Retrofit of Dunhuang 10 MW molten salt plant with a high temperature supercritical CO_2 cycle

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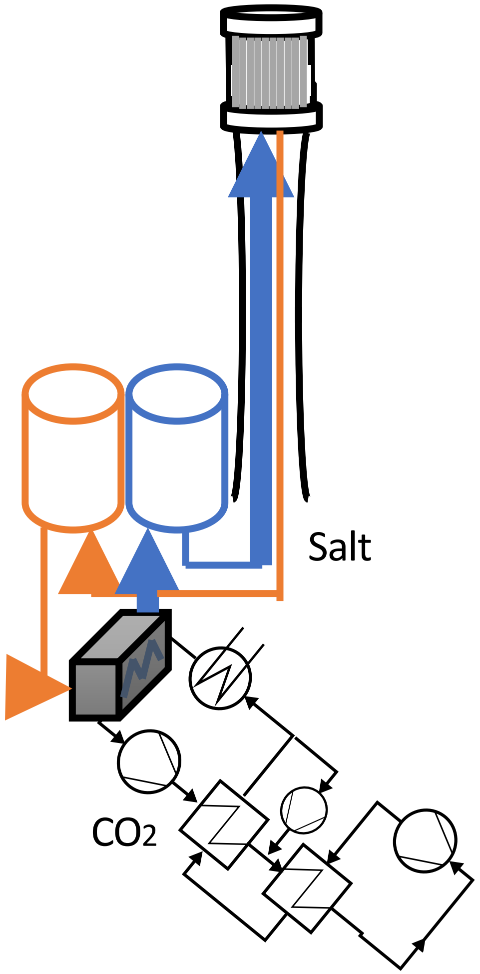
Interest SCO_2 cycle for CSP



Direct swap with steam cycle

Increase

Efficiency

For T above 550°C

Flexibility

Reduced start up time

Reduce

Water resource

No more steam

Complexity

Low number of equipment
Low number of valve

Equipment Size

Small turboset
Smaller air cooling HX

-10 to -25 % on LCOE

Today's vision on SCO_2 technology roadmap for CSP

Up to 560°C - Quick implementation of SCO_2 cycle

- ✓ Power block reduction
- ✓ Same efficiency
- ✓ No change of molten salt

Up to 650°C – SCO_2 commercial potential

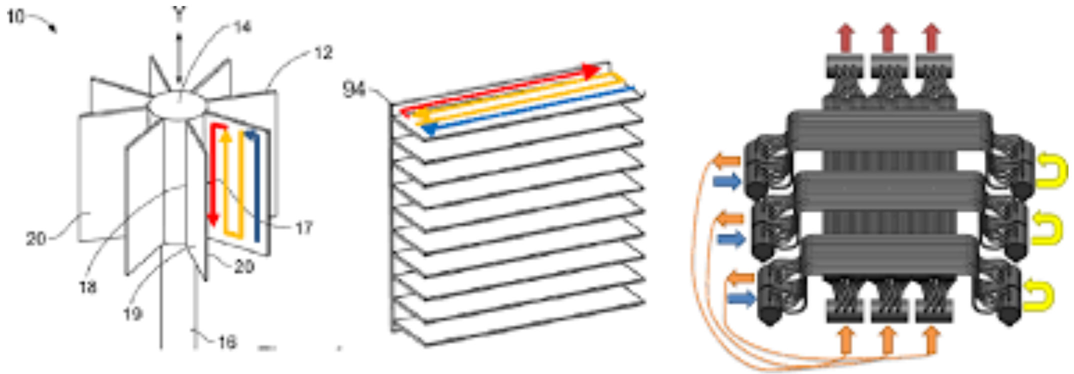
- ✓ Significant efficiency gain
- ✓ Optimized salt
- ✓ New bladed receiver

Up to 750°C – Long term CSP future of SCO_2 cycle

- ✓ High efficiency gain
- ✓ Use of hallide salt w or w/ intermediate HTF
- ✓ Use optimized bladed receiver
- ✓ Use internally insulated tank
  - ✓ Could also used particles receivers

Scope of present project

Demonstrate cycle technology
Assess equipment supply chain
Prepare commercial project in 3 years



Example of light-trapping bladed receiver
Ho, C.K., 2017, Solar Energy

EDF & Shouhang partnership

Companies profiles and interest for SCO_2 cycles

International utilities company

with business on all power generation, transport and commercialization chains

Leader in the low carbon power generation

Strong commitment in innovation and renewable power generation

Chinese leading equipment supplier for energy transition

with business in dry cooling system, CSP, waste heat recovery and multi energy system

Leader in CSP technologies in China (investor and supplier, Owner of SunCan brand)

Striving to innovate in CSP to maintain its competitive advantage

Aims of partnership

3 years project

- ✓ Assess the potential of SCO_2 cycles for near future CSP plant
- ✓ Develop a retrofit solution of Shouhang plant
- ✓ Operate and evaluate the performance of the demo cycle

Project signature & kick off ceremony

Existing molten salt plant in Dunhuang

Overall plant design

- ✓ Solar field - 180 000 m^2 (1500 Heliostat of 116 m^2)
- ✓ Tower receiver (138 m high)
- ✓ Solar salt storage – 15 h (5800 t of solar salt)
- ✓ Steam cycle – 10 MW
- ✓ Air condenser

Investment of 420 M RMB (≈63 M$)

70 % equipment supply by Shouhang

In operation since November 2016

Achieve 6 days 24h continuous operation in july 2018

Project key target and schedule

Project key boundary hypothesis

- ✓ No change on molten salt system
- ✓ Installation parallel to steam cycle
- ✓ 10 MW+ net power
- ✓ 500°C+ temperature
- ✓ Similarities with future SCO_2 cycle for CSP

Demonstration key target

- ✓ Test key equipment
  (15 MW+ turbine, 20 MW MS heater, 40 MW+ heat recup.)
- ✓ Test recompression loop & intercooled compression
- ✓ Test advanced inventory control system
- ✓ Test up to 620°C operation
- ✓ Test high T molten salt loop with electrical heating

2018
- May — Project kick off
- Oct — Conceptual study completed
- Dec — Feasibility study completed

2019
- Feb — Investment decision
- Mar — Start equipment manufacturing
- Sep — First equipment delivered & tested

2020
- Sep — Demonstration commisioning
- Nov — Demonstration test start up

Overall project key milestones

EDF

Cycle selection and design – methodology 1/2

Boundary hypothesis

1. Flow of 80 kg/s of 560°C molten salt
2. Has to cool the molten salt around 290°C
3. Provision for lower salt T and higher return T
4. Minimal achievable CO_2 temperature : 35°C
5. Maximal practical pressure : 250 bar

Site condition

Supplier review

Performance hypothesis at pre-design stage

1. Turbine efficiency : 85 %
2. Compressor efficiency : 80 %
3. Achievable pinch in heat exchanger : 10°C

Supplier review

HX cost optimization

Free parameter

1. Cycle architecture
2. Maximal CO_2 temperature
3. Minimal CO_2 pressure
4. CO_2 flowrate

Manual cycle screening
Global optimization
Engineering review

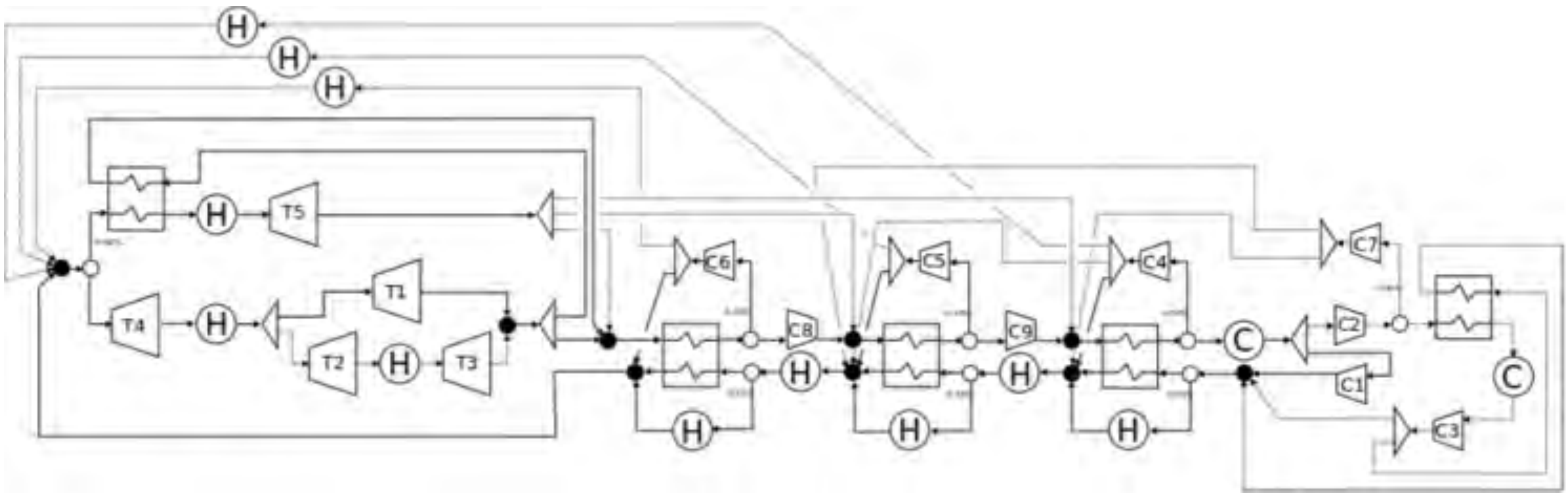
Objective function to maximize

Cycle net power
≈
salt heat use
x cycle efficiency

Cycle selection and design – methodology 2/2

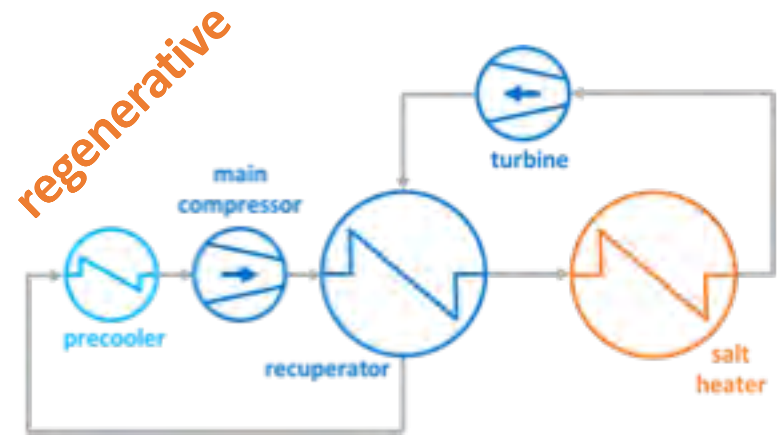
Optimization driven design with 2 approaches

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

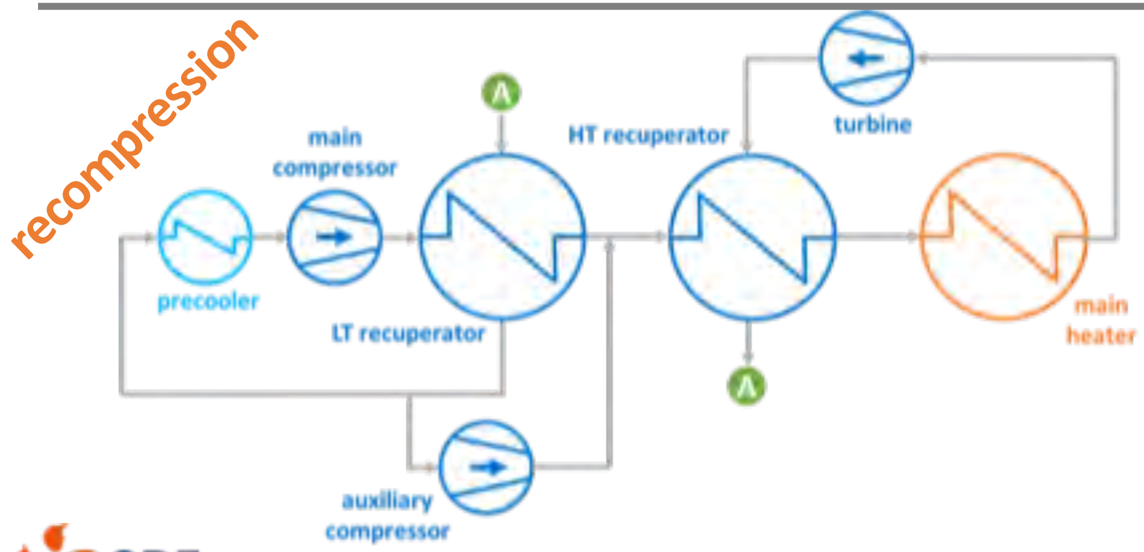


Cycle superstructure used for global optimization

The two reference SCO_2 cycles



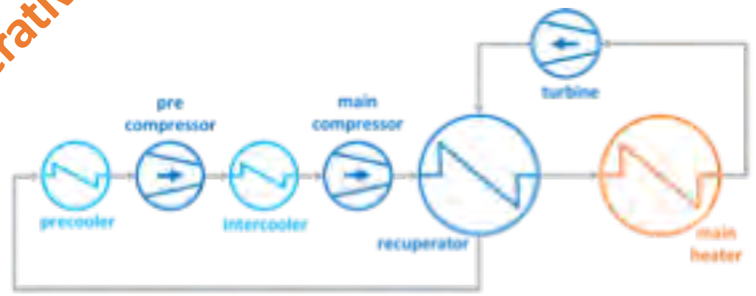
	max. efficiency	max. power
Tmax	550°C	495°C
Pmin	80 bar	85 bar
η	35.9 %	33.3 %
Exit salt T	344°C	290°C
Power	9.9 MW	11.4 MW
Rel. cost	1	0.76



	max. efficiency	max. power
Tmax	550°C	420°C
Pmin	85 bar	90 bar
η	41.1 %	33.2 %
Exit salt T	401°C	290°C
Power	8.7 MW	11.4 MW
Rel. cost	1.28	0.97

Interest of compression intercooling

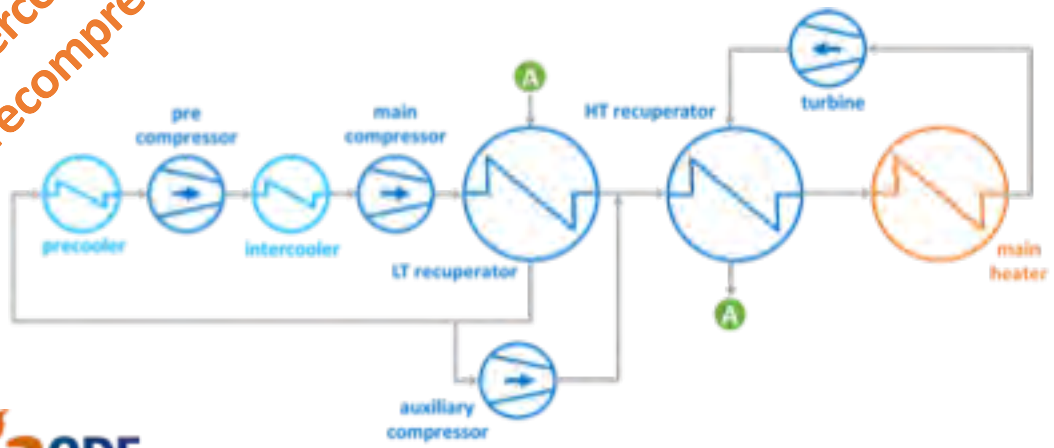
Intercooled regenerative



Tmax	495°C → 535°C	
Pmin	85 bar → 65 bar	
η	33.3 % → 34.7 %	
Exit salt T	290°C	
Power	11.4 MW → 11.9 MW	

No further significant amelioration

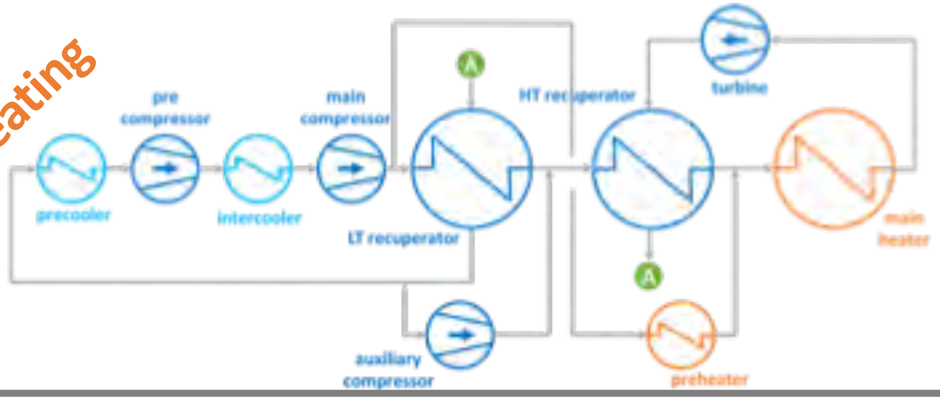
Intercooled recompression



Tmax	420°C → 430°C
Pmin	90 bar → 85 bar
η	33.2 % → 34.7 %
Exit salt T	290°C
Power	11.4 MW → 11.9 MW

Evaluation of CO_2 preheat scheme

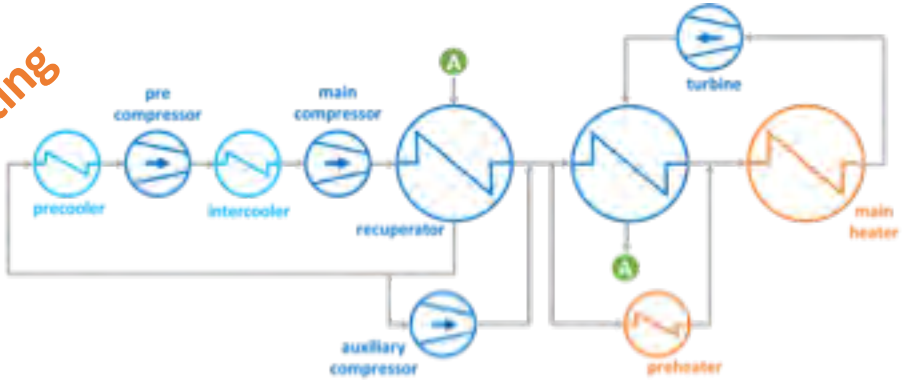
Low temp. CO_2 preheating



Tmax	430°C	→	500°C
Pmin	85 bar		
η	34.7 %	→	35.9 %
Exit salt T	290°C		
Power	11.9 MW	→	12.3 MW

+ 30 % UA HXs
+40 % UA heaters

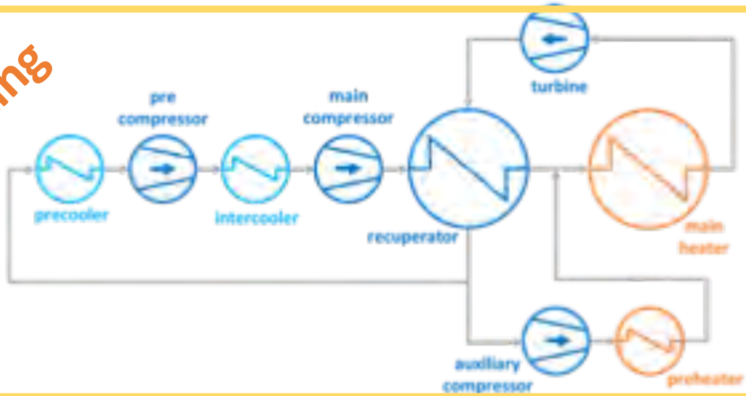
High temp. CO_2 preheating



Tmax	430°C	→	460°C
Pmin	85 bar		
η	34.7 %	→	36.8 %
Exit salt T	290°C		
Power	11.9 MW	→	12.6 MW

Higher efficiency
+ 45 % UA HXs
+25 % UA heaters

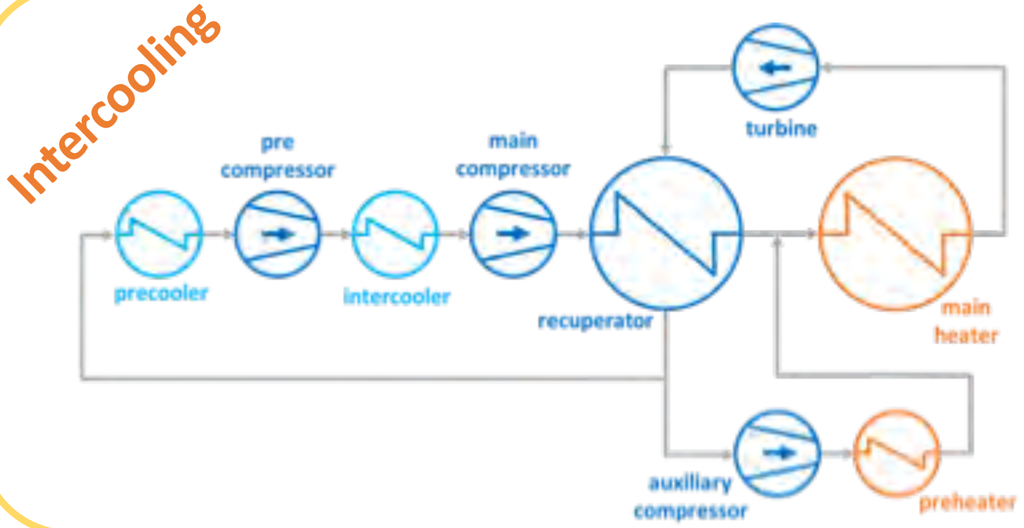
Recompressed CO_2 preheating



Tmax	430°C	→	485°C
Pmin	85 bar		
η	34.7 %	→	36.7 %
Exit salt T	290°C		
Power	11.9 MW	→	12.6 MW

+ 35 % UA HXs
- 1 HX
- 1 splitter/mixer
+40 % UA heaters

Benchmark with partial cooling cycle

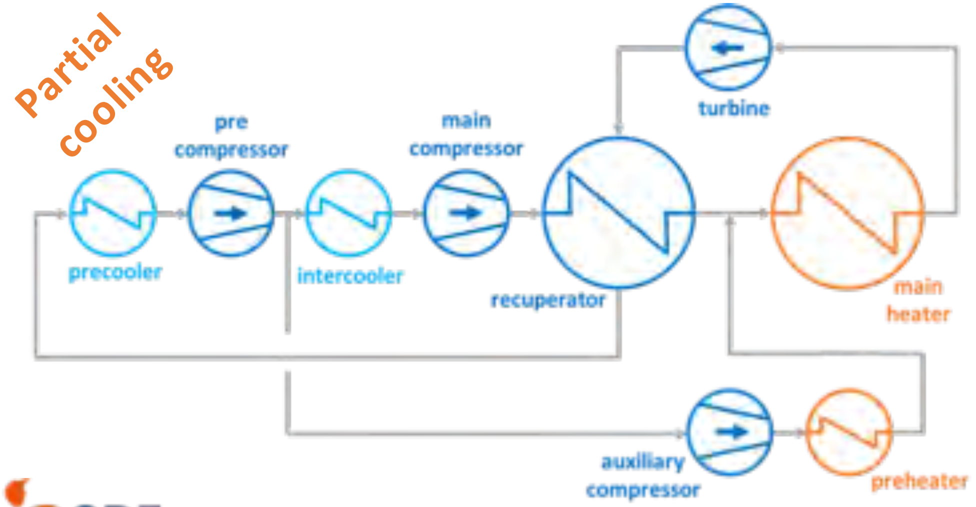


Tmax	485°C
Pmin	85 bar
η	36.7 %
Exit salt T	290°C
Power	12.6 MW

Higher efficiency
Simpler part load control

40 % UA increase on recuperator

Power block cost : < 3 % increase



Tmax	515°C
Pmin	75 bar
η	36.1 %
Exit salt T	290°C
Power	12.4 MW

Higher compressor efficiency

Lower efficiency
30 % UA increase for salt heater
12 % PR increase for compressor

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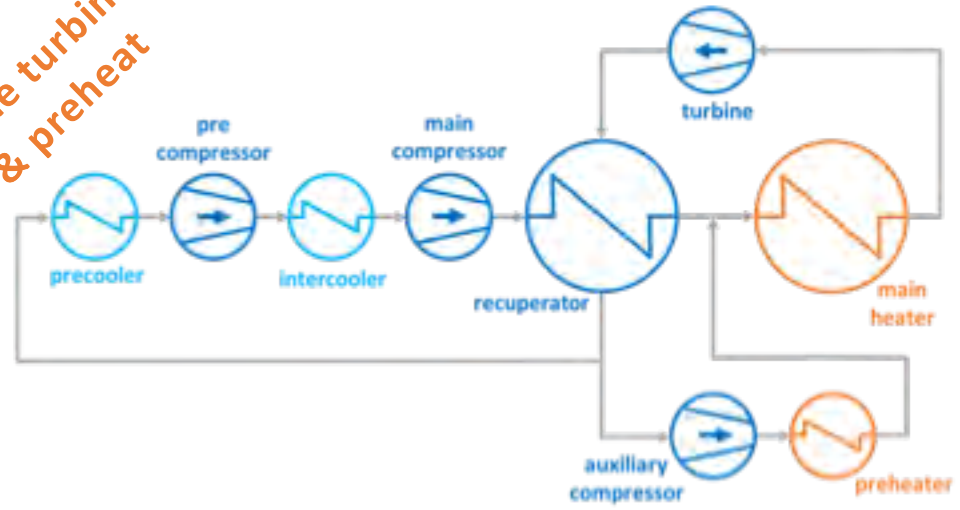
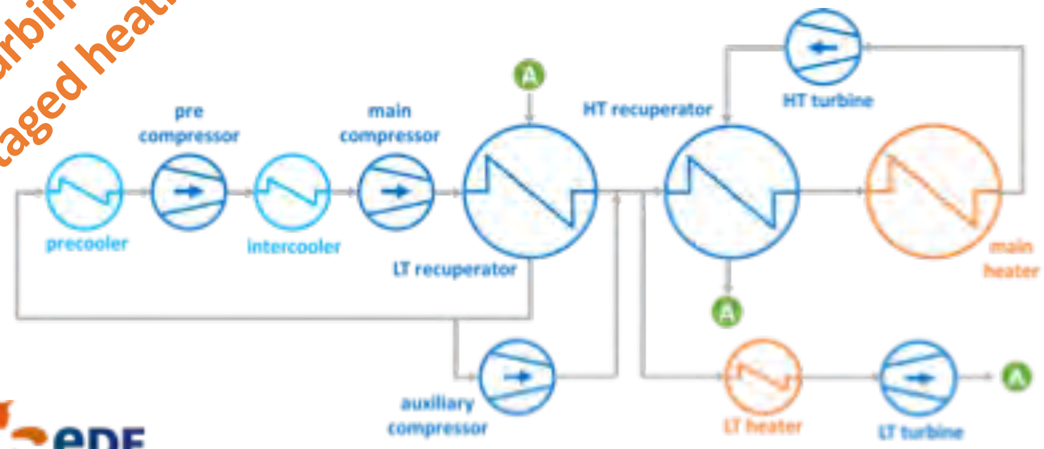
Benchmark with dual temperature cycle

Single turbine & preheat



Tmax	485°C
Pmin	85 bar
η	36.7 %
Exit salt T	290°C
Power	12.6 MW

2 turbines & staged heating



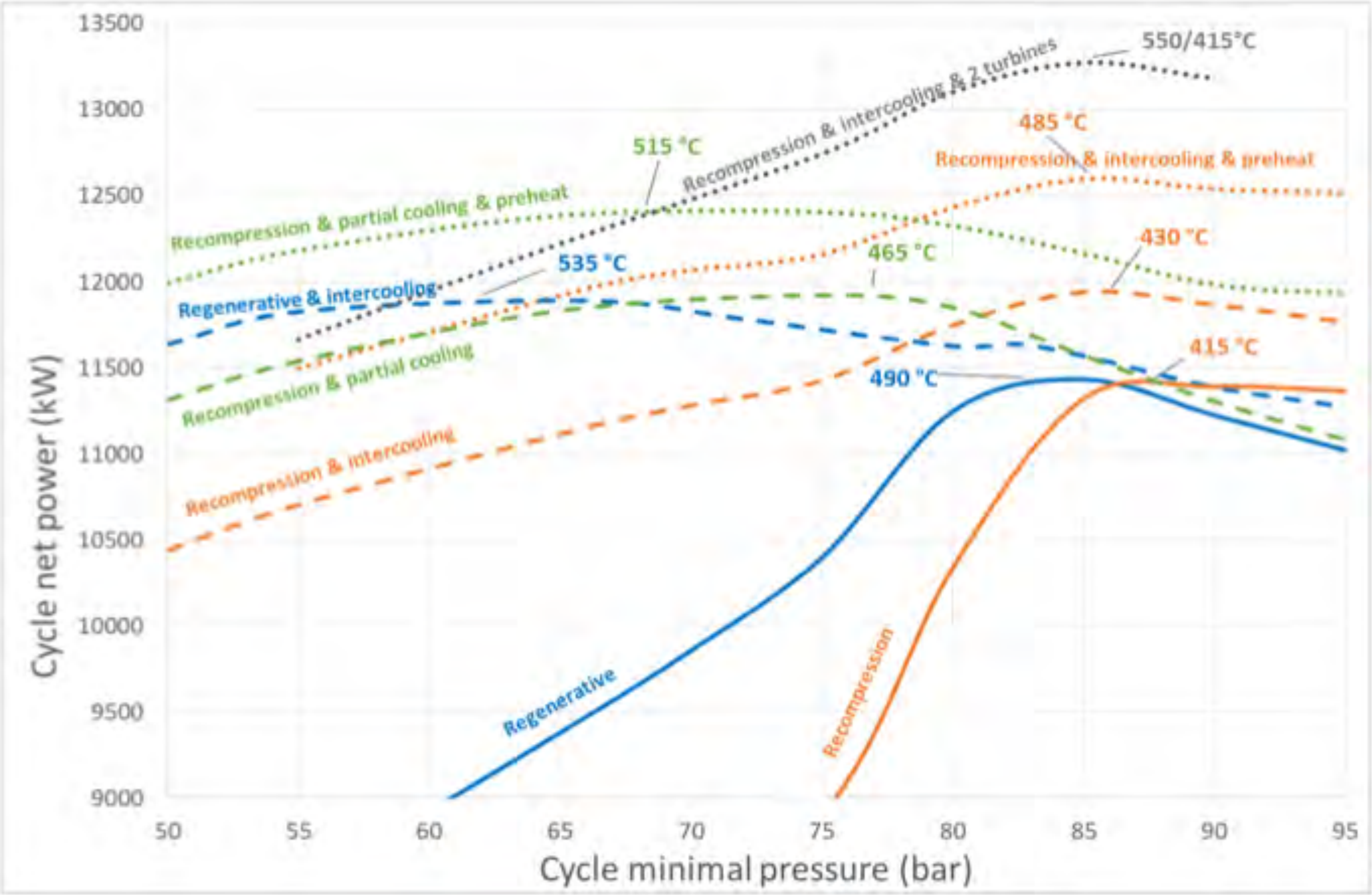
Tmax	550 / 410°C
Pmin	85 bar
η	38.4 %
Exit salt T	290°C
Power	13.2 MW

Higher efficiency
LT turbine could drive all comp.

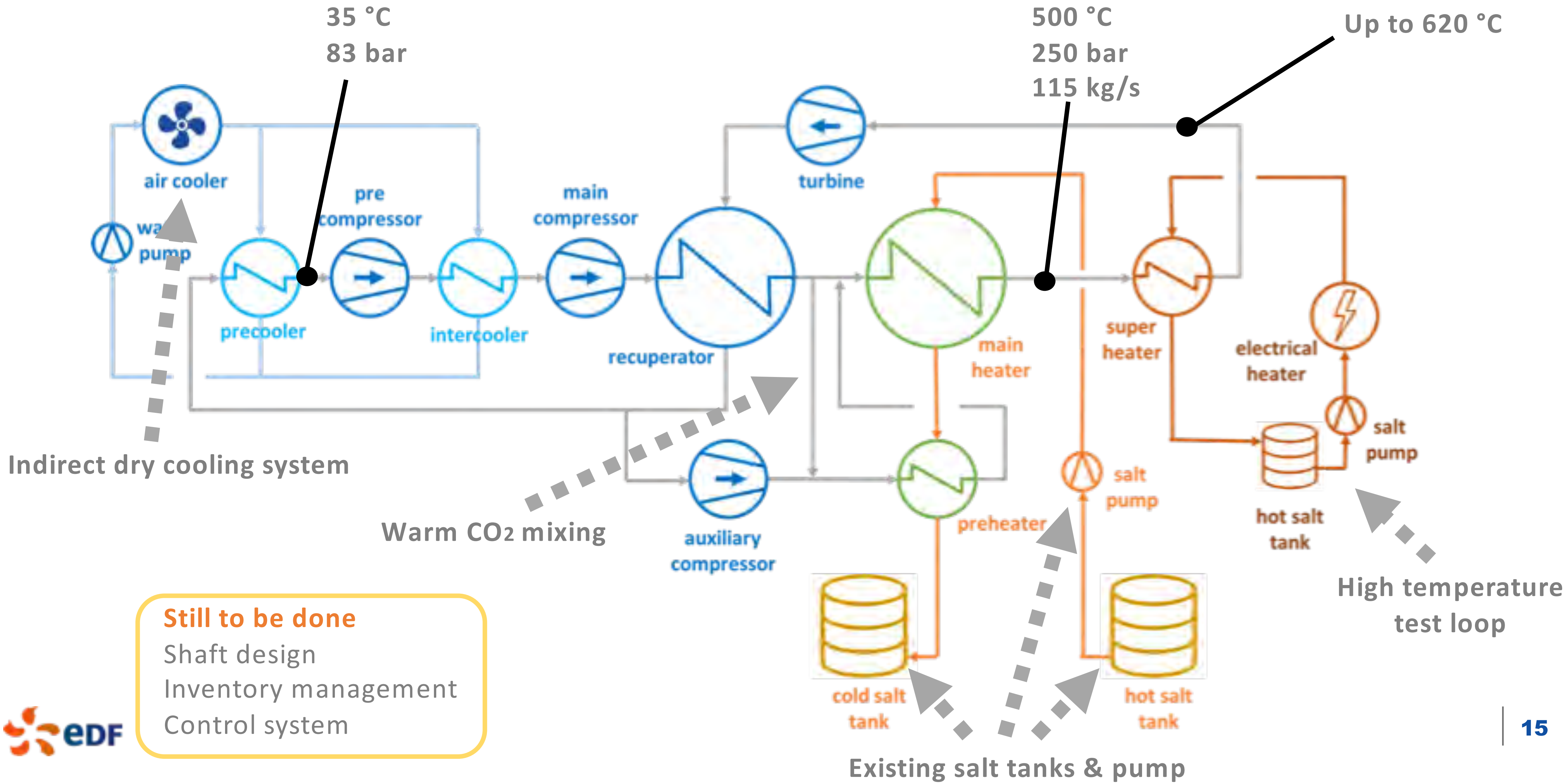
15 % UA increase on recuperators
90 % UA increase on heaters
2 turbines (13 & 6.5 MW)

More complex layout
Mixing for salt freezing protect. ?

Selection of studied cycles – final remarks



Final layout considered : intercooled recompression cycle



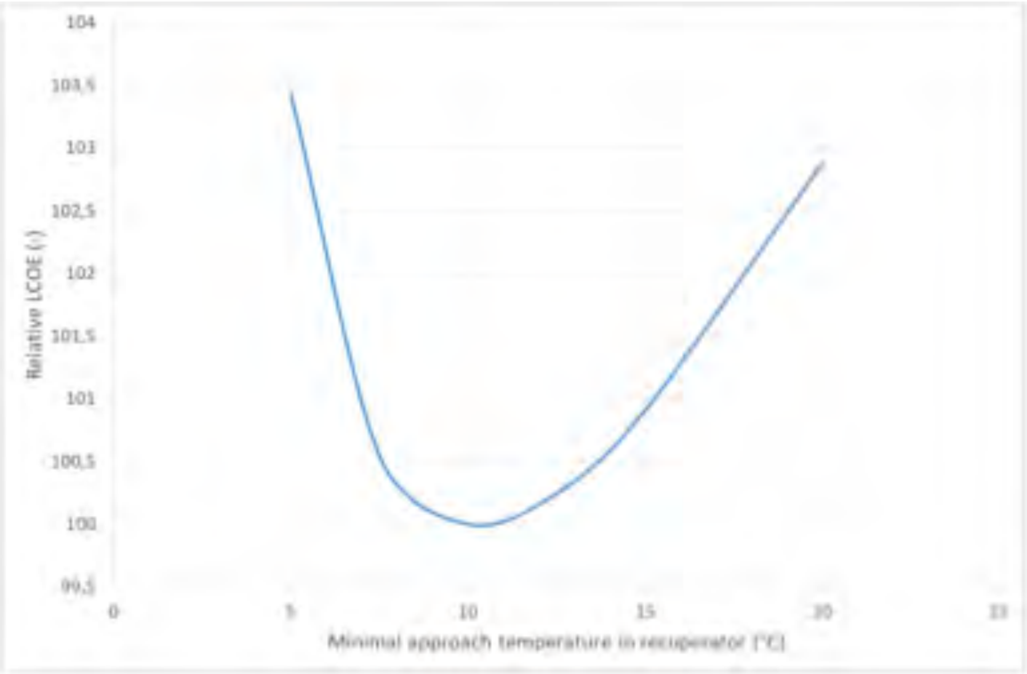
Still to be done
Shaft design
Inventory management
Control system

Cycle selection: heat exchanger detailed specification

Recuperator temperature approach selection

Techno-economical choice based on
Levelized cost of generating heat of 20 to 25 $/MWh

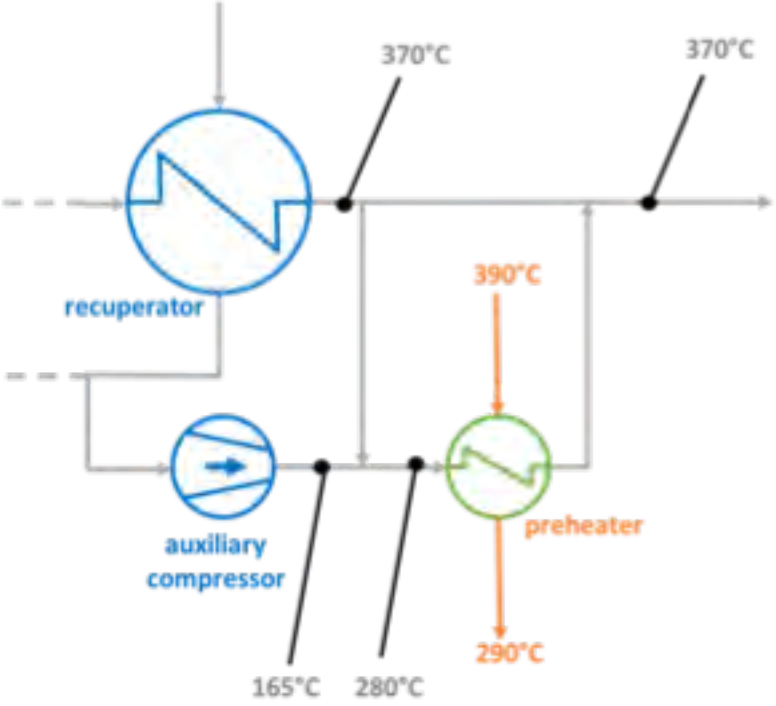
10°C appears reasonable



Preheater salt freezing protection

Flexible protective measure

Mixing of hot warm CO_2 in cold warm CO_2
Increase by 500 % preheater UA



Supplier review: first lesson learned

More than 25 suppliers consulted for turbine, compressor and heat recuperator

From China, Japan, Korea, US, UK, Germany, Switzerland & France
Good reception of the request for proposal and constructive/commercial answer

✓ Turbine

- No key issue to design and manufacture but no firm performance guarantee
- Efficiency above 85 % is foreseen
- Radial and Axial design still co-exist at 18 MW

✓ Compressor

- No issue linked to transcritical compression
- Compressor inlet around critical pressure make design dificult (especially combined with high PR)
- Performance guarantee around 80 % for compressors
- Radial design

✓ Heat recuperator

- Almost all suppliers goes for PCHE technology
- No design issue and performance guaranteed

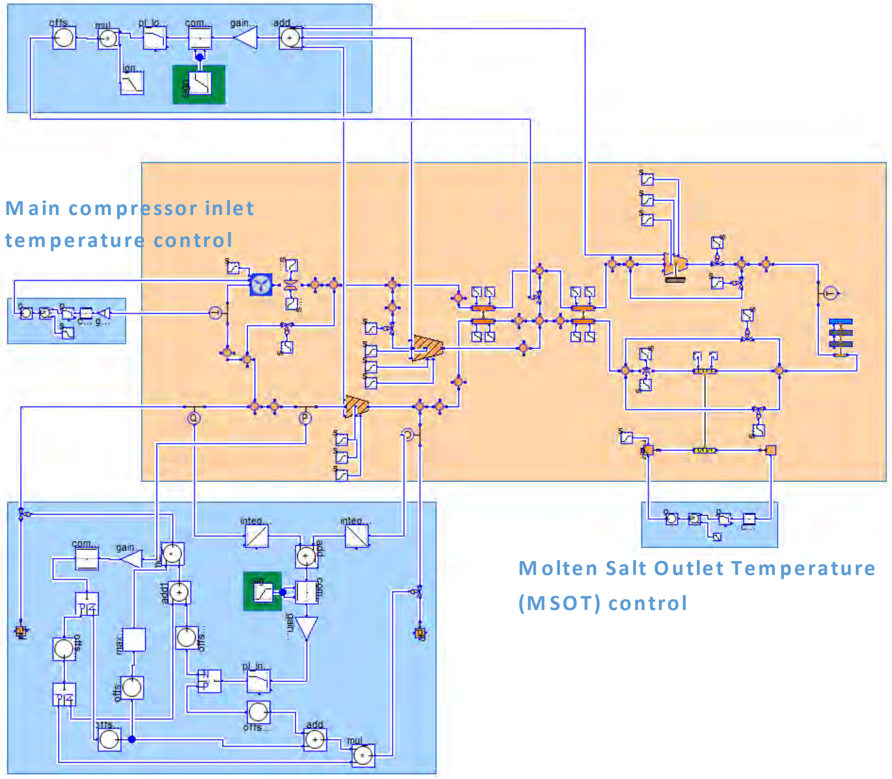
All key equipment can be readily manufactured with obviously some lack of references

Supplier pre-selection to be done end of 2018

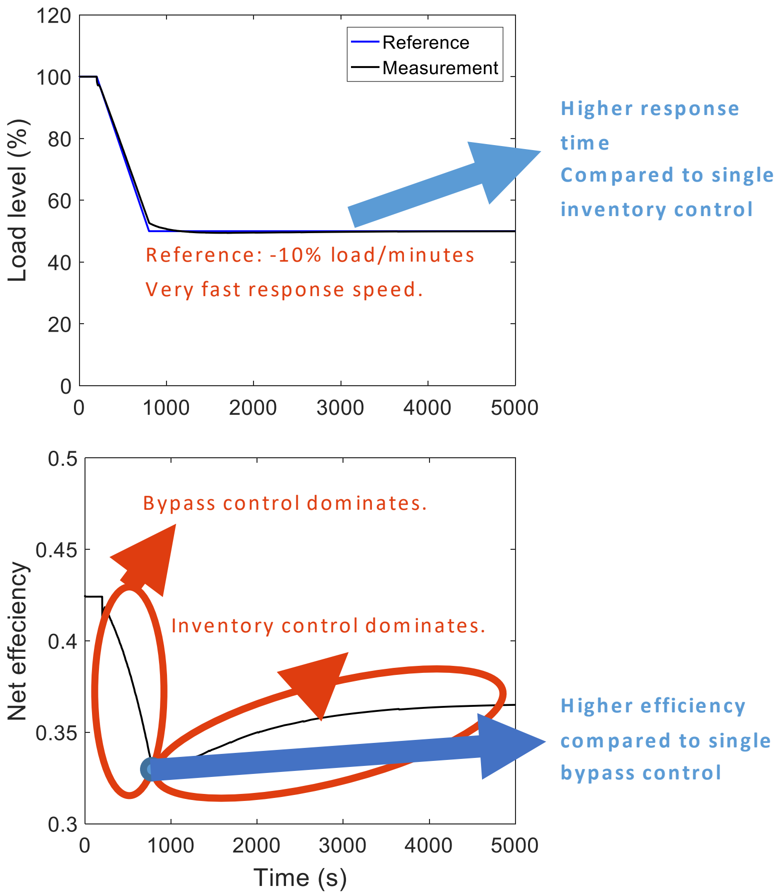
Control design and operability

To test control option and detailled design option

Control design based on a fully physical dynamic model of the plant



Dynamic model developed in Dymola



Case study: Part-load control: Inventory + bypass control

For more information, see the poster :
Dynamic modeling and part load control strategy of a molten salt heated recompression SCO_2 Brayton cycle

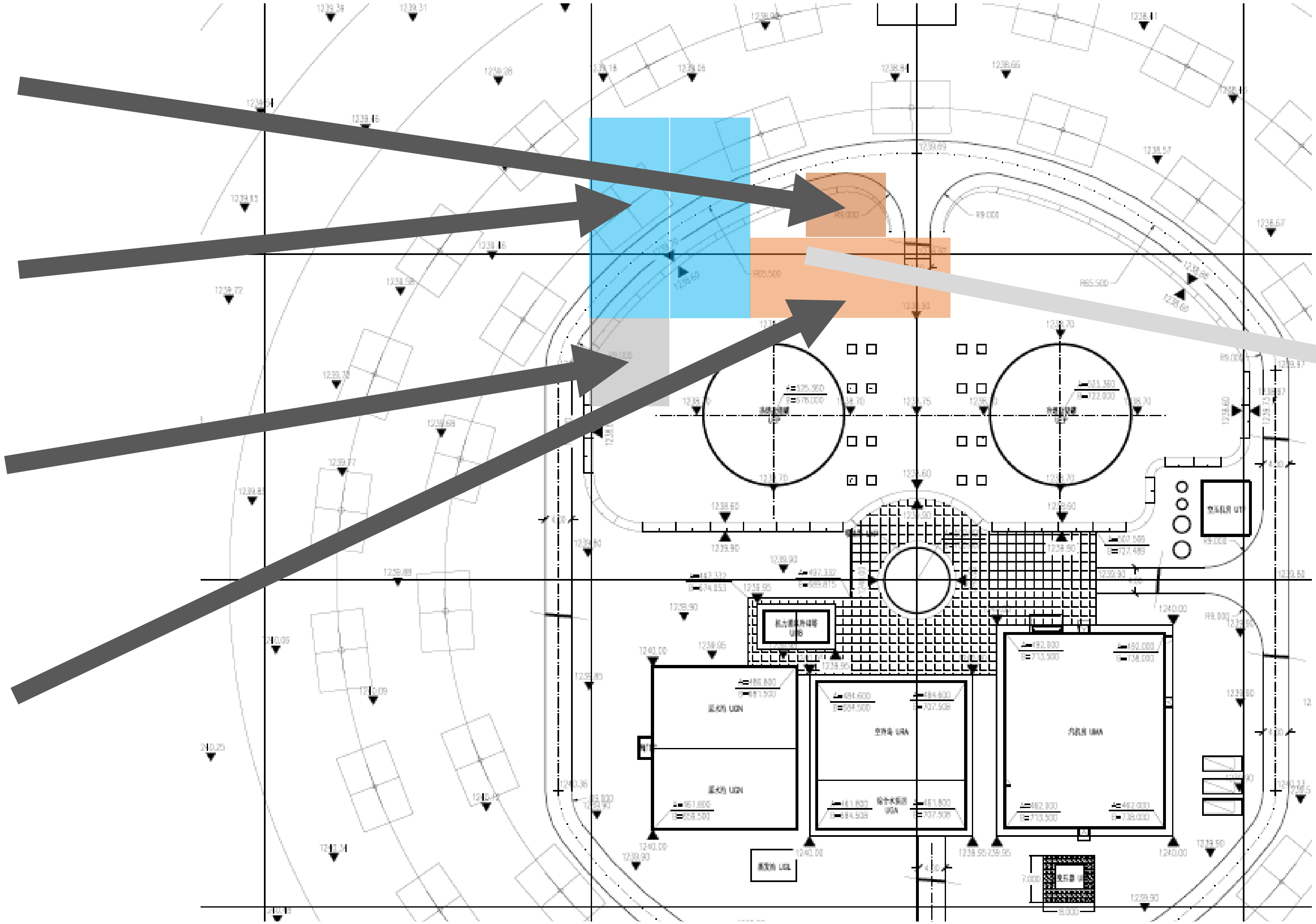
Preliminary site implementation proposal

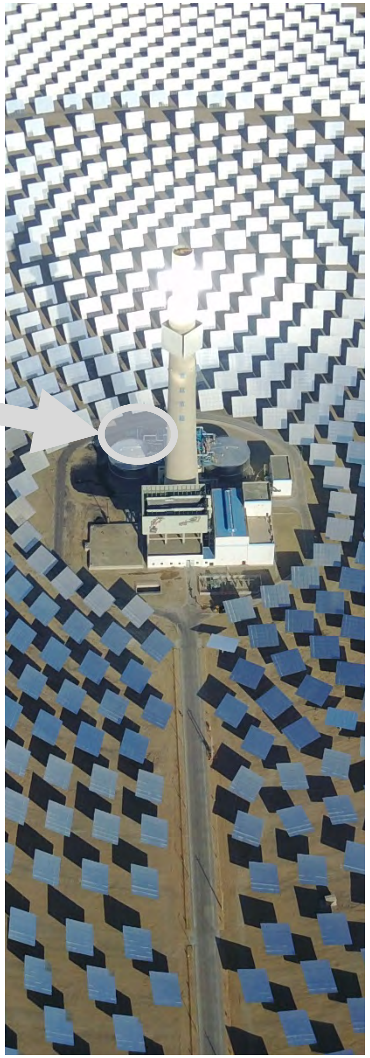
HT salt loop

Cooling system

CO_2 storage

Power block
& auxiliaries





Conclusion…for now

Retrofit of 10 MW Shouhang CSP plant in Dunhuang is on the way

- Demonstrator cycle and layout selected
- Supplier reviewed (preselection soon)
- Shaft design and balance of plant before nov.
- Formal feasibility study report by Chinese Design Institute (late 2018)
- Investment decision (early 2019)

For SCO_2 cycle technologies

- Suppliers ready to start real project
- No technical showstopper for design
- Need to dive into control and operation aspect
- Good potential even at medium T

  Foresee 45% cycle efficiency for commercial at 550°C


Thank you
Any question ?