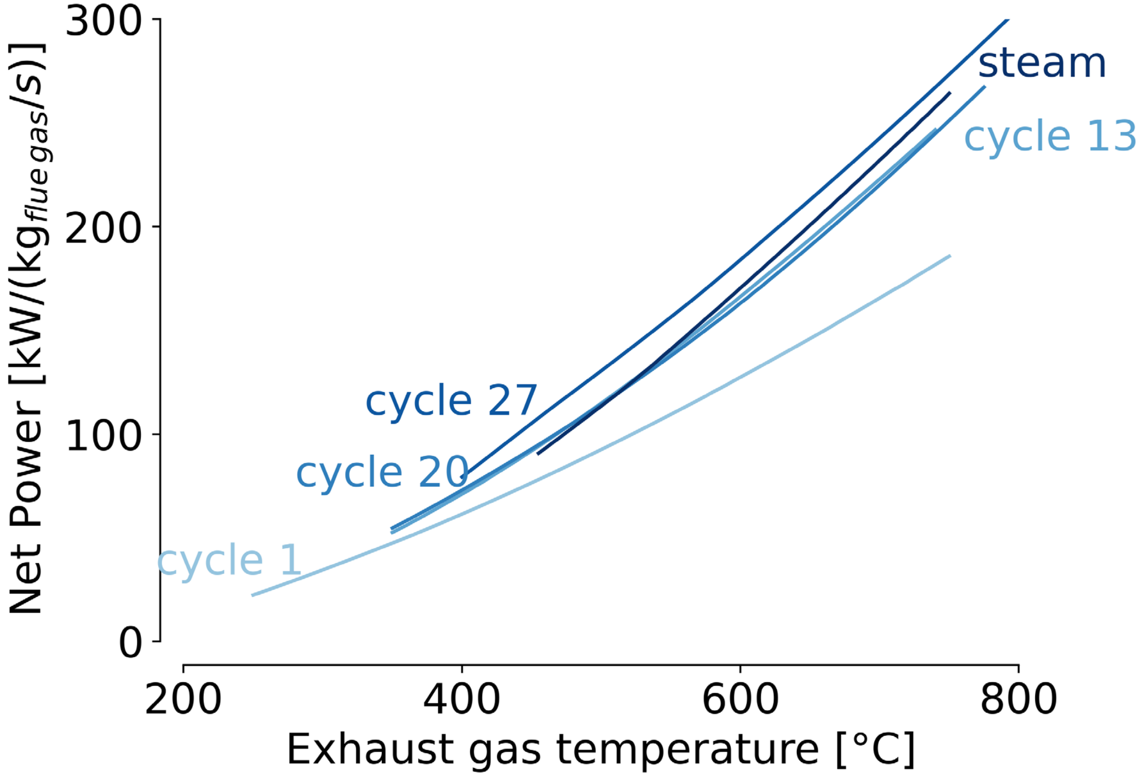
sCO_2 cycles can outperform steam !

- Net work produced by unit of exhaust gas flow rate:

$$\frac{P_{net}}{\dot{m}_{exhaust\ gas}}$$

- Cycle 13 more interesting than cycle 20
  → similar performances for fewer components





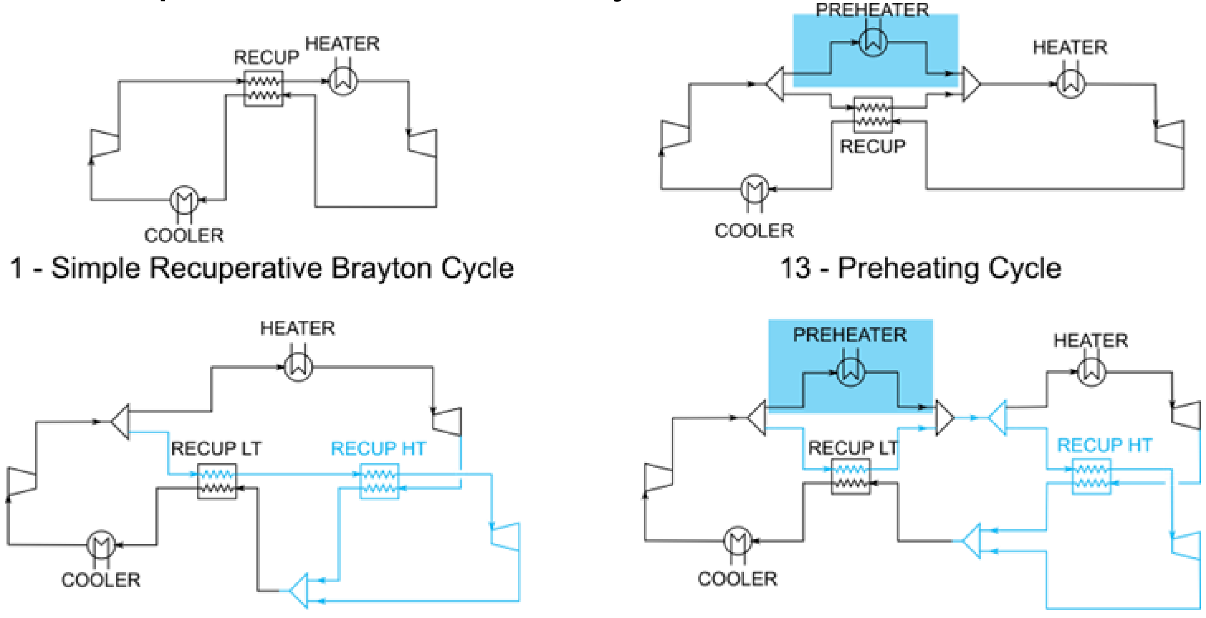
A dimensionless version is required to differentiate the curves!

The energy efficiency is not a suitable indicator for waste heat sources!

- Ratio between the net work produced and the heat flux consumed:

$$\eta = \frac{P_{net}}{Q_{extracted}}$$

- The energy efficiency **does not evaluate** the recuperativeness of the cycle



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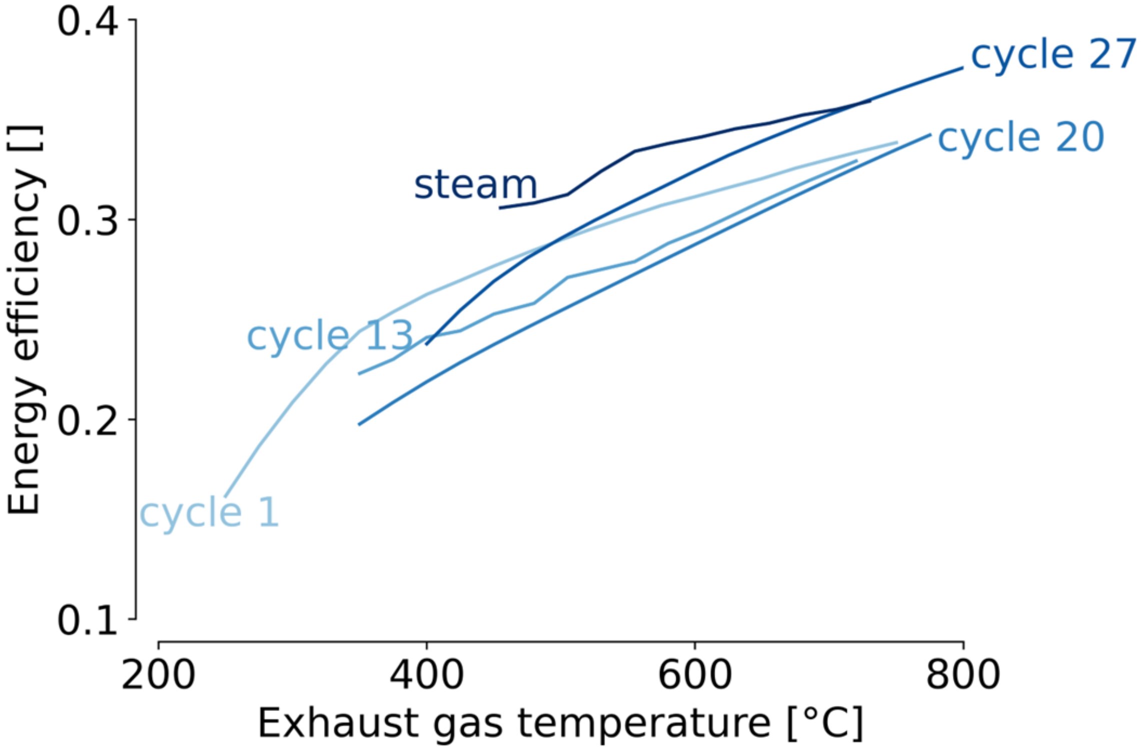
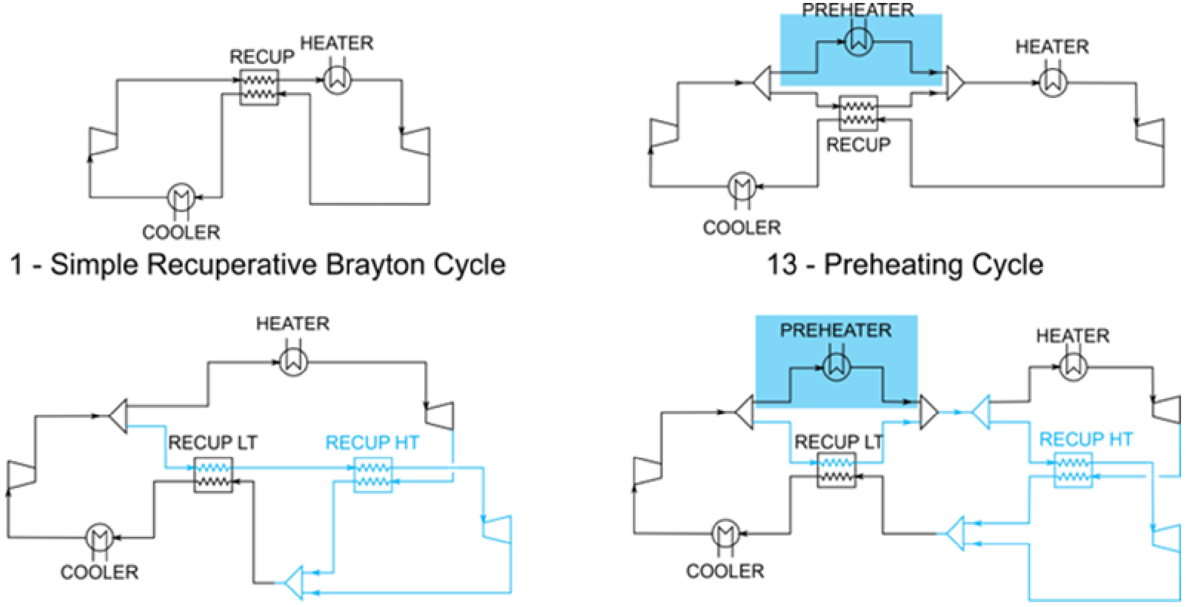


How can the source potential be considered?

The exergy efficiency demonstrates the clear advantage of sCO_2!

- Ratio between the net work and the maximal work potential that could be extracted in the exhaust gases

$$\psi_{25} = \frac{P_{net}}{j_{25}}$$



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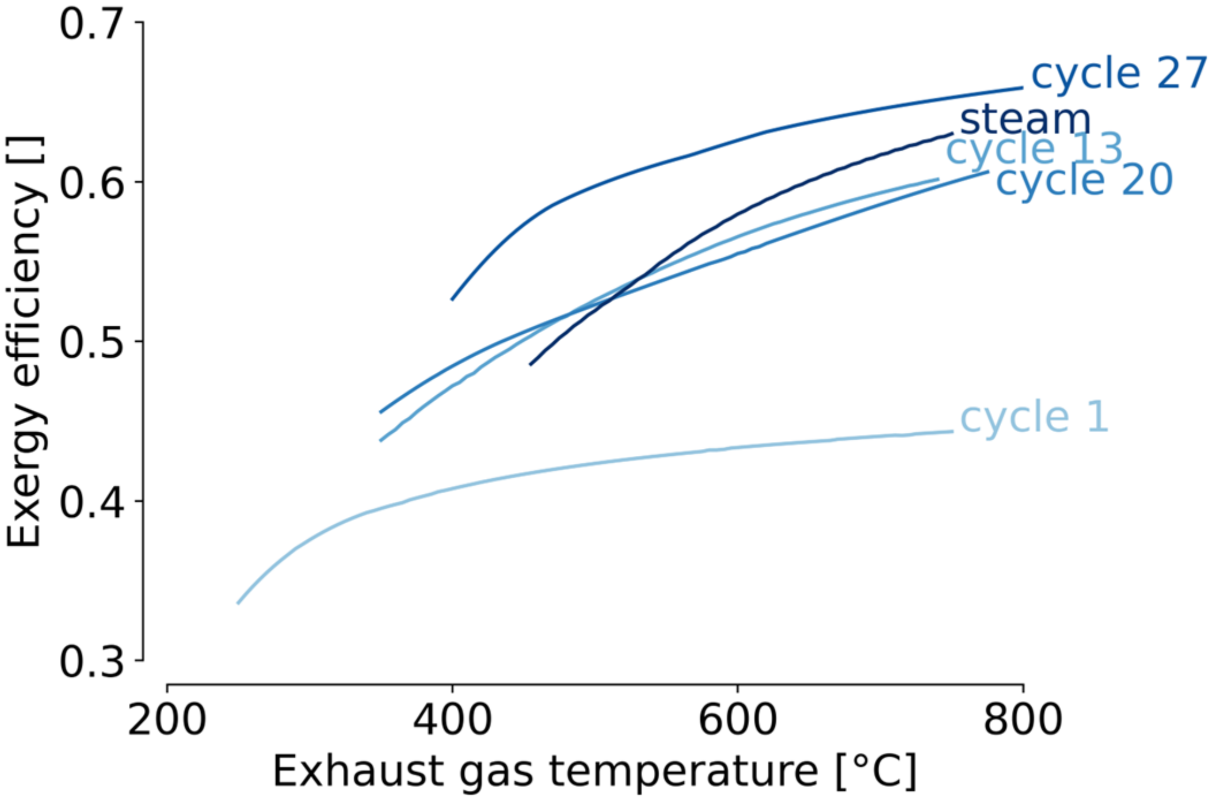

To what extend could those curves be applied?

Outline

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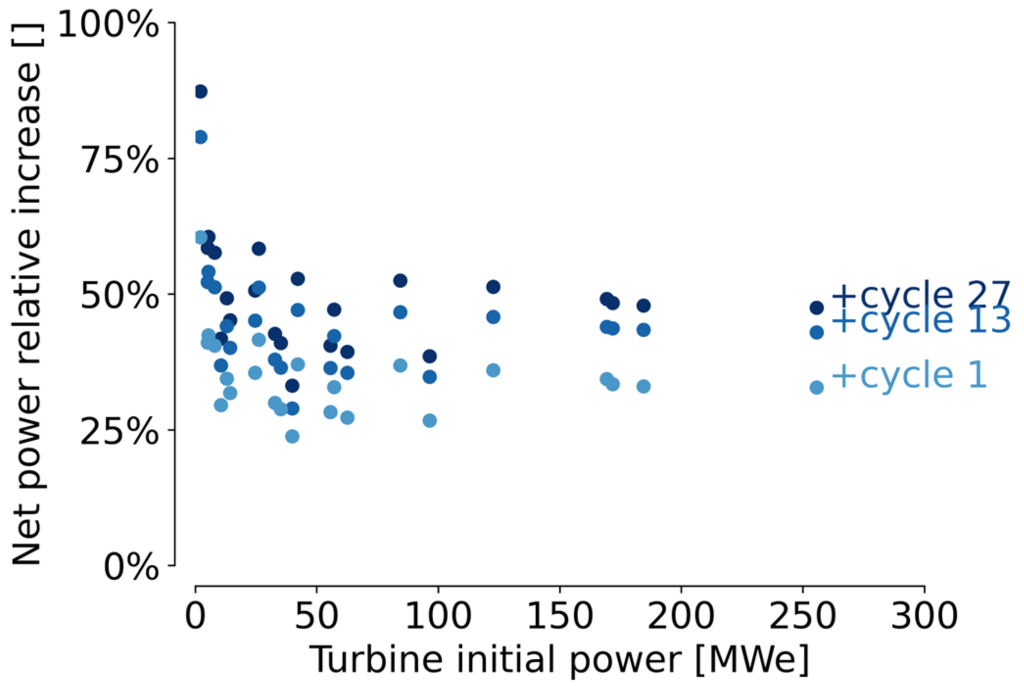
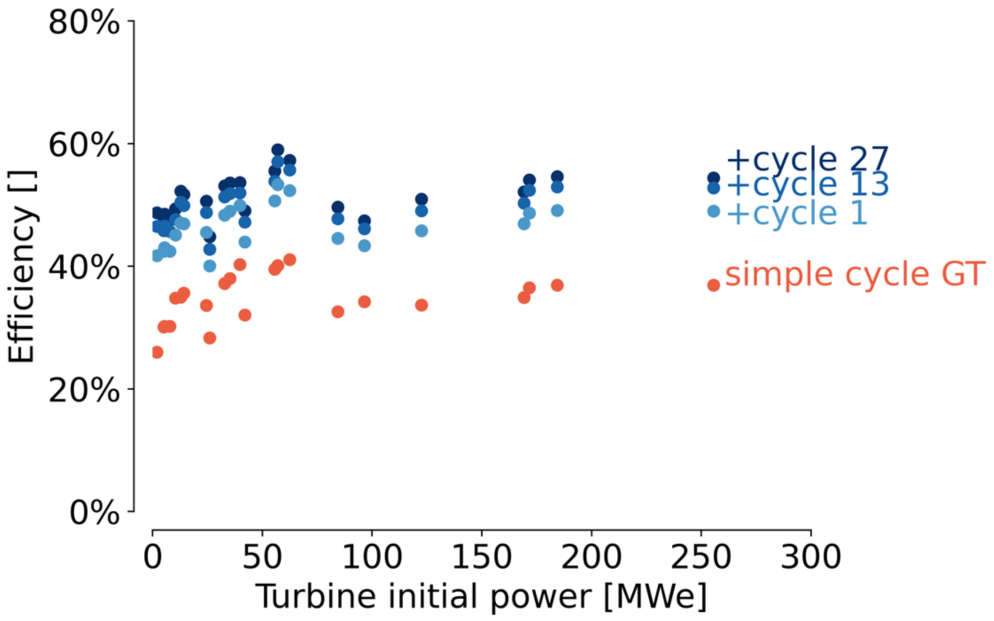
What can we expect from supercritical cycles? **01**

Potential for the market
How apply sCO_2 cycles to the industrial GTs' market? **02**

Looking at 23 industrial turbines, sCO_2 bottoming cycles increase on average the power by 48%!

- Data from 23 industrial GTs based on exhaust gases characteristics
- Cycle 20 overtaken by cycle 13 → not represented
- Preferential market → smaller GTs for technical reasons (thermo-electrical balance)





What additional costs does this involve?

Only the preheating cycle is economically investigated!

Hypotheses:

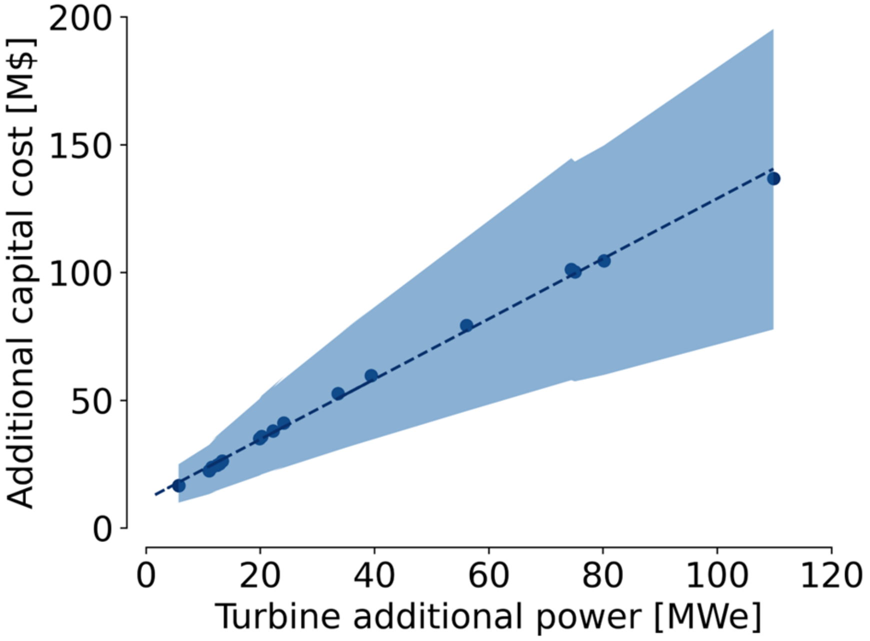
- CEPCI 2022
- 11% discount rate
- 10 years lifetime
- 80% usage ratio

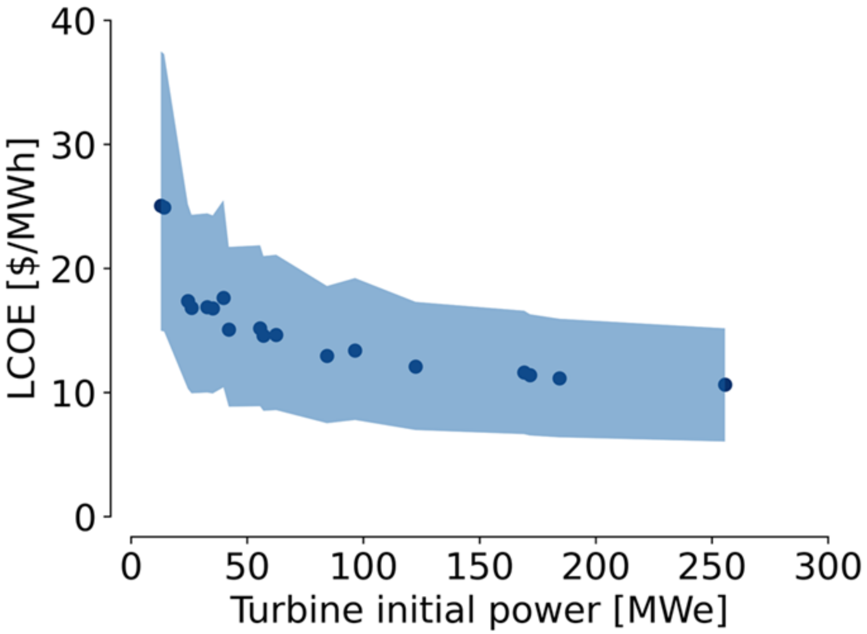
Capital costs:

- sCO_2: 0.67-1.67 M$/MWe
- steam: 1.5-2 M$/MWe

LCOE:

- sCO_2: 7.6-38 $/MWh
- steam: 25 $/MWh





What about the largest-scale GTs?

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Potential for the largest scale
Can sCO_2 replace steam in the bottoming cycle of an H-Class CCGT? **03**

Although sCO_2 performs well, the maturity of the H-Class CCGT is unbeatable!

Larger-scale GTs are difficult to beat (steam cycle highly performant with reheats and expansions)

sCO_2 performances can be improved on 4 aspects:

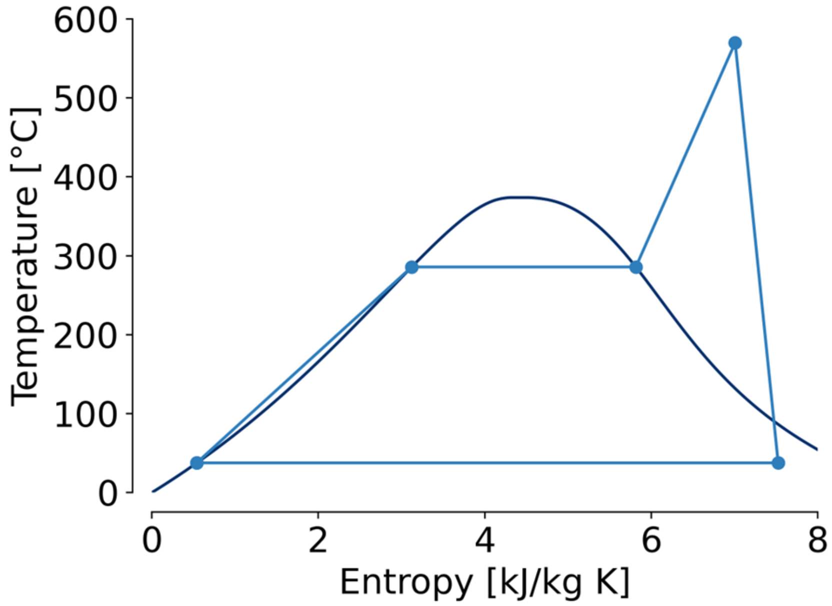
1. technological development of the components
2. technological development of the cycle
3. economic advantages
4. addition of heat recovery

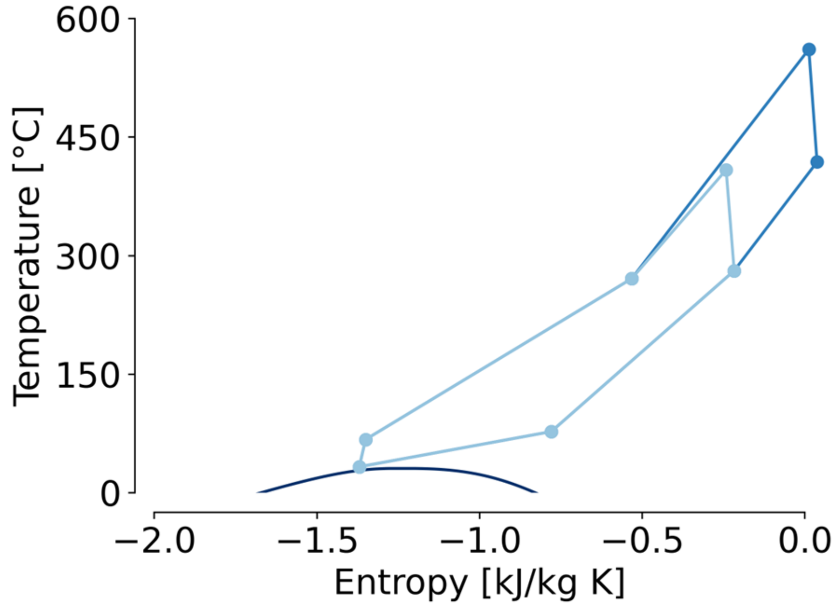
Value	Steam	1	13	27	Unit
P_{net}	278	170	224	245	MW
ΔP_{steam}	0	-108	-54	-33	MW
$\boldsymbol{T_{stack}}$	**90**	**256**	**98**	**98**	**°C**
Q_{cool}	410	330	430	440	MW
$\boldsymbol{T_{cool,in}}$	**37**	**78**	**78**	**78**	**°C**
$T_{cool,out}$	37	33	33	33	°C
$\boldsymbol{\eta}$	**41**	**34**	**33**	**36**	**%**
$\boldsymbol{\psi_{25}}$	**76**	**47**	**61**	**67**	**%**

The difference of temperature in the cooler can be valorised!

sCO_2 implies a temperature difference in the cooler that can be valorized!

Value	Steam	1	13	27	Unit
Q_{cool}	410	330	430	440	MW
$\boldsymbol{T_{cool,in}}$	**37**	**78**	**78**	**78**	**°C**
$T_{cool,out}$	37	33	33	33	°C





How can the cooling heat be valorised?

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Integration of amine-based carbon capture
How can sCO_2 cycles be integrated with PCC? **04**

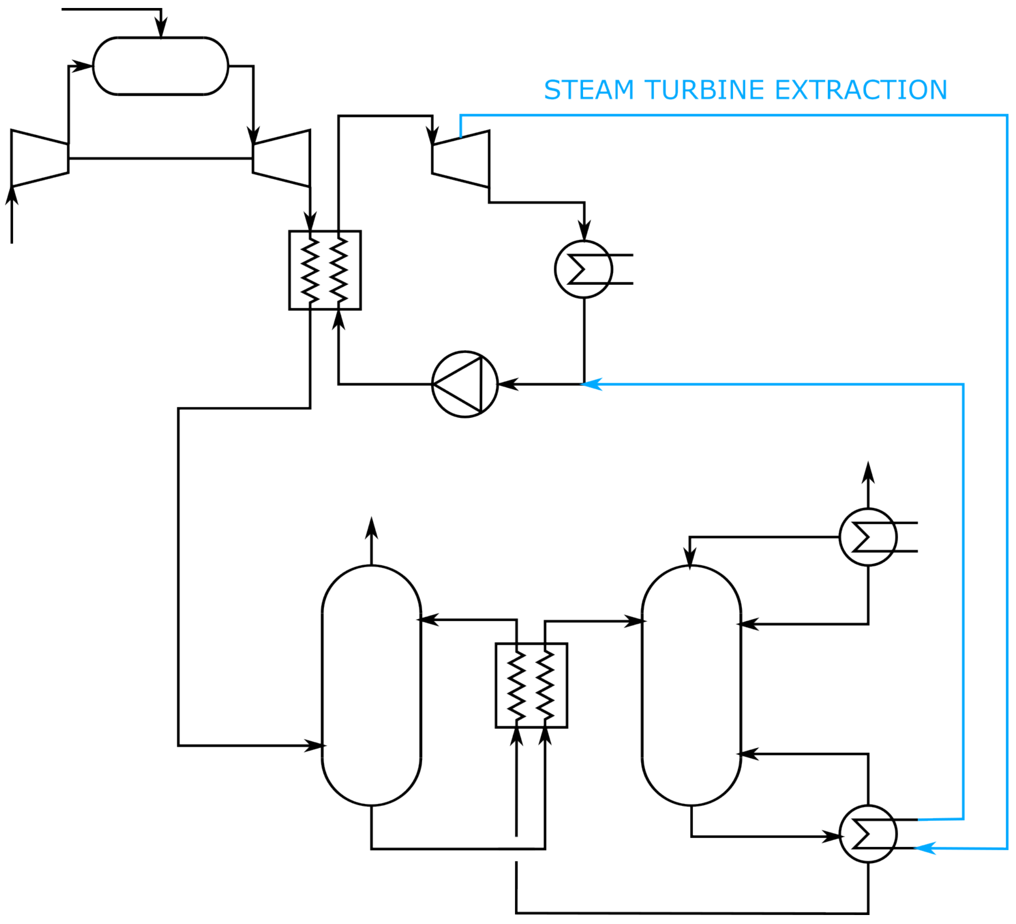
Amine-based carbon capture decreases the net production of the steam cycle by 28%!

Working conditions:

- SGT5-9000 HL
- P_{GT}: 570 MWe
- $P_{steam\ cycle}$: 220 MWe
- P_{total}: 790 Mwe

- 35% EGR
- $\Phi_{stripper}$: 230 MW at 120 °C

→ Decrease the net production by 28%!



Can sCO_2 setup decrease the penalty of the capture?

Different cogeneration setups for CC are investigated but none of them outperforms steam!

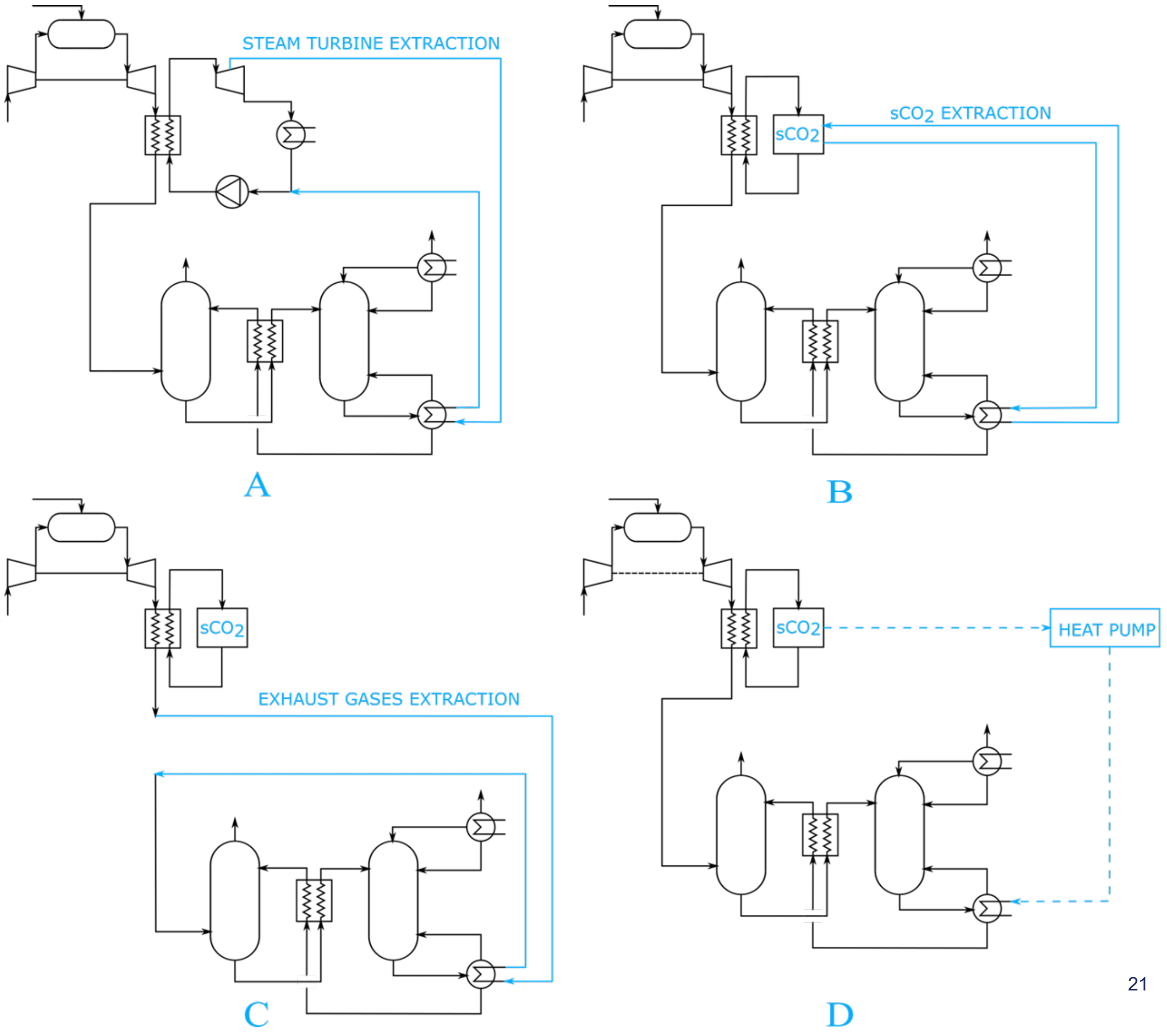
New configurations investigated:

- Subtract sCO_2
- Recover heat on the exhaust gases
- Integrate an industrial heat pump

Critical notes:

- The constant temperature during the phase change is the most suitable for the amines
- The initial steam cycle is already well optimized

→ **sCO2 expects less performances**

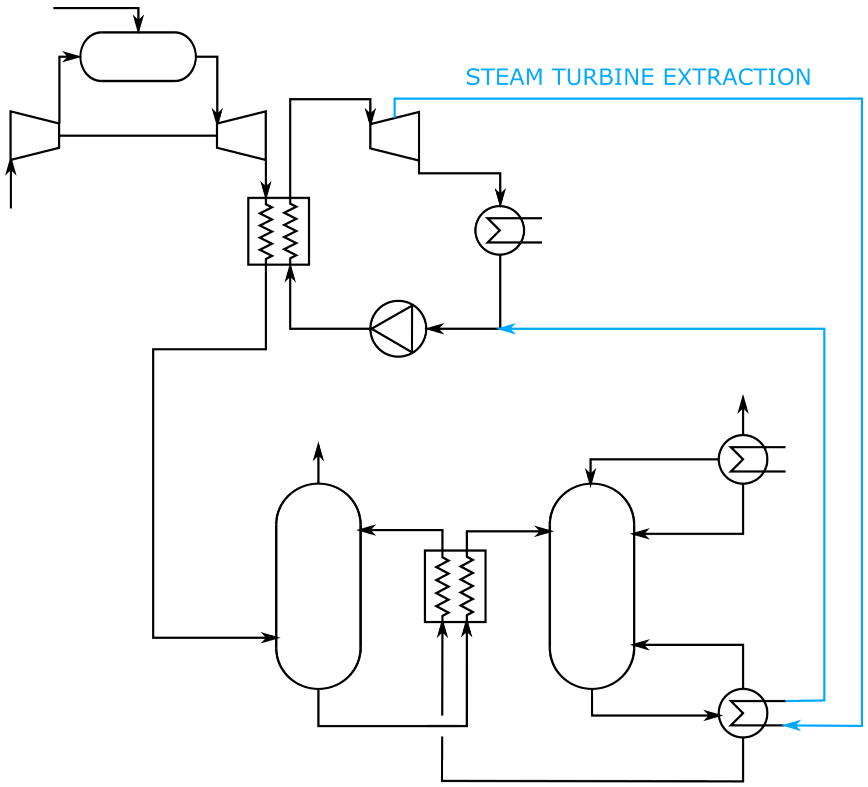


Different cogeneration setups for CC are investigated but none of them outperforms steam!

Comparison between the power production of the cycle 13 with different setup and the steam cycle coupled with CC:

Setup	$P_{cycle\ 13}$	$\Delta P_{steam+CC}$	
Maximal potential without CC penalty	225	7	MW
Invert Rankine cycle	126	-92	MW
HP on cooler	129	-89	MW
HP on cooler + exhaust gases	138	-80	MW
Subtract sCO_2	148	-70	MW
Heat recovery on exhaust gases	**165**	**-53**	**MW**

→ Minimization of the exergy destruction



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Are sCO_2 cycles valuable in the industry as bottoming cycles?

Performance maps
What can we expect from supercritical cycles?

01 4 sCO_2 cycles have been identified with efficiencies close to the “simple” steam cycle

Potential for the market
How apply sCO_2 cycles to the industrial GTs’ market?

02 The application for small-scale gas turbine (<50 MWe) is relevant to benefit from the compacity/low cost of sCO_2 technologies

Potential for the largest scale
Can sCO_2 replace steam in the bottoming cycle of an H-Class CCGT?

03 The large-scale steam cycle with several reheats and expansions appears unbeatable

Integration of amine-based carbon capture
How can sCO_2 cycles be integrated with PCC?

04 The steam cycle better integrates the carbon capture unit than sCO_2 cycles

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