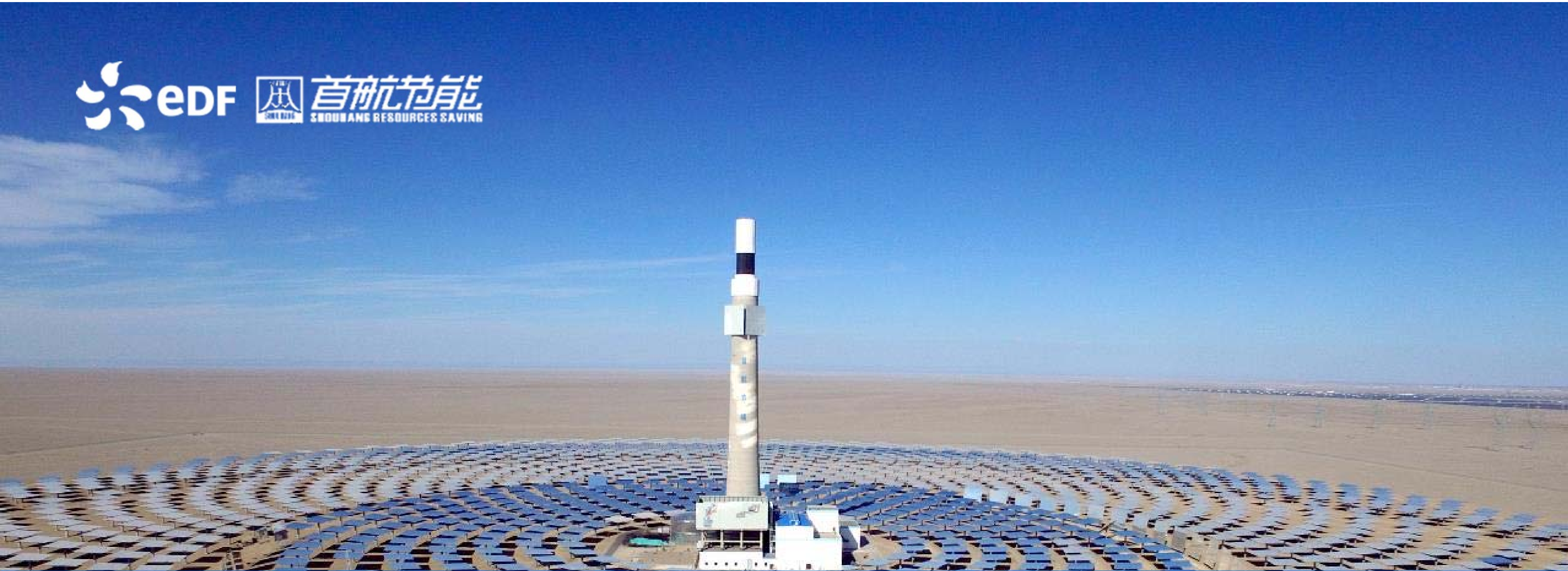


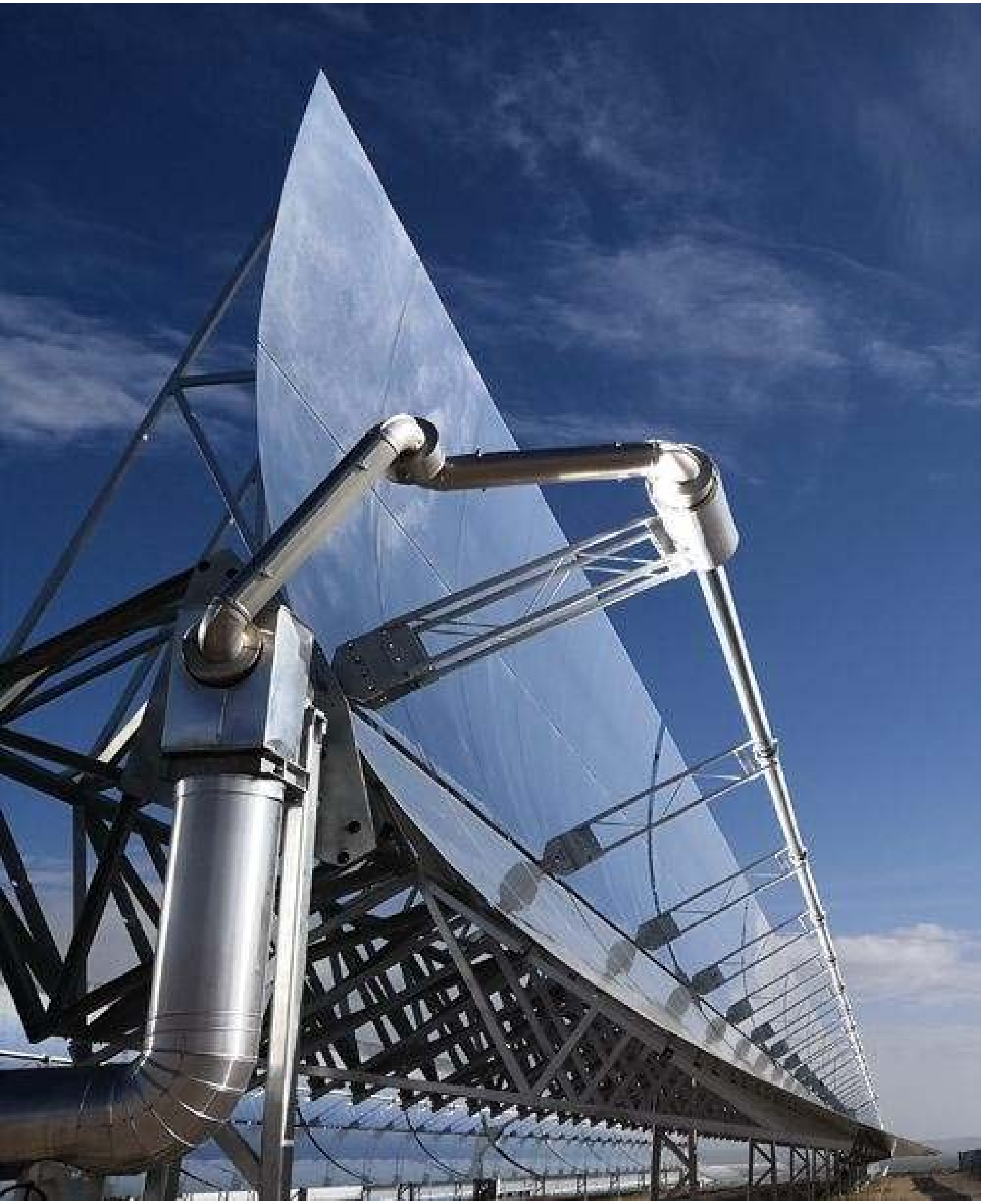
Shouhang – EDF 10MWe Supercritical CO_2 Cycle for CSP Demonstration Project

3rd European sCO_2 Conference

EDF R&D China

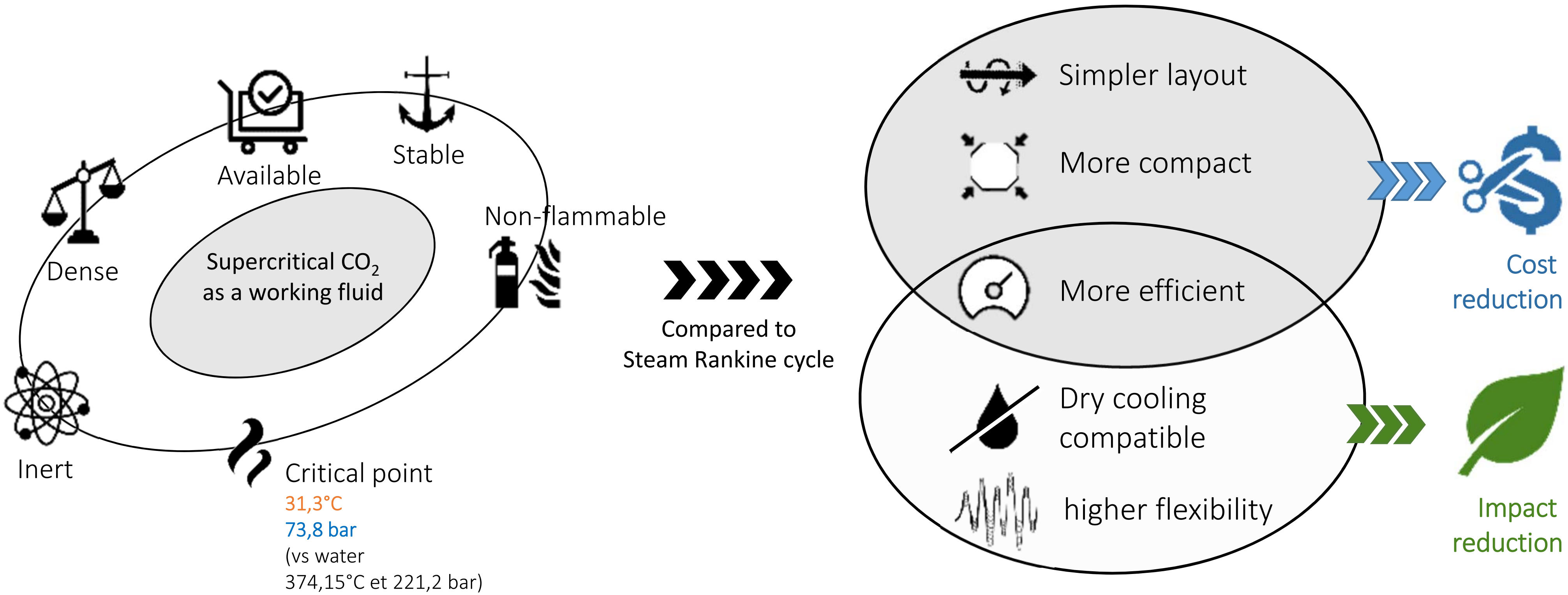
2019.09.19

From EDF: Zhou Pan, Xiong Yili, Yann Le Moullec, Zhang Jinyi, Yang Zijiang
From Shouhang: Qi Zhipeng, Chen Wenlong, Wang Xihua, Jing Chengtao



OUTLINE

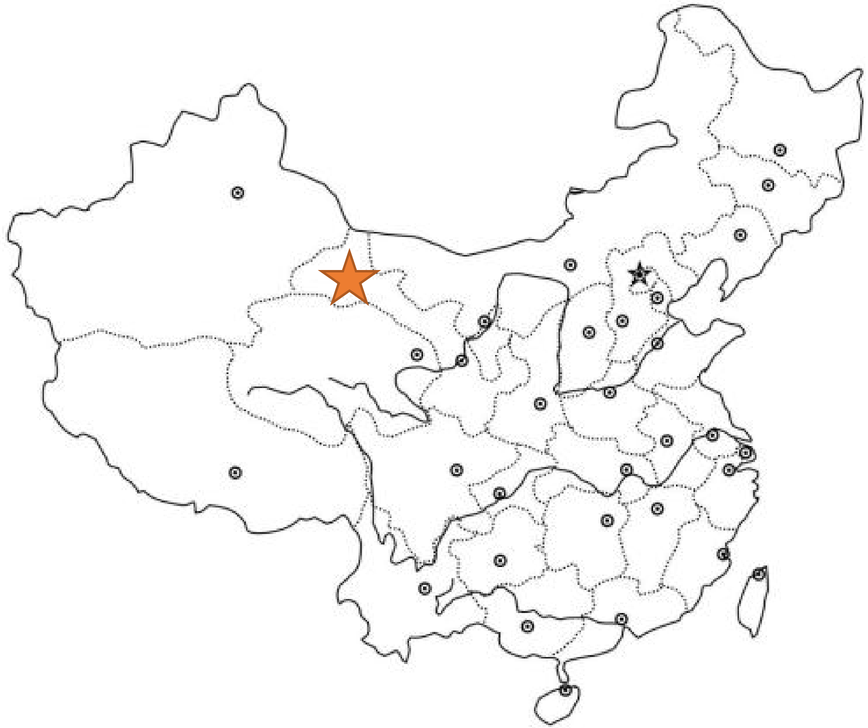
Why using Supercritical CO_2 cycle for power generation?



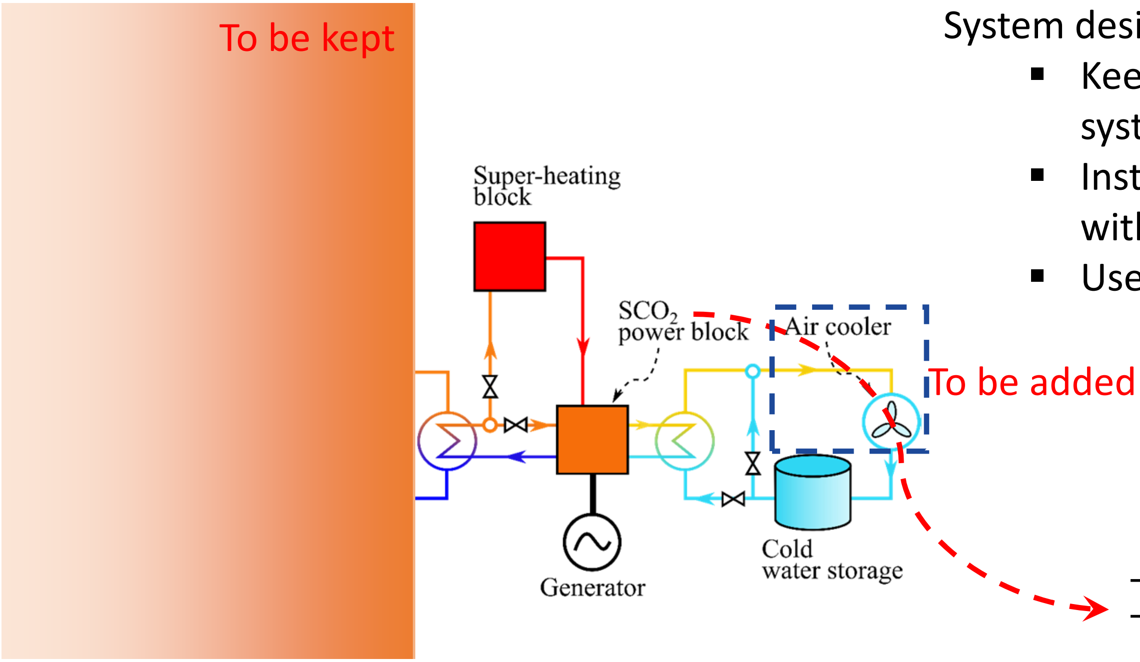
Introduction

Shouhang – EDF 10MWe sCO_2 demonstration project (1)

- Collaboration signed in 2018
- Retrofit Shouhang's 10MWe CSP plant with sCO_2 cycle
- To investigate:
  - Optimal sCO_2 cycle design for CSP
  - Industrial scale SCO_2 equipment
  - Cycle control and operation
  - Material test
- Operate and evaluate the performance of the demo cycle
- Current 10MWe CSP with steam Rankine cycle
  - Situated in Dunhuang
  - 15h thermal storage with molten salt

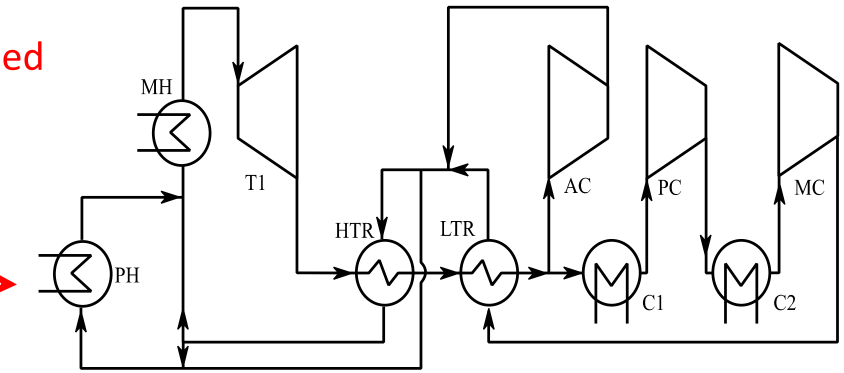


Shouhang – EDF 10MWe sCO_2 demonstration project (2)



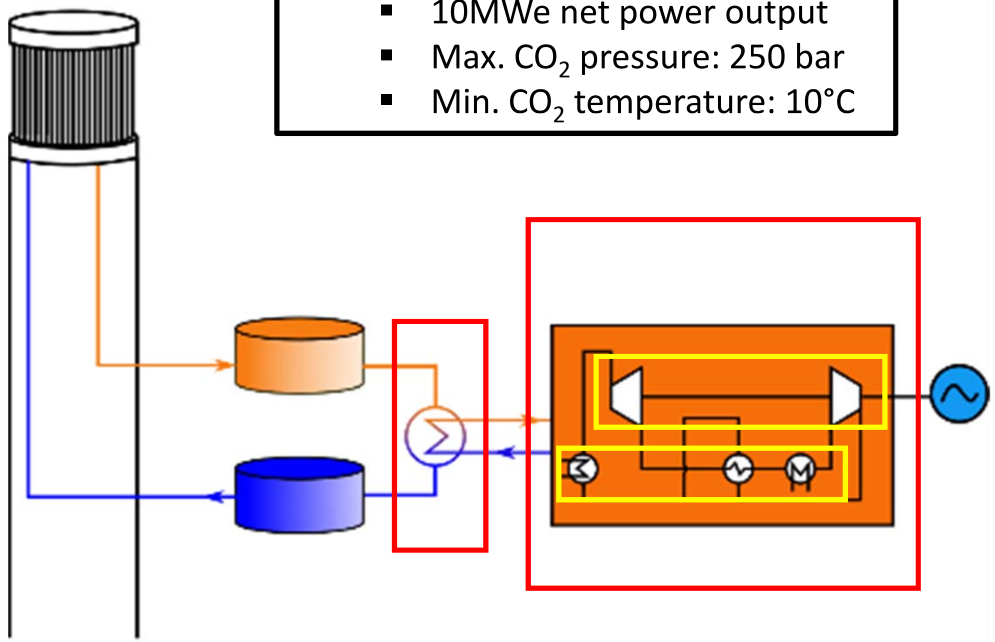
System design concept

- Keep the current solar field and thermal storage system
- Install a 10MWe sCO_2 power block in parallel with the current steam Rankine cycle
- Use indirect dry cooling



Boundary conditions of cycle design

Cycle parameters
- 10MWe net power output
- Max. CO_2 pressure: 250 bar
- Min. CO_2 temperature: 10°C



Turbomachinery related parameters
- Isentropic efficiency : 80% for compressor and 85% for turbine

Heat exchanger related parameters
- Min. pinch: 10°C
- Pressure drop: 1 bar

Molten salt related parameters
- 290°C < Molten salt exhaust temperature < 320°C
- Max. temperature: 530°C
- Mass flow rate: 80 kg/s

sCO_2 cycle design (1)

Optimization-driven design with 2 approaches:

1. « Classic design » by simulation based on expertise
   learn and understood the design drivers
2. Global optimization tool coupled with a cycle superstructure
   sure to not miss a good solution and explore out of the box ideas

6 Cycles selected

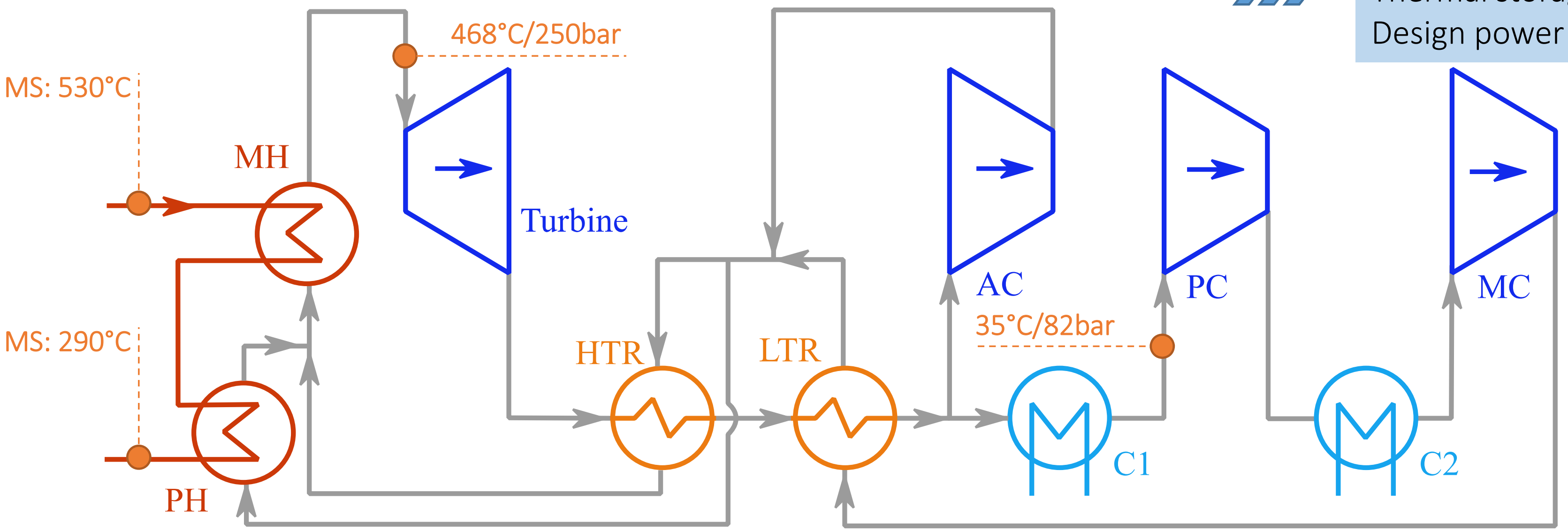
Cycle	Max .T	Min. P	CO_2 flow	Split ratio	Power	Eff.	MS Outlet T+	HX UA (100% = 4857 kW/°C)*	Complexity (Nbr. Turbomachinery)	
	°C	bar	Kg/s	%	MWe	%	°C	%		
RG-IC	520	68.5	96.2	-	10.06	34.6	290	100.00	3	Pinch problem
RC-IC	438	82.6	145.9	31.67	9.95	34.2	290	107.47	4	Low output power
RC-IC	470	82.0	126.5	33.04	9.33	36.6	320	98.68	4	
RC-PH	439	87.1	162.94	34.17	10.01	34.4	290	133.05	3	30% more heat exchangers
RC-DPH	464	86.9	141.8	24.92	10.18	34.9	290	100.29	3	
RC-IC-PH	468	82.1	137.7	27.74	10.35	35.6	290	113.87	4	
PartC-PH	485	72.3	122.0	41.32	10.40	35.8	290	101.00	4	Transcritical operation

sCO_2 cycle design (2)

Key cycle features:

- Recompression to increase the recuperation effectiveness
- Intercooling to reduce compressor consumption and to increase thermal storage utilization
- Pre-heating to better utilize the low-temperature molten salt

Cycle net efficiency: 35.6%
Thermal storage utilization: 100%
Design power output: 10.3MWe



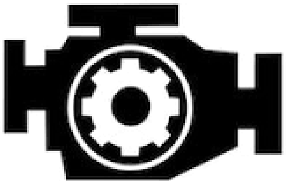
Superheating subsystem

Advantage of sCO_2 cycle is evident at high temperature
↓
Necessity of superheating subsystem

1. Direct heating of sCO_2
2. Heating of high temperature heat transfer fluid

Storage tank

-Storage system not able to withstand 600°C
-High investment



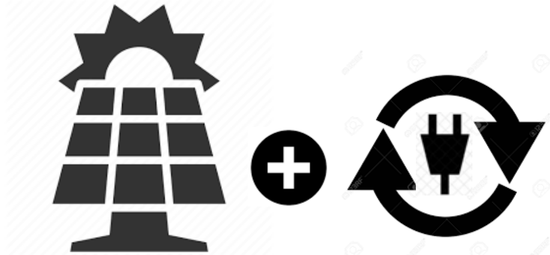
Gas engine

-No available gas engine with an exhaust gas T above 650°C
-Reduce lifetime cost of the demonstration

Gas combustion

-Expensive
-Low efficiency of boiler

-Expensive
-Low efficiency of boiler



PV solar farm

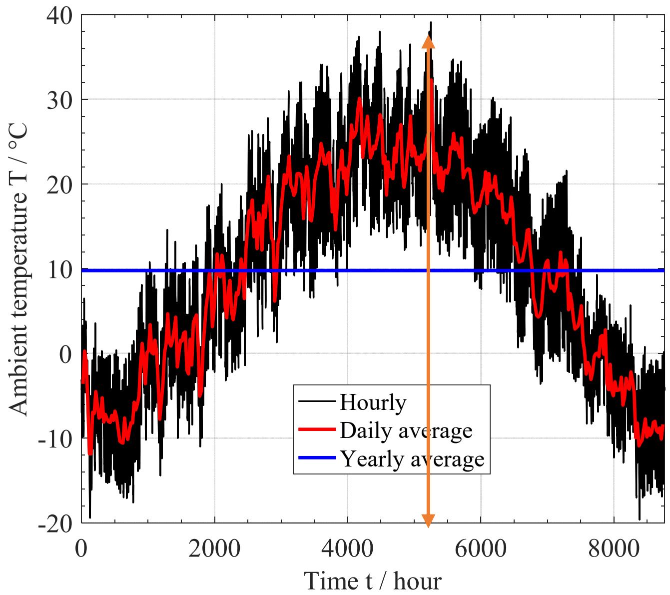
-More investment
-Policy complexity

Auto-consumption

-Expensive electric heater

-Able to demonstrate the HTF/CO2 HX and HTF heater

Cooling system with cold storage (1)



Annual temperature difference: 58.7°C
Annual average: 9.78°C
High daily temperature difference
↓
Ideal case to test cold storage

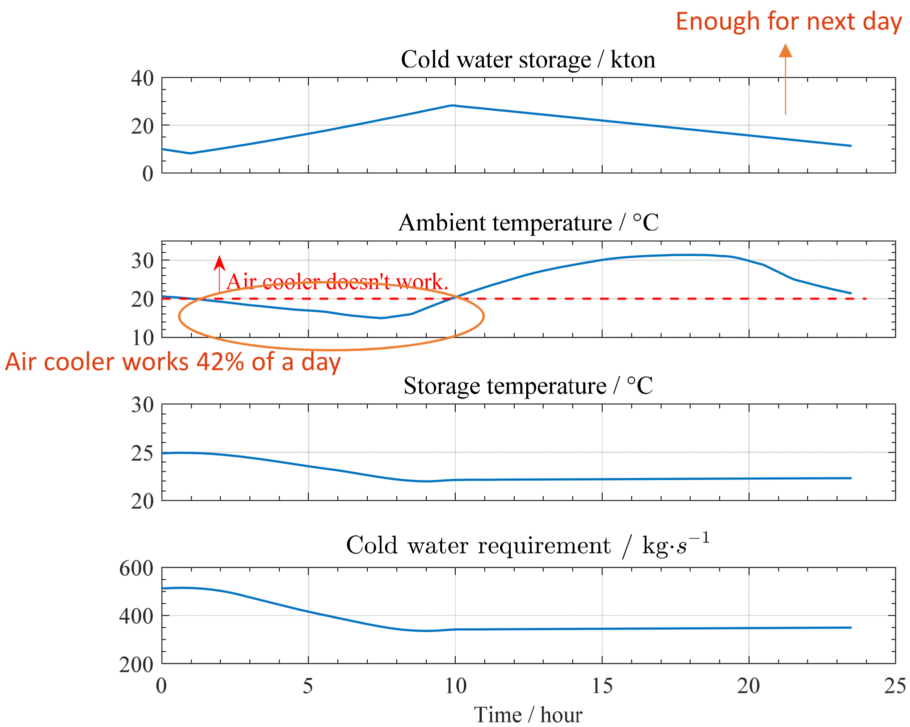
A **simplified dynamic model** to test the performance of cold storage:

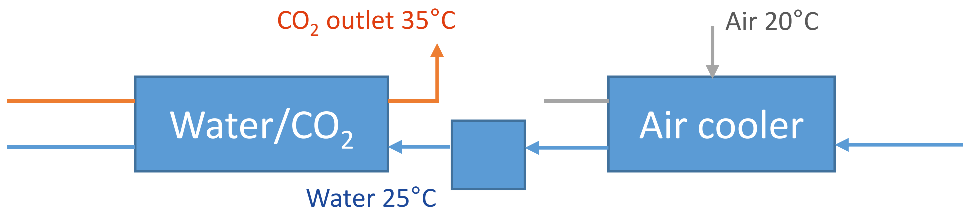
- Air cooler with ideal controller to control the outlet water T
  Water/CO_2 heat exchanger
  Cold storage water tank perfectly stirred

Working logical:

Air cooler operates when ambient temperature below designed T_{amb}
Cold storage discharged when the cooling water is needed at required flow rate

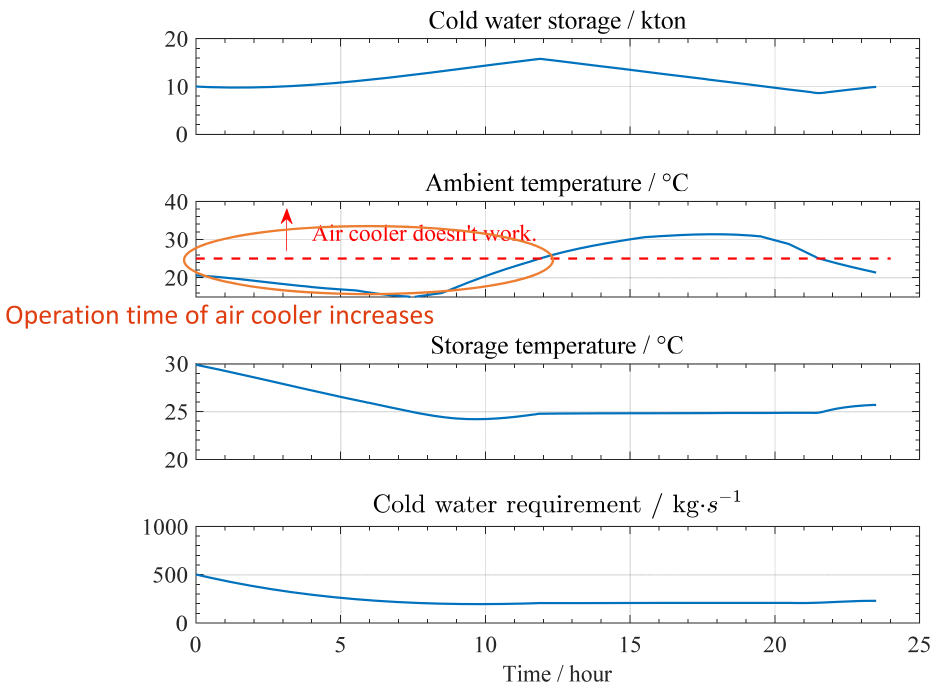
Cooling system with cold storage (2)

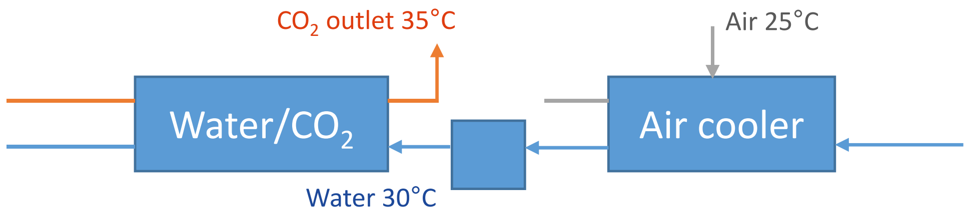




- 24-hour full load continuous cycle operation at the hottest month
- Suppose:
  10°C pinch for water/CO_2 heat exchanger
  5°C pinch for air cooler
- Air cooler works when ambient temperature below 20°C

Cooling system with cold storage (3)





- 24-hour full load continuous cycle operation at the hottest month
- Suppose:
  5°C pinch for water/CO_2 heat exchanger
  5°C pinch for air cooler
- Air cooler works when ambient temperature below 25°C

Shouhang-EDF 10MWe SCO_2 demo project: Brief planning

2018
- May. 22 — Contract signed between Shouhang, EDF R&D and EDF China
- Dec. 30 — Conceptuel design

2019
- Feb. 15 — Request for proposal
- Jun. 30 — Fix the Short list
- Dec. 30 — Fix the main equipment supplier

2020
- April. 30 — Civil works
- Dec. 30 — Installation of Heat exchangers (PCHE)

2021
- June. 30 — PCHE installation & testing
- Aug. 30 — Turbine installation & testing
- Dec. 30 — Cycle commissioning

2022
- Jan. 30 — Cycle starting

2023

Current status → **Basic design**; Detailed engineering design

FSR

EDF

Conclusions

An industrial scale sCO_2 project integrated with a commercial CSP plant:

- sCO_2 RC-IC-PH is selected as a compromise of demonstration interest for future salt utilization, cost, complexity and efficiency

- Able to demonstrate equipment design, system design and operation that could be scaled up to large industrial application of sCO_2 cycle

- Superheating solutions under investigation
- Suitable location to test cold storage

Next steps:

- Basic design & final budget evaluation
- Supplier selection

Questions?