SCO_2 BRAYTON CYCLE FOR RETROFITTING EXISTING STEAM POWER UNIT

A GOOD WAY TO PUSH INDUSTRIAL SCALE DEMO PROJECT

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IEA-CCT2017 Cagliari

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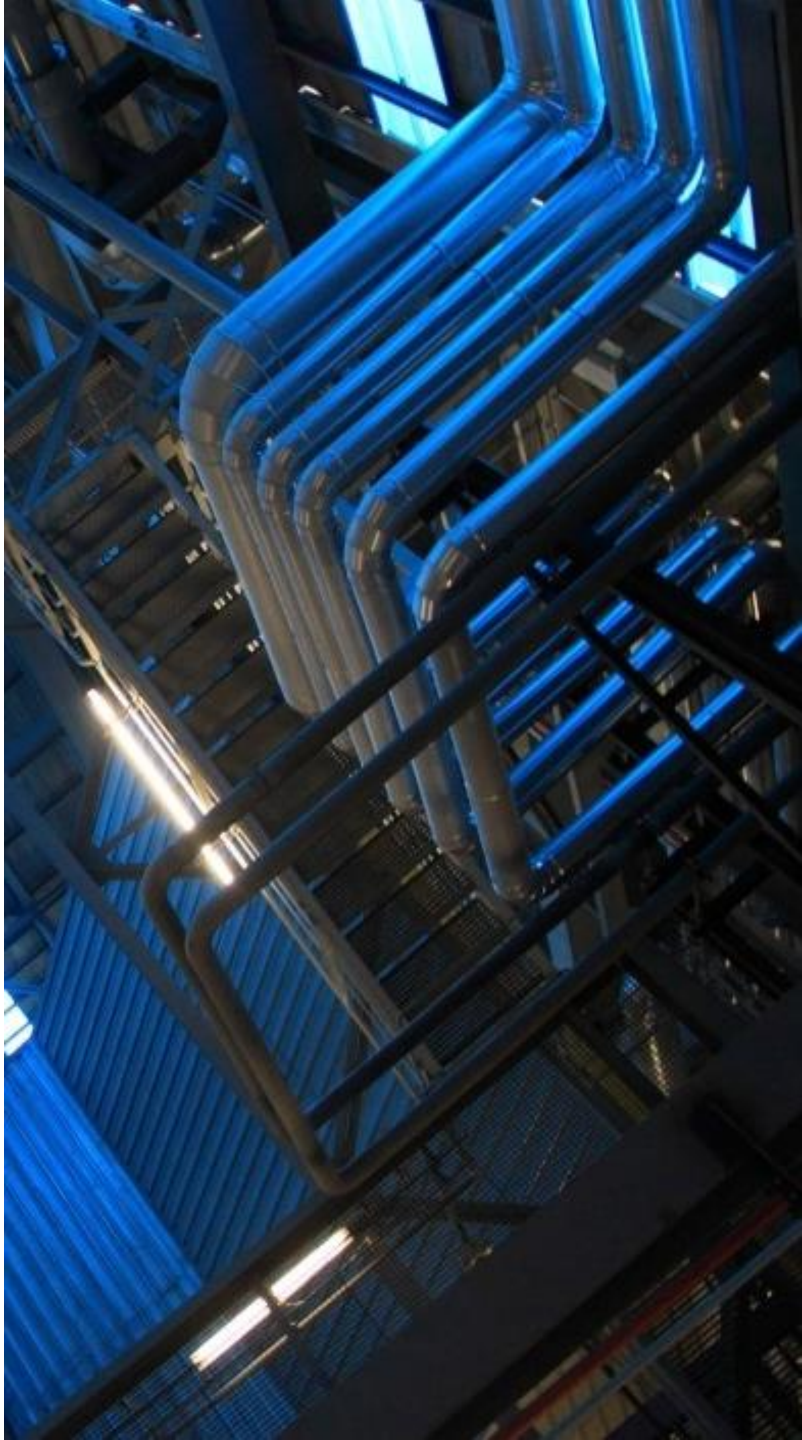
Annex



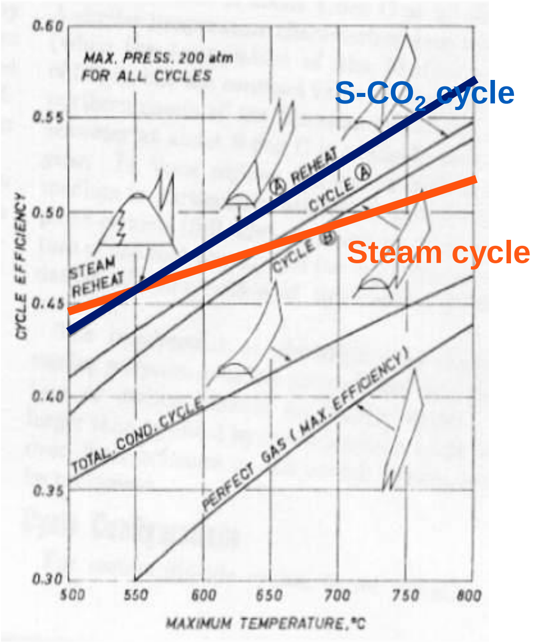
SUPERCRITICAL CO_2 BRAYTON CYCLE
WHY IS IT INTERESTING ?

CO_2 turbomachinery and cycle
- High efficiency (better than steam above 550°C)
- High compactity
- Convenient thermo-physical properties

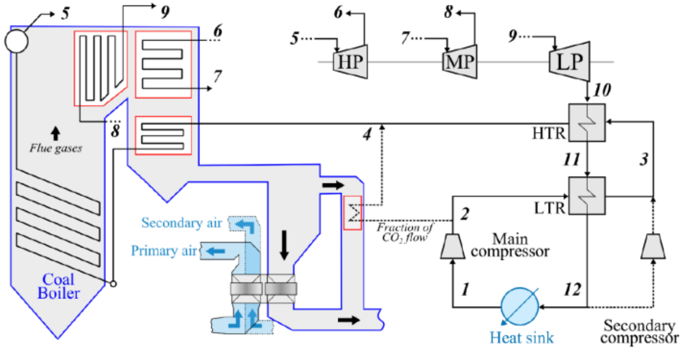
CO_2 physical properties
- Abundant and inexpensive
- Chemically inert & non toxic
- Non flammable
- Very well characterized

In-direct fired Multi-purpose cycle
- Fossil-fired
- Nuclear
- CSP, geothermal, waste heat

Some drawbacks
- Low technology maturity
- Corrosive above 500°C



Carbon Dioxide Condensation Cycles for Power Production
G. Angelino,



Coal-fired power plant with CO2 Brayton cycle (Mecheri, 2016)

RETROFITTING STEAM UNIT
WHY CONSIDER RETROFITTING?

Current stage with CO2 cycle

- Ready for pre-industrial demonstration
- High key equipment cost (Boiler, PCHE)
- Lack of incentive to push the technology development

Retrofitting steam units with CO2 topping cycle

- Reduce cost of the key equipment
- Reduce construction cost and length
- Add incentive to the technology development
- Fast way to up-size the demonstration project

Analysis of the effect of SCO_2 retrofit steam units

- Overall net plant efficiency change after retrofitting

Fusion-bonded printed heat exchanger

A 1GW Ultra-supercritical power plant

CONTENT OF STUDY
METHODOLOGY

Simulation tool

- Commercial process simulation software

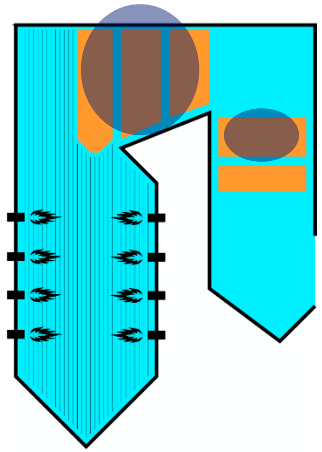
ProSim

Reference plant

- A state of the art steam cycle (600°C, 24.6 MPa)
- Net cycle efficiency: 43.6%

Key assumptions (Steam part)

- Suspended heat exchanger & reheater parts replaced by CO_2 superheaters
- Boiler at full load operating condition
- Derated steam cycle, at a minimum 60% of full load with reduced Max T and P
- Turbine design unchanged
- Combustion air T: 300°C
- Flue gas boiler outlet T: 320°C



Retrofitted parts of the boiler

CONTENT OF STUDY

METHODOLOGY

Key assumptions (CO2 part)

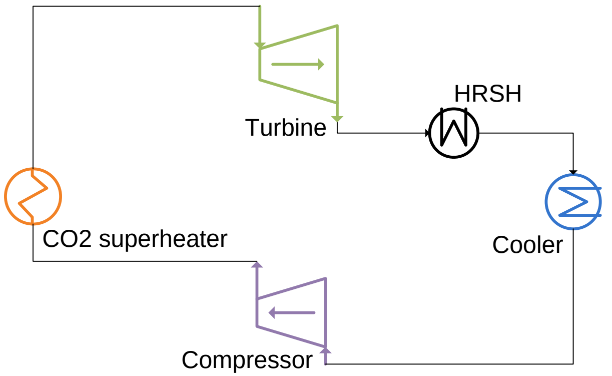
- Max Operating condition 700°C, 20 MPa
- Lowest pressure and temperature in the cycle remain above the CO_2 critical point (74bar and 35°C)

SCO_2 cycles

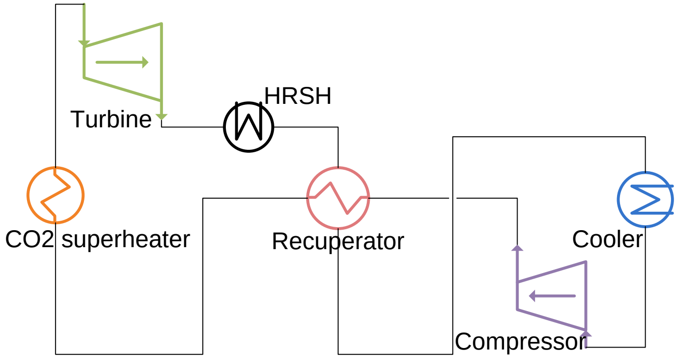
- Simple
- Recuperated
- Recompression Part-flow

Cycle integration

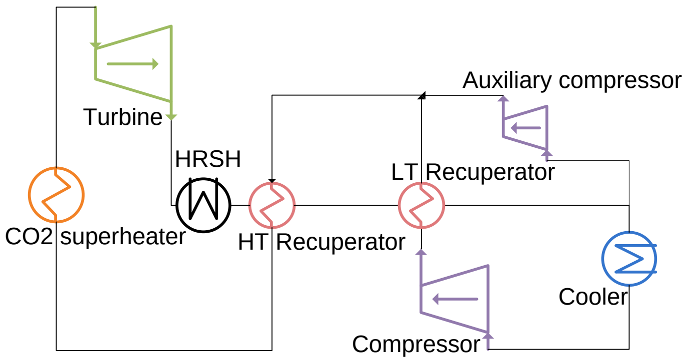
- Steam-CO_2 HRSH



Simple Brayton cycle



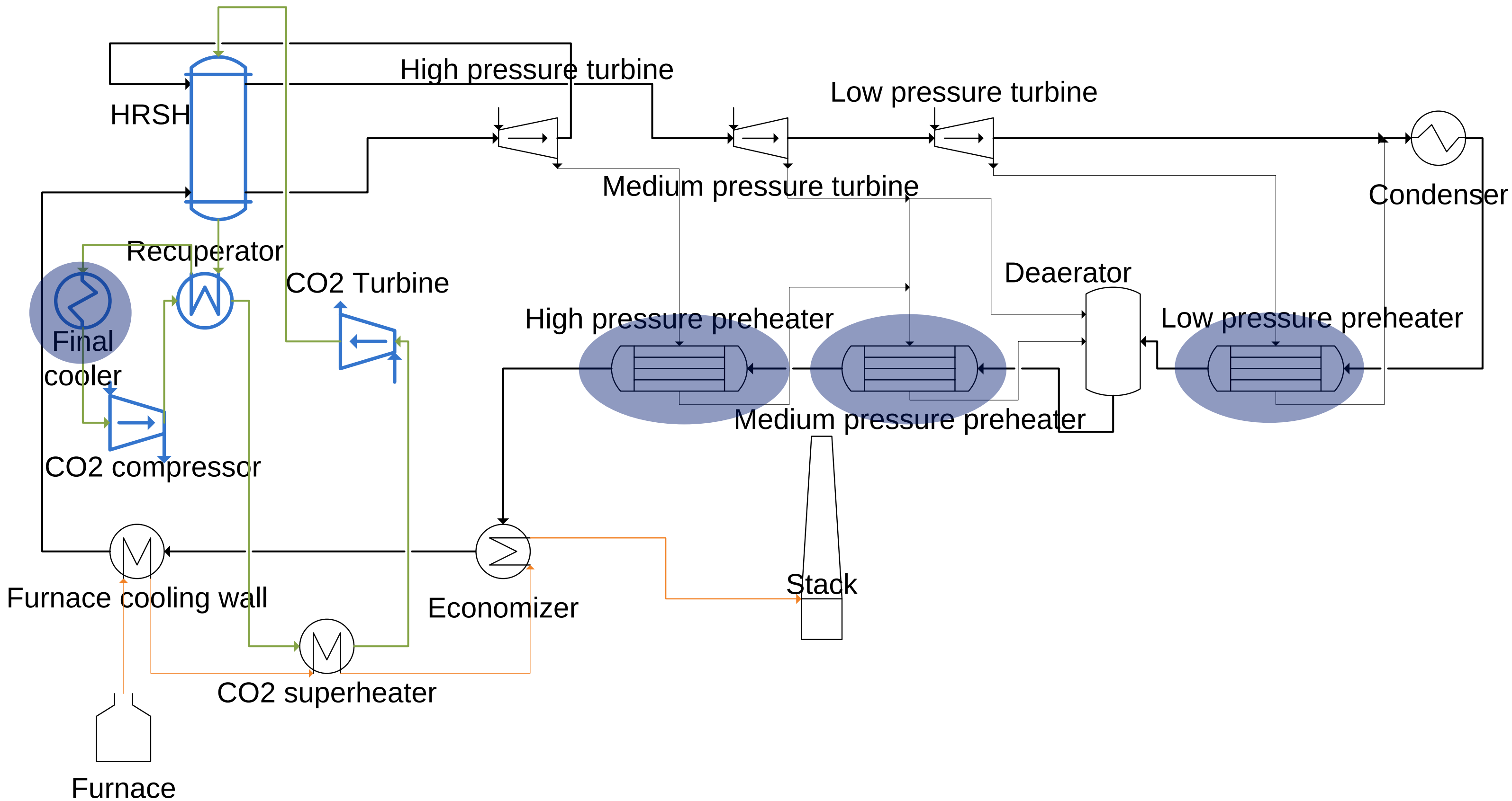
Recuperated SCO_2 cycle



Recompression part-flow CO_2 cycle

Cycle integration (continued)

- Other heat integrations options explored



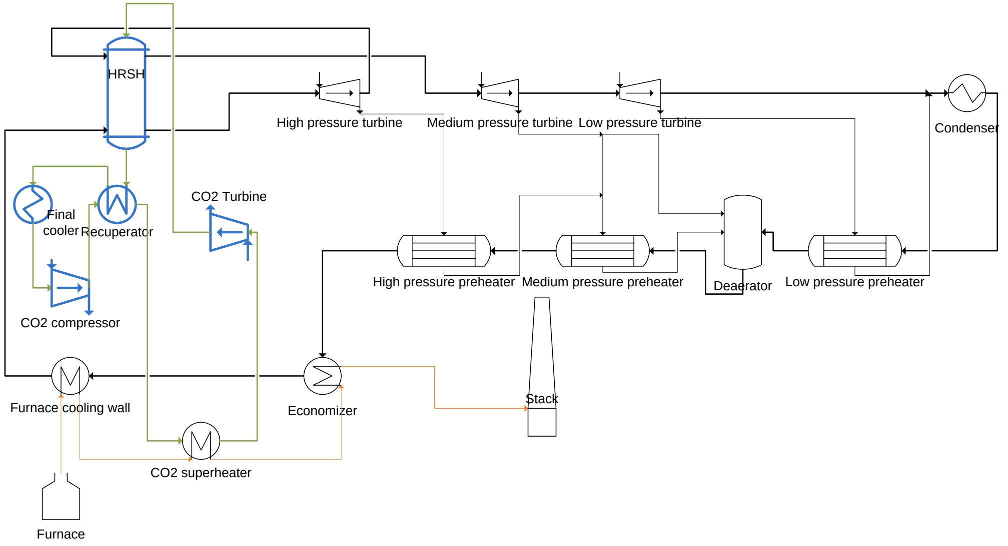
RESULTS & DISCUSSION

- **9 selected cases**

Cycle type	Description
Recuperated cases	
Case 1	Standard recuperated cases
Case 2	Part of the LP preheater is heated by the CO2 stream instead by the turbine bleeding
Case 3	HP, MP and LP heaters are heated by the CO2 stream instead by the turbine bleeding.
Simple SCO2 cycle	
Case 4	Standard Simple SCO2 cycle without the CO2 final cooler
Case 5	Standard Simple SCO2 cycle without the CO2 final cooler with higher air inlet Temperature
Case 6	Standard Simple SCO2 cycle without the CO2 final cooler with higher CO_2 operating pressure
Case 7	HP, MP and LP heaters are heated by the CO2 stream instead by the turbine bleeding. The CO2 final cool is also removed
Recompression "part-flow" loop	
Case 8	Standard Recompression "part-flow" loop
Case 9	Part of the LP preheater is heated by the CO2 stream instead by the turbine bleeding

RESULTS & DISCUSSION
RECUPERATED CYCLE

- **Case 1**
  - ~60% steam cycle loading
  - HRSH outlet T 520°C
  - 41.09% net cycle efficiency
  - - 2.52% pt
- **Case 2**
  - Heat integration at LP heater
  - 41.21% net cycle efficiency
  - - 2.40% pt
- **Case 3**
  - No turbine bleeding
  - 43.66% net cycle efficiency
  - +0.05% pt



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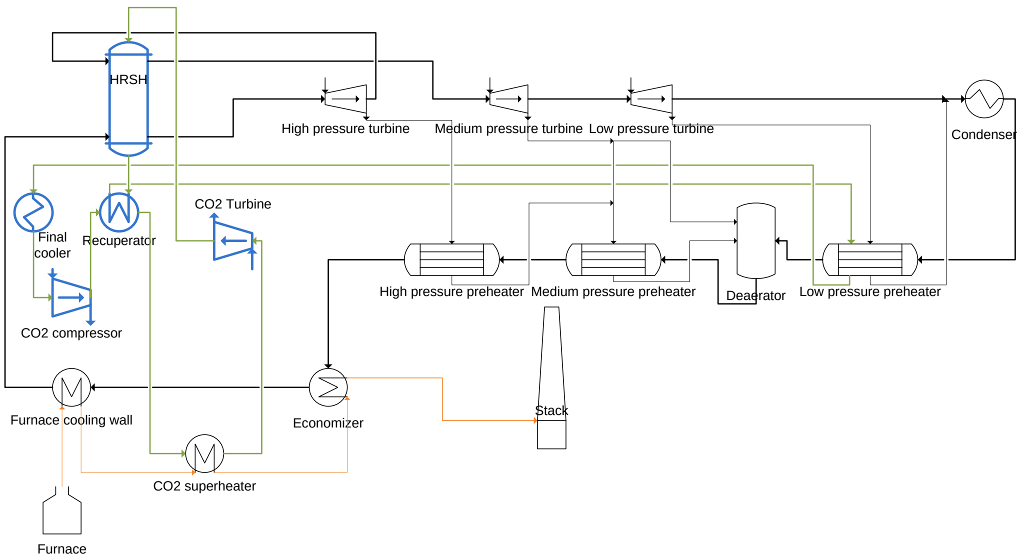

RESULTS & DISCUSSION

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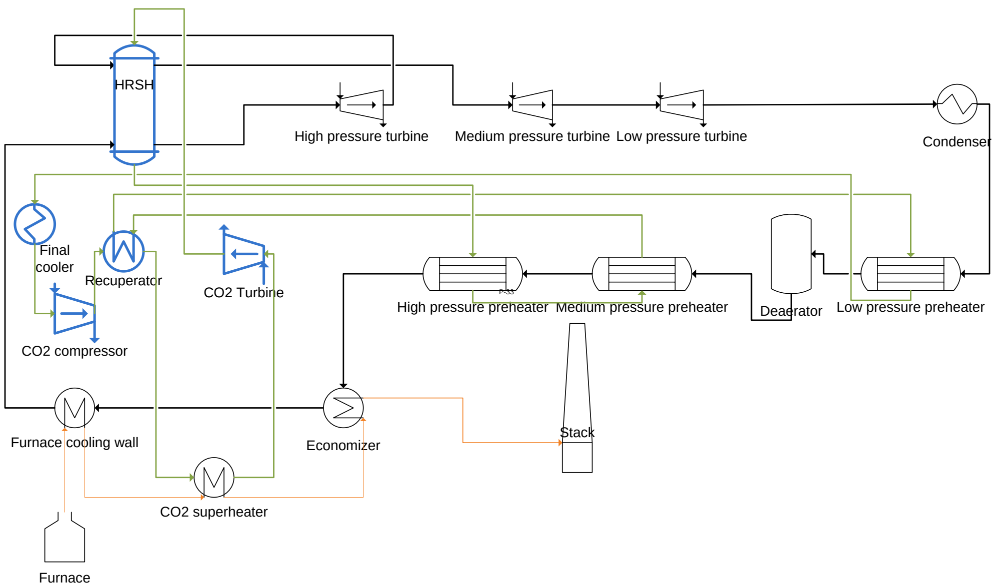
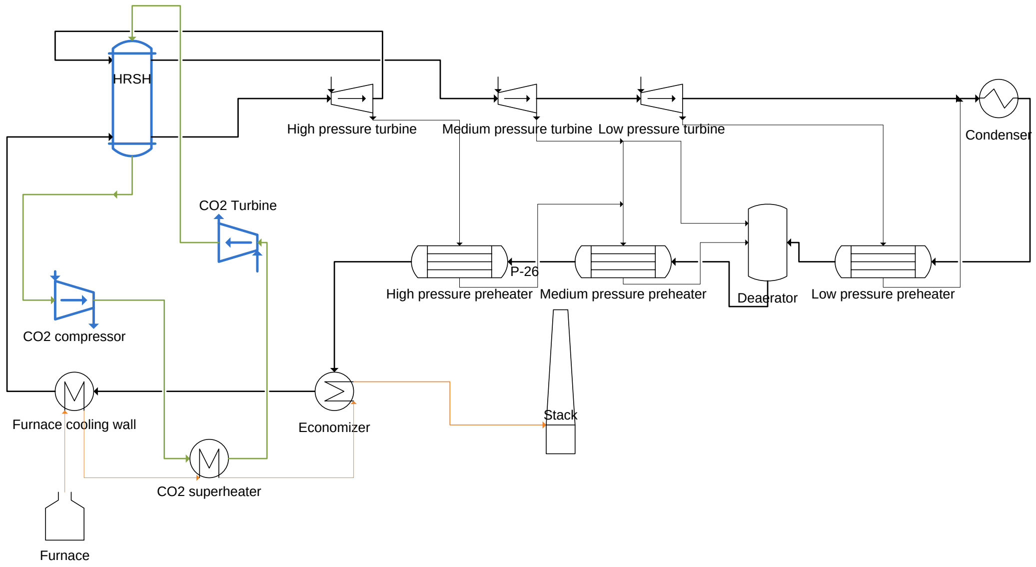


RESULTS & DISCUSSION

SIMPLE SCO_2 CYCLE

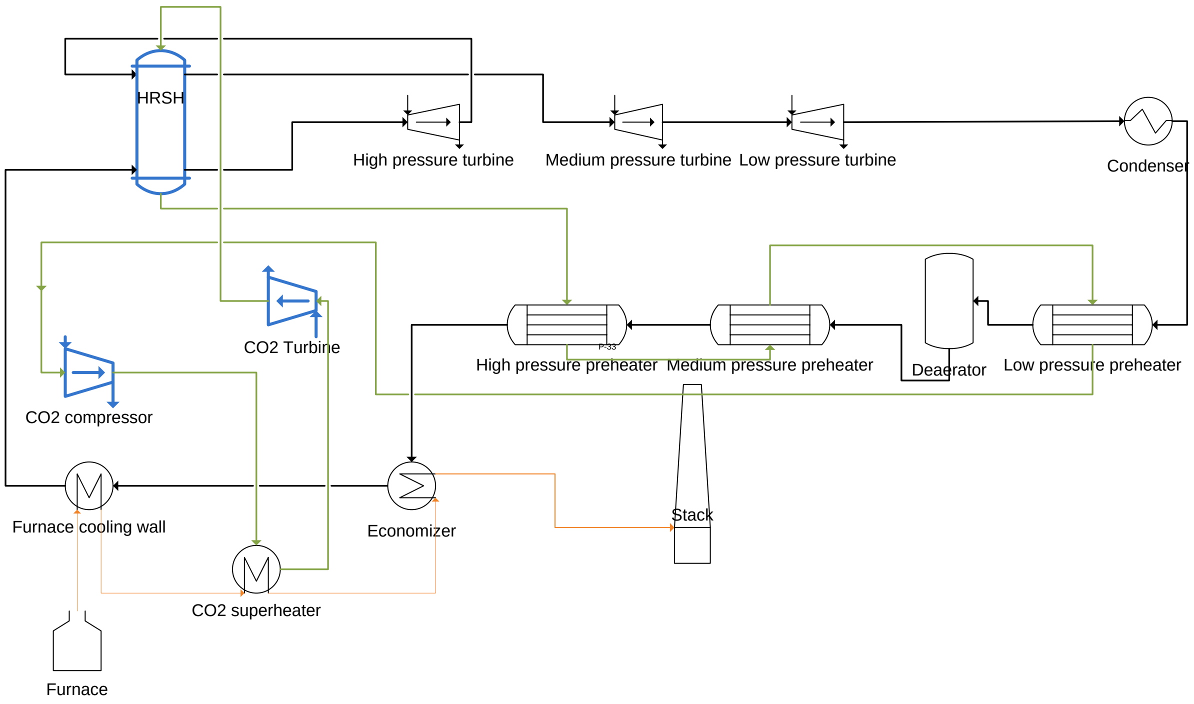
- **Case 4**
  - Over 90% steam cycle loading
  - HRSH outlet T ~340°C
  - 44.77% net cycle efficiency
  - +1.16% pt
- **Case 5**
  - Increased combustion air T
  - 46.74% net cycle efficiency
  - +2.40% pt
- **Case 6**
  - Increased co_2 operating P
  - 44.21% net cycle efficiency
  - +0.60% pt



RESULTS & DISCUSSION

SIMPLE SCO_2 CYCLE

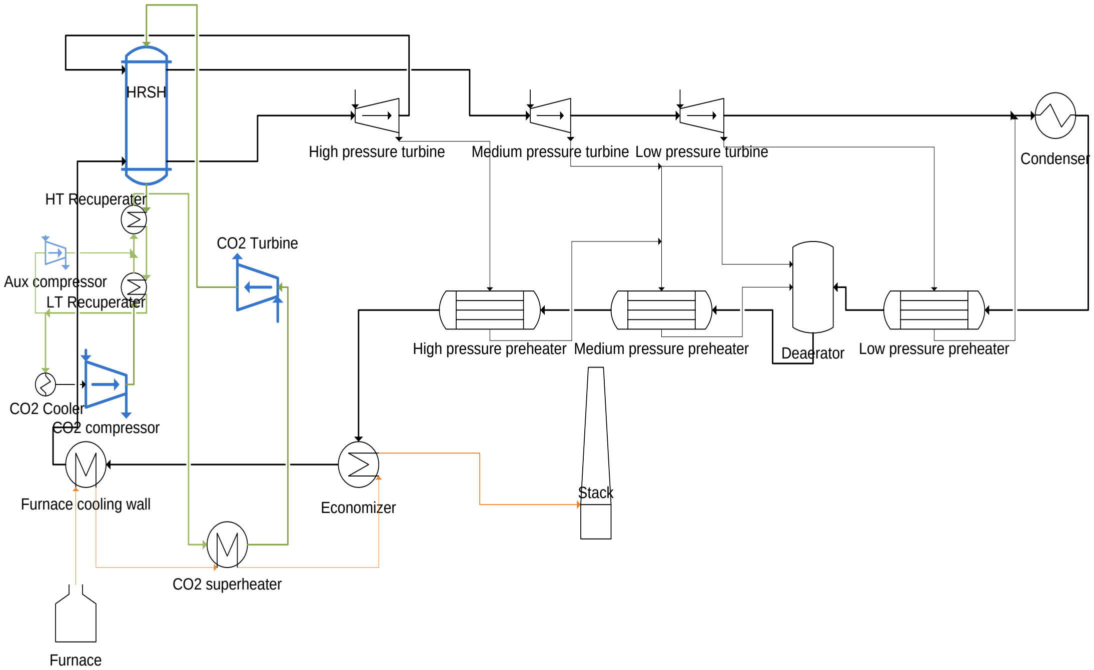
- **Case 7**
  - No turbine bleeding
  - 42.02% net cycle efficiency
  - - 1.59% pt



RESULTS & DISCUSSION

RECOMPRESSION PART FLOW CO_2 CYCLE

- **Case 8**
  - ~60% steam cycle loading
  - 33% split ratio
  - 43.16% net cycle efficiency
  - - 0.45% pt
- **Case 9**
  - Heat integration in LP heater
  - Reduced HRSH outlet T
  - 33% split ratio
  - 42.26% net cycle efficiency
  - - 1.35% pt



RESULTS & DISCUSSION

RECOMPRESSION PART FLOW CO_2 CYCLE

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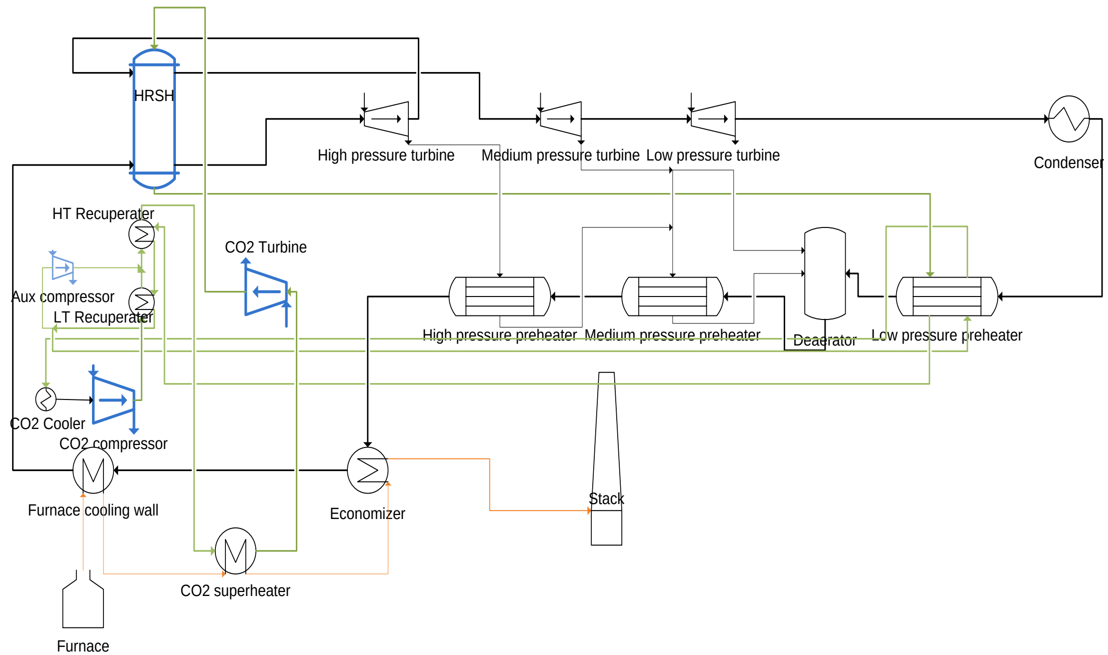
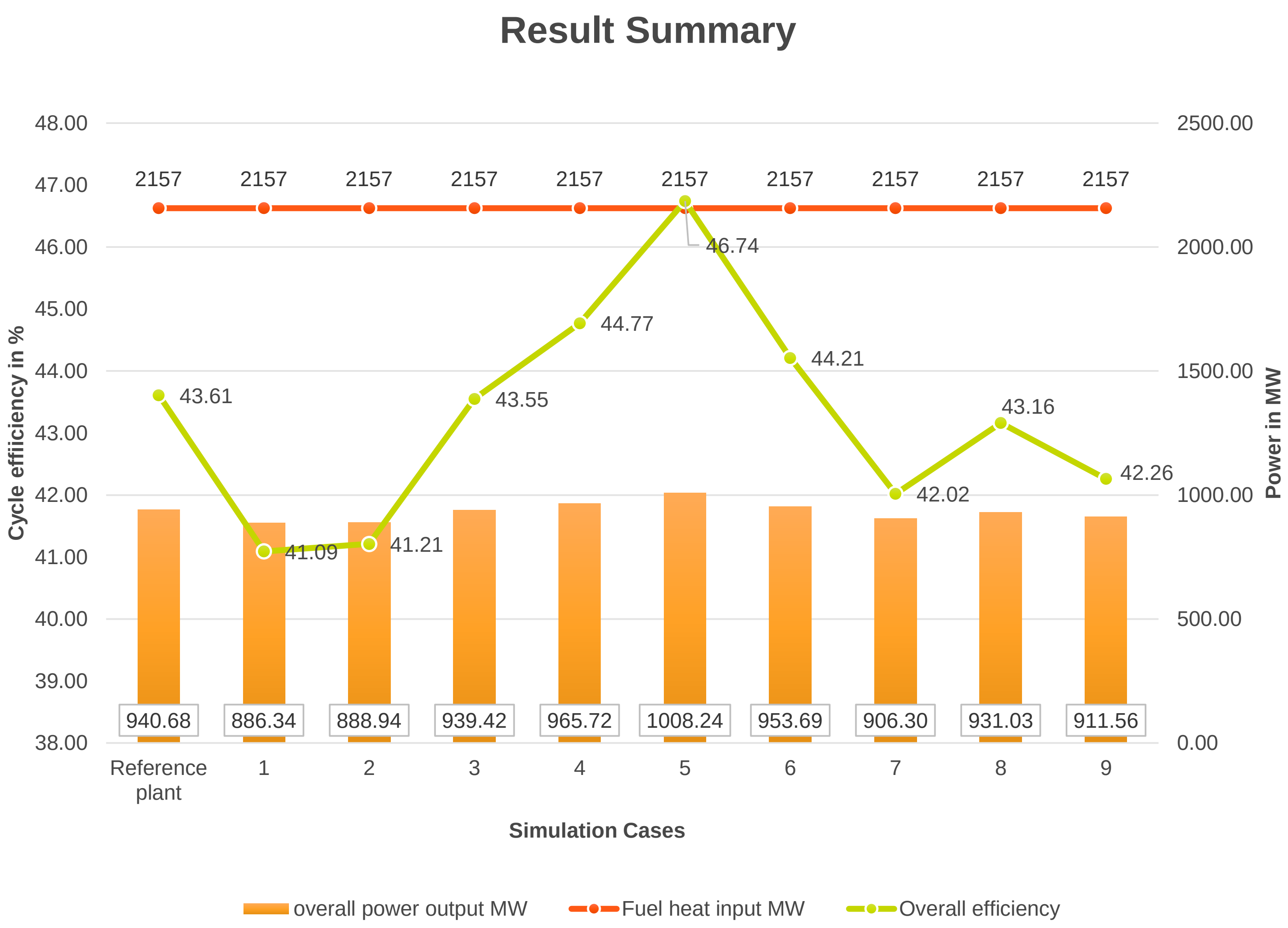


RESULTS & DISCUSSION
SUMMARY



CONCLUSION
RETROFFITING STEAM UNIT WITH SCO_2 TOPPING CYCLE

No significant efficiency boost with USC unit

- Most promising case +0.05% pt
- Possible more significant gain with older units
- Efficiency boost with better cycle optimization

Overall power output	235	MW
Turbine	46	MW
HRSH	112	MW
Recuperator	41	MW

Key equipment size for 250MW retrofits

Industrial scale SCO_2 demo through retrofitting is feasible

- Easy modification on the existing boiler
- Low impact on the steam cycle operation
- Small key equipment to be hosted
- Reduce construction period and cost

THANK YOU

CONTACT

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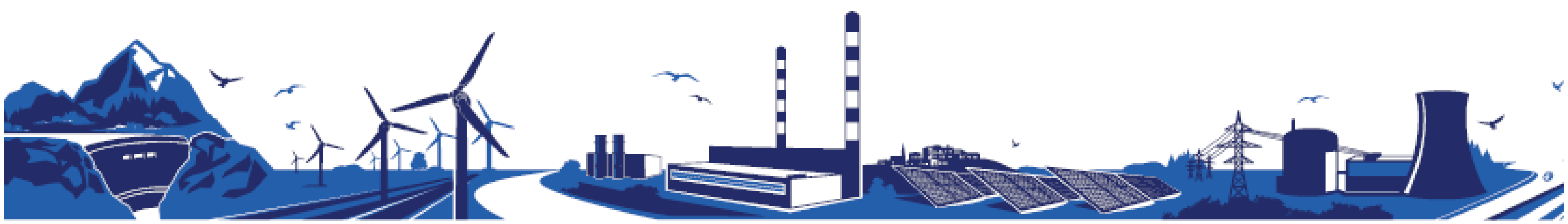

Annex

CASE NUMBER	UNITS	REFERENCE PLANT	1	2	3
STEAM FLOW RATE	T/h	2680	1610	1612	1799
CO2 FLOW RATE	kg/s	0	2910	2915	1500
FUEL HEAT INPUT	MW	2157	2157	2157	2157
TOTAL HEAT ABSORBED	MW	1993	1992	1992	1993
HRSH OUTLET TEMPERATURE	°C	N/A	520	520	350
WATER WALL OUTLET TEMPERATURE	°C	396	515	515	399
STEAM CYCLE OUTPUT	MW	981	590	590	809
CONDENSER POWER	MW	1015	677	720	1031
STEAM CYCLE EFFICIENCY	%	43.61	45.76	44.19	42.04
CO2 TURBINE OUTPUT	MW	N/A	358	360	185
CO2 COMPRESSOR CONSUMPTION	MW	N/A	62	61	54
CO2 FINAL COOLER DUTY	MW	N/A	430	384.6	16
CO2 CYCLE NET OUTPUT	MW	N/A	297	299	131
CO2 CYCLE EFFICIENCY	%	N/A	40.75	43.73	88.85
OVERALL NET POWER OUTPUT	MW	941	886	889	942
OVERALL CYCLE NET EFFICIENCY	%	43.61	41.09	41.21	43.66
GAIN IN EFFICIENCY POINTS			2.52	2.40	0.05

CASE NUMBER	UNITS	4	5	6	7
STEAM FLOW RATE	t/h	2650	2775	2570	1690
CO2 FLOW RATE	kg/s	3120	3120	3150	1505
FUEL HEAT INPUT	MW	2157	2157	2157	2157
TOTAL HEAT ABSORBED	MW	1992	2083	1992	1991
HRSH OUTLET TEMPERATURE	°C	340	340	350	317
WATER WALL OUTLET TEMPERATURE	°C	399	405	365	397
STEAM CYCLE OUTPUT	MW	919	961	911	778
CONDENSER POWER	MW	1028	1075	1040	1008
STEAM CYCLE EFFICIENCY	%	46.41	46.39	45.42	39.15
CO2 TURBINE OUTPUT	MW	386	386	395	186
CO2 COMPRESSOR CONSUMPTION	MW	339	339	352	58
CO2 FINAL COOLER DUTY	MW	0.0	0.0	0.0	0.0
CO2 CYCLE NET OUTPUT	MW	46.9	46.9	43.0	128
CO2 CYCLE EFFICIENCY	%	94.75	96.90	98.40	99.55
OVERALL NET POWER OUTPUT	MW	966	1008	954	906
OVERALL CYCLE EFFICIENCY	%	44.77	46.74	44.21	42.02
GAIN IN EFFICIENCY POINTS		1.16	3.13	0.60	-1.59

eDF

CASE NUMBER	UNITS	8	9
STEAM FLOW RATE	t/h	1720	1720
CO_2 FLOW RATE	kg/s	2220	1800
FUEL HEAT INPUT	MW	2157	2157
TOTAL HEAT ABSORBED	MW	1992	1993
WATER WALL OUTLET TEMPERATURE	°C	501	504
STEAM CYCLE OUTPUT	MW	618	658
CONDENSER POWER	MW	732	865
STEAM CYCLE EFFICIENCY	%	46.02	47.99
CO_2 TURBINE OUTPUT	MW	410	332
CO_2 COMPRESSOR CONSUMPTION	MW	97	79
CO_2 FINAL COOLER DUTY	MW	329	217
CO_2 CYCLE NET OUTPUT	MW	313	254
CO_2 CYCLE EFFICIENCY	%	48.83	53.11
OVERALL NET POWER OUTPUT	MW	931	912
OVERALL CYCLE EFFICIENCY	%	43.16	42.26
GAIN IN EFFICIENCY POINTS		-0.45	-1.35

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