sCO_2 Cycle as an Efficiency Improvement Opportunity for Air-Fired Coal Combustion

Charles W. White, Walter W. Shelton,
Nathan T. Weiland, Travis R. Shultz

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U.S. DEPARTMENT OF ENERGY

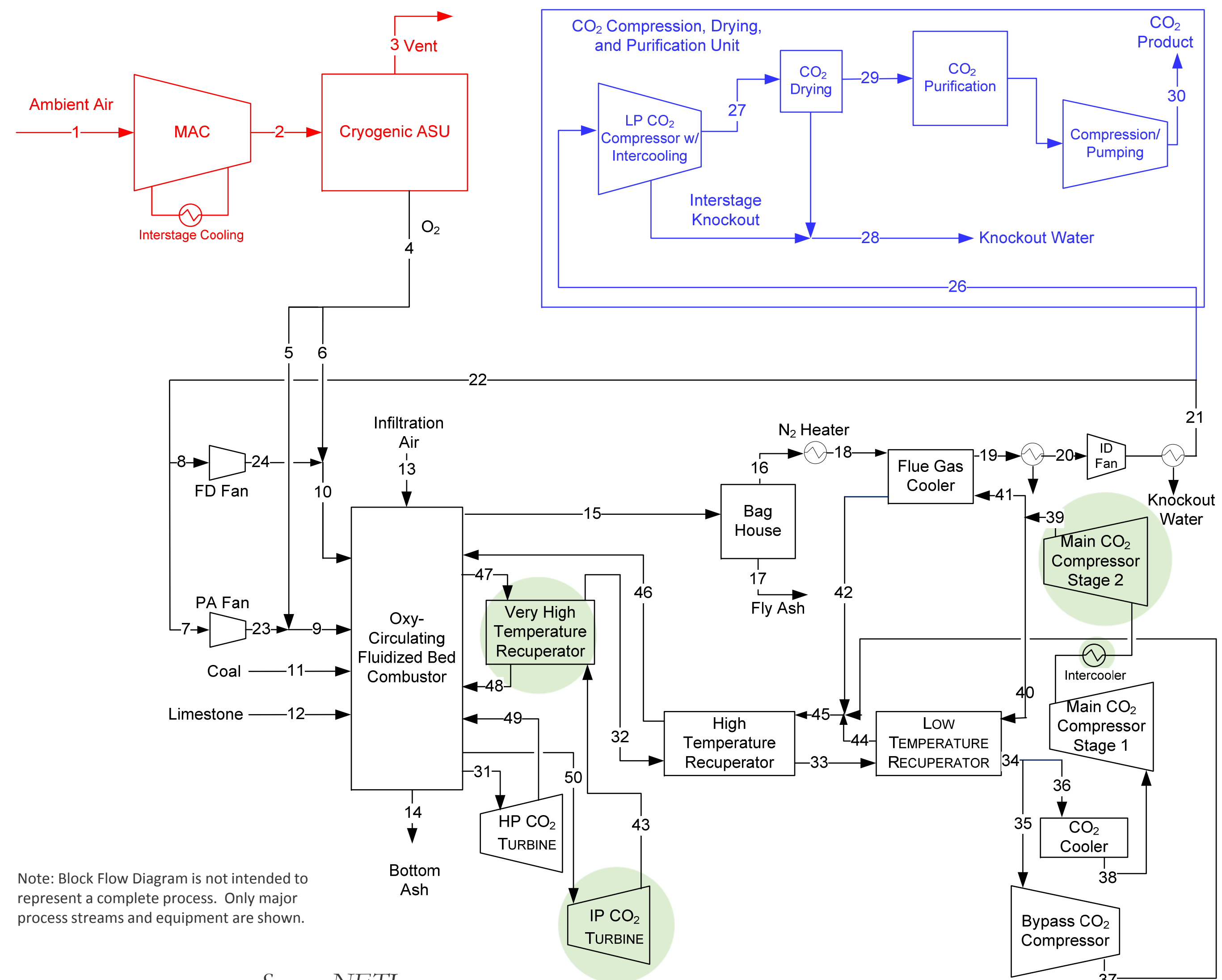
Presentation Outline

- Oxy-CFB Coal-fired Indirect sCO_2 Power Plant Study
- Non-Capture Indirect sCO_2 Plant Study
- Development of Improved sCO_2 Power Cycles
- Techno-Economic Analysis Results Summary
- Sensitivity Analysis Results Summary
- Heat Integration Analysis Results Summary
- Summary & Conclusions
- Ongoing and Future sCO_2 System Analysis

Source: NETL

Oxy-CFB Coal-fired Indirect sCO_2 Power Plant Study

- **A recent NETL report[1] examined the cost and performance of power plants with carbon capture based on:**
  - Coal-fired oxy-CFB heat source
  - Indirect recompression sCO_2 Brayton cycle
- **4 Cycle Configurations Examined**
  - Recompression Brayton cycle (Base)
  - Reheat sCO_2 turbine (Reheat)
  - Intercooled 2-stage main sCO_2 compressor (Intercooled)
  - Reheat sCO_2 turbine and Intercooled main sCO_2 compressor (Reheat+Intercooled)



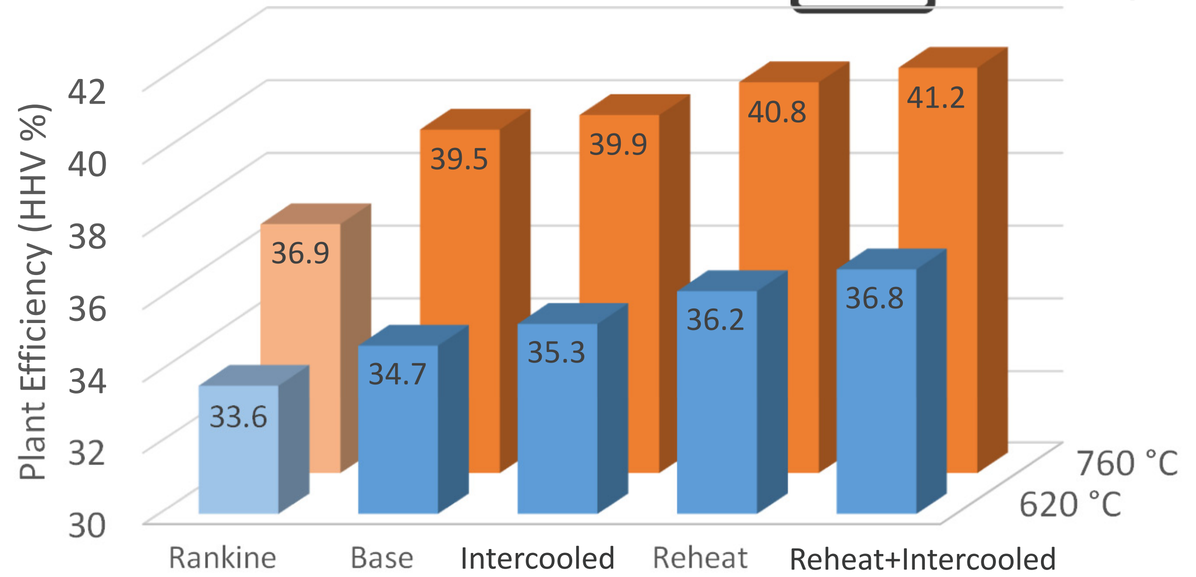
Source: NETL

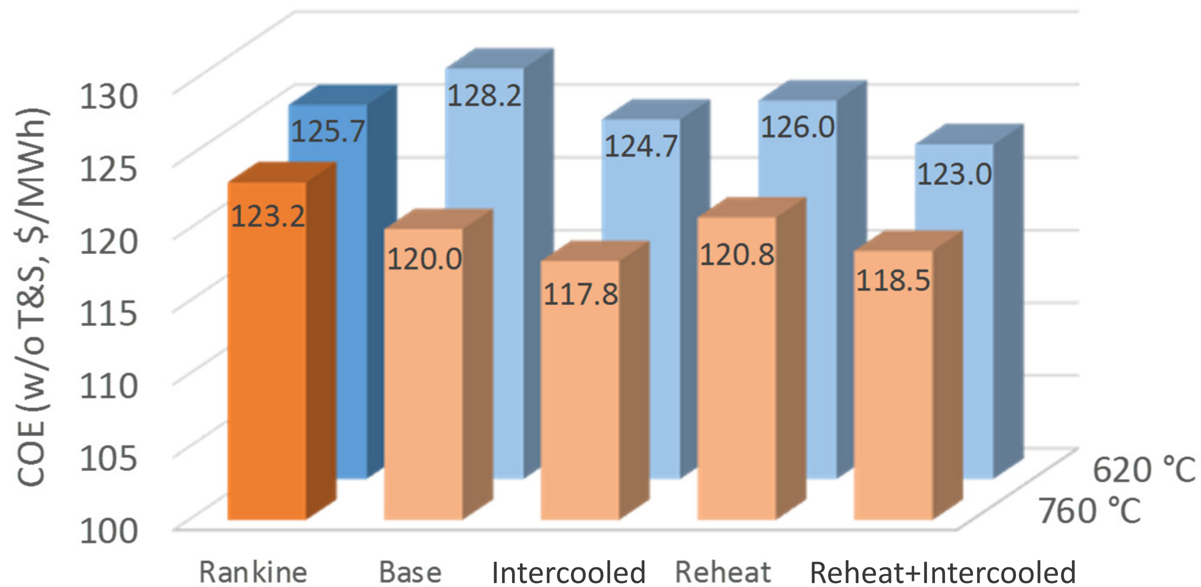
[1] National Energy Technology Laboratory (NETL), "Techno-economic Evaluation of Utility-Scale Power Plants Based on the Indirect sCO_2 Brayton Cycle, "DOE/NETL- 2017/1836, Pittsburgh, PA, September 2017 , https://www.netl.doe.gov/research/energy-analysis/search-publications/vuedetails?id=2511

Oxy-CFB Coal-fired Indirect sCO_2 Power Plant Study

Cost and Performance Results

- **Results shown for two different turbine inlet temperatures**
  - 620 °C (similar to ultra-supercritical (USC) Rankine cycle conditions)
  - 760 °C (approximating advanced ultra-supercritical (AUSC) Rankine cycle conditions)
- **Compared to plants employing Rankine cycles at operating conditions similar to the corresponding sCO_2 plants, the sCO_2 plant offered:**
  - Significantly higher plant efficiency
  - Lower COE
- **Results were consistent with prior sensitivity analyses on indirect sCO_2 cycle sensitivity to turbine inlet temperature**

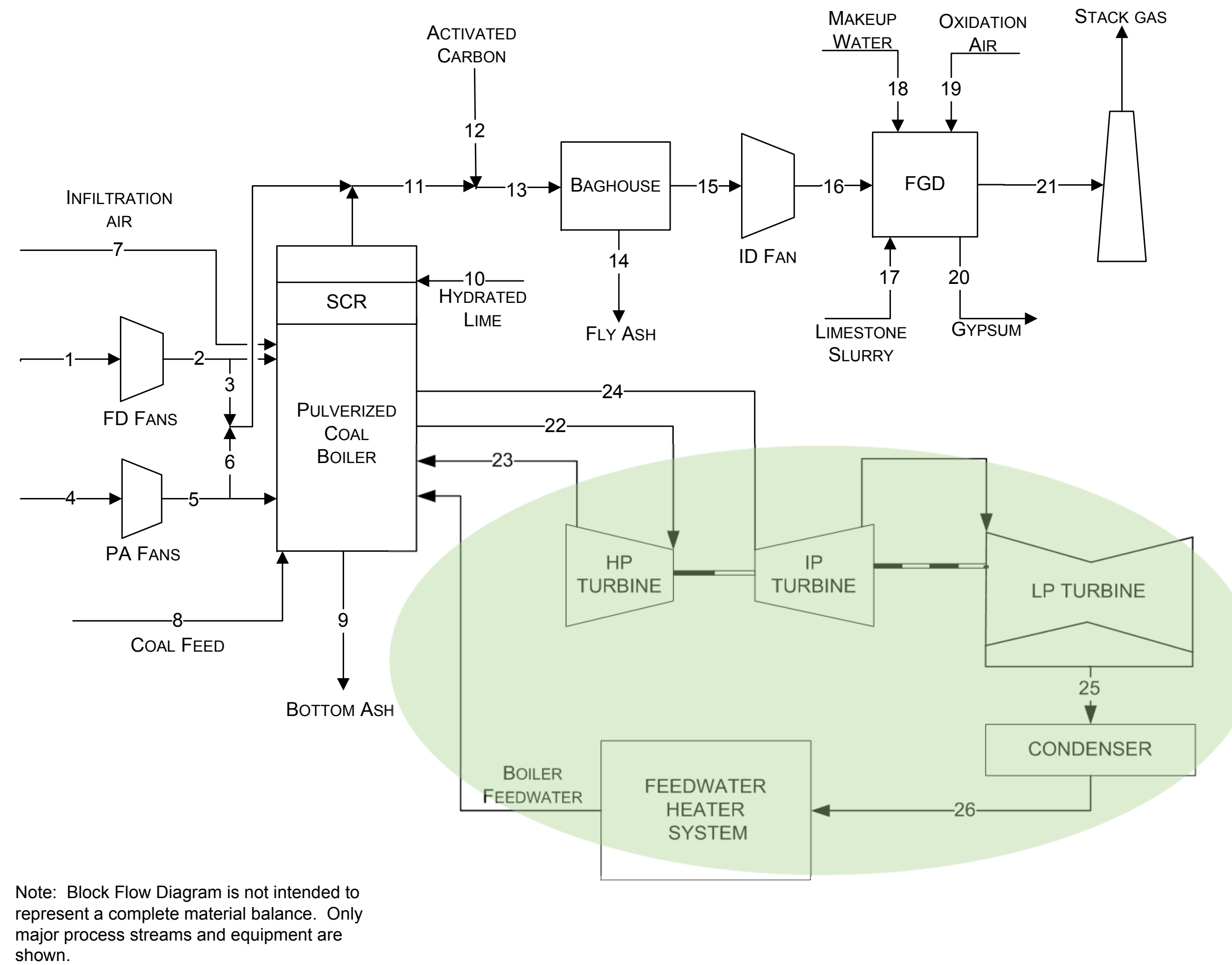




Non-capture Indirect sCO_2 Plant Study

Steam Rankine Comparison Cases

- **Air-fired PC Boiler**
  - Bituminous coal
  - 99% carbon conversion
  - Hydrated lime injected for SO_3 control
  - Powdered activated carbon (PAC) for Hg control
  - SCR and OFA for NOx control
  - Infiltration air 1.7% of feed air to PC boiler
- **Operating conditions for Rankine plants**
  - Supercritical (SC) Rankine cycle[1]
    (Case B12A: 24.1 MPa/ 593 °C/ 593 °C)
  - Advanced ultra-supercritical (AUSC) Rankine cycle[2]
    (AUSC Case 5: 34.5 MPa/ 732 °C / 760 °C)
- **No low temperature flue gas heat recovery**
- **Wet FGD (98% efficiency) for sulfur removal (Gypsum)**



Source: NETL

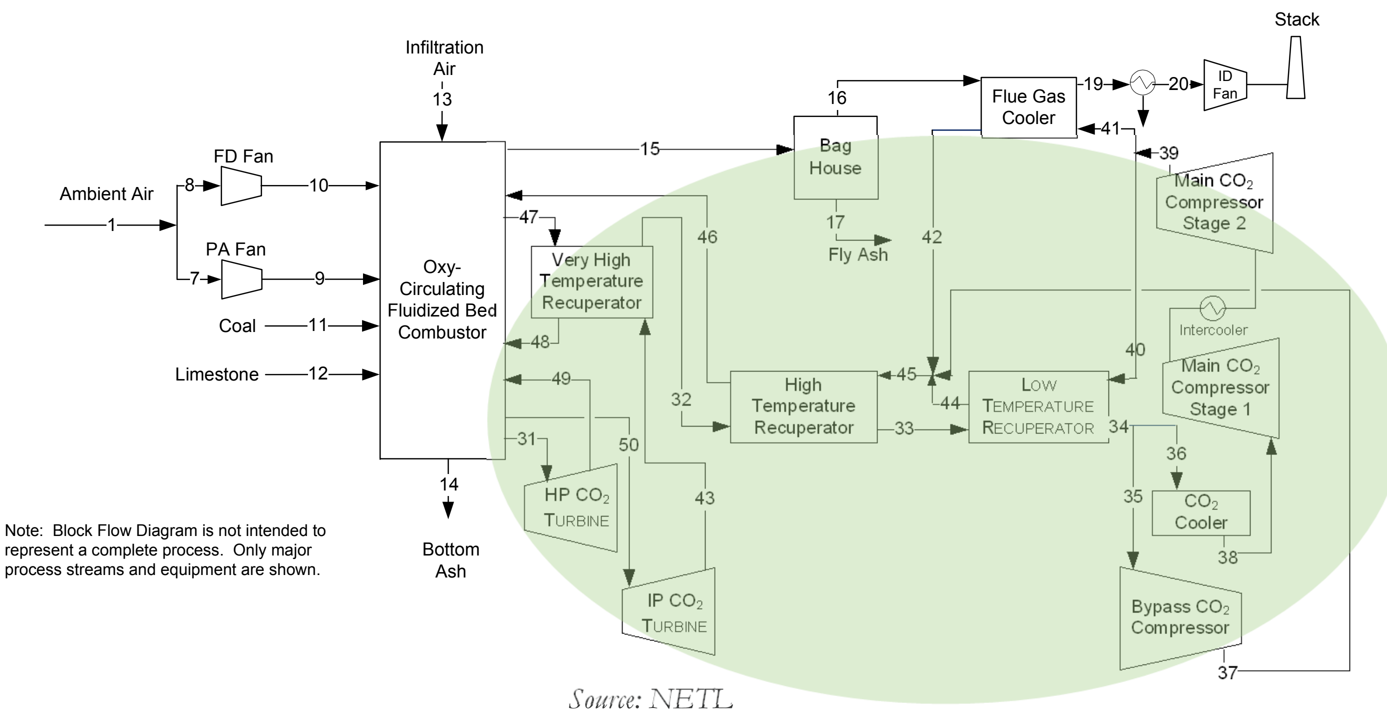
[1] National Energy Technology Laboratory (NETL), "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 3," NETL, Pittsburgh, PA, June 2015.

[2] National Energy Technology Laboratory (NETL), "Development of Advanced Ultra-Supercritical (AUSC) Pulverized Coal (PC) Plants," NETL – PUB – 21022, Pittsburgh,PA,December 2016

Non-capture Indirect sCO_2 Plant Study

Reference sCO_2 Process without CO_2 Capture – Case RhtIC760A

- **From Oxy-CFB Coal-fired Indirect sCO_2 Plant, Case RhtIC760A removes:**
  - Air Separation Unit (ASU)
  - CPU (Carbon Purification Unit) – no CO_2 capture
  - Recycle Flue Gas to CFB
- **Air-fired-CFB**
  - Bituminous coal
  - 99% carbon conversion
  - 3.1% excess O_2 to CFB
  - In-bed sulfur capture (94%), 140% excess $CaCO_3$
  - Infiltration air 2% of feed air to CFB
- **Recompression sCO_2 Brayton cycle**
  - Turbine inlet temperature 760 °C
- **High temperature heat recovery from flue gas (Economizer)**
- **Low temperature flue gas heat recovery in sCO_2 power cycle**



Note: Block Flow Diagram is not intended to represent a complete process. Only major process streams and equipment are shown.

Source: NETL

Non-capture Indirect sCO_2 Plant Study

sCO_2 Cycle and Heat Source Parameters – Reference Case RhtIC760A

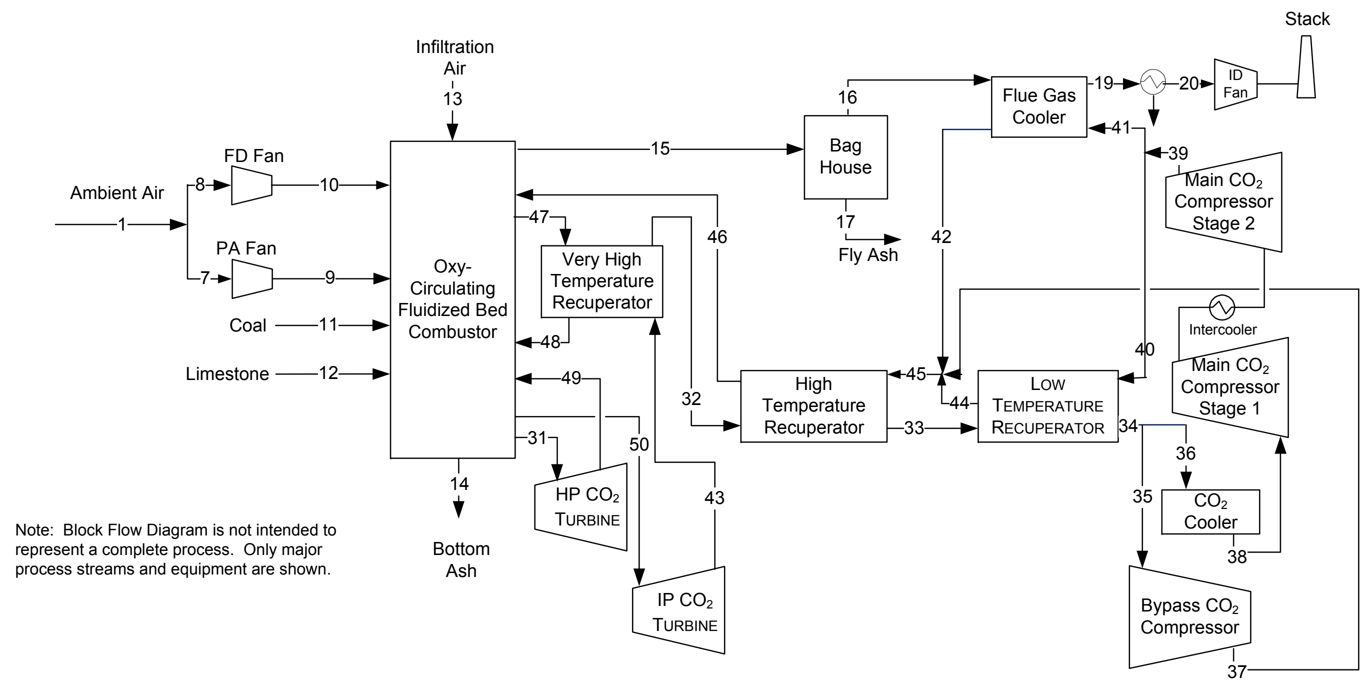
Section	Parameter	Reference Case RhtIC760A
CFB	Primary air fraction	0.235
	Secondary air fraction	0.765
	Pressure drop	6.6 kPa
	Excess air	3.1%
	Infiltration air	2%
	Lime molar feed rate	2.4 times sulfur feed rate
Expander	Inlet temperature	760 °C
	Max inlet pressure	34.5 MPa
	PR, P_{exit}	4.05, 8.51 MPa
	Isentropic efficiency	0.927
Recuperator	P_{drop} HP side	0.2%
	P_{drop} LP side	0.8%
	LTR Avg T_{app}	5.6 °C
	HTR Min Tapp	5.6 °C
CO_2 cooler	Non-cond cooler	35 °C
	P_{drop} CO_2 side	0.8%

Section	Parameter	Reference Case RhtIC760A
CO_2 main compressor intercoolers	Non-cond cooler	35 °C
	P_{drop} CO_2 side	13.8 kPa per stage
	Stages	1
	Cooling source	Process cooling water/Cooling tower
Recompression	CO_2 bypass	22.4%
CO_2 main compressor	P_{inlet}	7.75 MPa (≥ P_c)
	P_{exit}	35.10 MPa
	Isentropic efficiency	0.85
	Stages	2
	Intercooling stages	1
CO_2 bypass compressor	Exit pressure	35.03 MPa
	Isentropic efficiency	0.85
	Stages	2
	Intercooling stages	0
CO_2 main compressor intercoolers	Non-cond cooler	35 °C
	P_{drop} CO_2 side	13.8 kPa per stage

Development of Improved sCO_2 Power Cycles

Approach and Methodology for Case Permutations

- **Starting with reference Case RhtIC760A:**
  - Developed cycle state point changes and minor cycle configuration changes
  - Applied each individually to reference Case RhtIC760A
  - Modifications that increased process efficiency and either reduced or minimally increased COE retained for further consideration
- **Using T-Q diagram for recuperator train:**
  - Adjustments proposed to the heat integration scheme that were likely to increase the power cycle efficiency without having a significantly adverse impact on the COE
- **The combination of these two approaches led to:**
  - Baseline Case
  - Alternate Configuration Case



Source: NETL

Development of Improved sCO_2 Power Cycles

Selection of Cycle Configurations

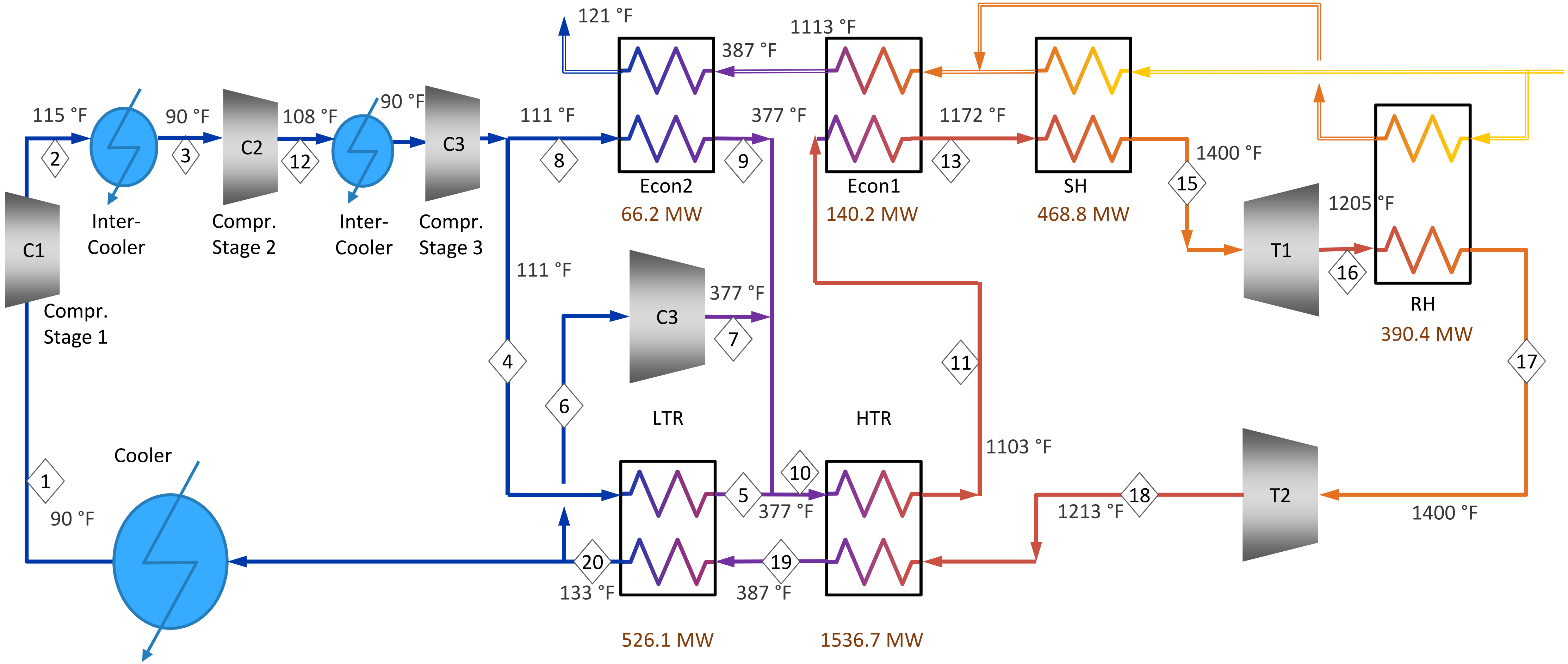
- **Baseline Case:**
  - Applied the promising cycle state point and configuration changes to reference Case RhtIC760A **sequentially**
  - Order of introduction of changes was based on the results obtained from the one-off analysis
    - Changes that both increased process efficiency and lowered COE were applied first
    - Changes that increased efficiency with a neutral or slightly negative impact on COE applied next
    - Changes that would adversely impact efficiency but lead to a large drop in COE were only considered if the COE goal could not otherwise be achieved

- **Alternate Configuration Case:**
  - Developed by first identifying promising changes in the heat integration scheme
  - If a preliminary techno-economic analysis yielded a higher efficiency or lower COE than for reference Case RhtIC760A:
    - Configuration was retained for further study
    - Same methodology for sequentially applying process changes used
    - Only the most promising of these alternatives were investigated

Baseline Case

State Point and Configuration Changes Adopted

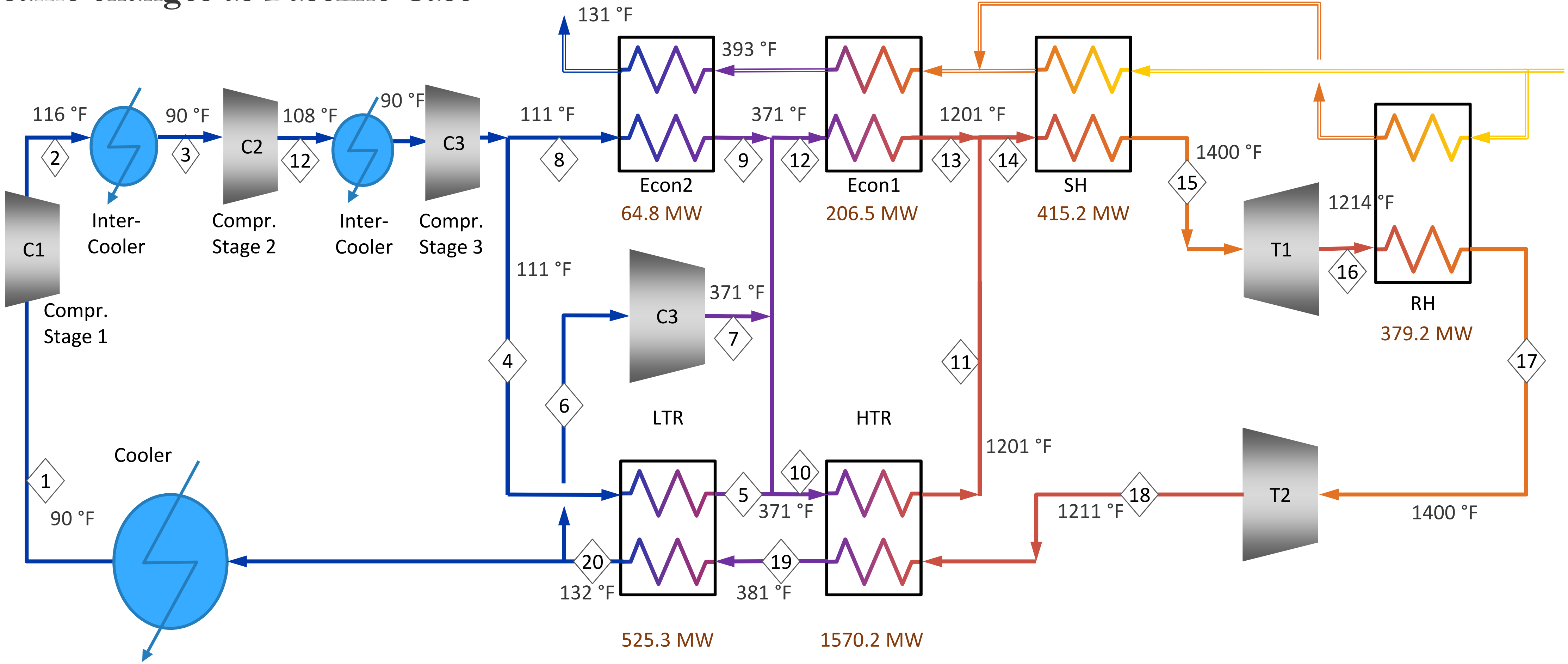
- Elimination of VTR
- Reduction in CO_2 cooler temperature to 90 °F
- Additional main CO_2 compressor intercooler stage
- Slight increase in CFB pressure



Alternate Configuration Case

State Point and Configuration Changes Adopted

- **High temperature economizer (Econ1) in parallel with HTR**
- **Plus same changes as Baseline Case**



Techno-economic Analysis Results Summary

Comparison of Baseline sCO_2 Plant with Rankine Plants

- Compared to reference Case B12A, Baseline Case has:
  - 8.8 percentage point higher process efficiency (HHV)
  - 6.6 percentage point higher cycle efficiency
  - 36% lower water consumption
  - 16% reduction in CO2 emissions
  - Lower CO_2 emissions than current EPA limit*

Performance Summary	Reference Case B12A	AUSC Case 5	Baseline Case	Alternate Config
Total Gross Power, MWe	**580**	**578**	**584**	**584**
Total Auxiliaries, MWe	**30**	**27**	**17**	**17**
Net Power, MWe	**550**	**550**	**567**	**567**
HHV Net Plant Efficiency (%)	40.7%	44.1%	49.5%	49.5%
LHV Net Plant Efficiency (%)	42.2%	45.8%	51.3%	51.3%
HHV Boiler Efficiency, %	89.1%	89.1%	92.9%	92.9%
LHV Boiler Efficiency, %	92.4%	92.4%	96.3%	96.3%
Power Cycle Efficiency, %	48.2%	52.0%	54.8%	54.8%
CO_2 Cycle Cooling Duty/Condensor Duty, GJ/hr (MMBtu/hr)	2,192 (2,078)	1,873 (1,776)	1,701 (1,612)	1,701 (1,613)
As-Received Coal Feed, kg/hr (lb/hr)	179,193 (395,053)	165,482 (364,825)	152,162 (335,460)	152,162 (335,460)
Limestone Sorbent Feed, kg/hr (lb/hr)	17,707 (39,037)	16,352 (36,050)	35,618 (78,525)	35,618 (78,525)
HHV Thermal Input, kWt	1,350,652	1,247,323	1,146,927	1,146,927
LHV Thermal Input, kWt	1,302,740	1,203,058	1,106,225	1,106,225
Raw Water Withdrawal, $(m^3/min)/MW_{net}$ (gpm/MW_{net})	0.035 (9.3)	0.030 (8.0)	0.024 (6.2)	0.024 (6.2)
Raw Water Consumption, $(m^3/min)/MW_{net}$ (gpm/MW_{net})	0.028 (7.4)	0.024 (6.4)	0.018 (4.7)	0.018 (4.7)
O_2 Mole Percent in Boiler Exit, %	3.4%	3.4%	1.0%	1.0%
CO_2 Emissions (lb CO_2/MWh-gross)	1,617	1,490	1,353	1,353

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* However, the EPA's standard is based on average annual emissions – additional analyses are required to assess system performance under realistic annual operating profiles, including part-load

Techno-economic Analysis Results Summary

Comparison of Baseline sCO_2 Plant with Rankine Plants

- **Compared to reference AUSC Case 5, Baseline Case has:**
  - 5.4 percentage point higher process efficiency
  - 2.8 percentage point higher cycle efficiency
  - 22% lower water consumption
  - 9% reduction in CO2 emissions
  - Lower CO_2 emissions than current EPA limit*

Performance Summary	Reference Case B12A	AUSC Case 5	Baseline Case	Alternate Config
Total Gross Power, MWe	**580**	**578**	**584**	**584**
Total Auxiliaries, MWe	**30**	**27**	**17**	**17**
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* However, the EPA's standard is based on average annual emissions – additional analyses are required to assess system performance under realistic annual operating profiles, including part-load

Techno-economic Analysis Results Summary

Comparison of Baseline sCO_2 Plant with Rankine Plants

- **Compared to Alternate Configuration Case, Baseline Case has:**
  - Essentially identical performance

Performance Summary	Reference Case B12A	AUSC Case 5	Baseline Case	Alternate Config
Total Gross Power, MWe	**580**	**578**	**584**	**584**
Total Auxiliaries, MWe	**30**	**27**	**17**	**17**
Net Power, MWe	**550**	**550**	**567**	**567**
HHV Net Plant Efficiency (%)	40.7%	44.1%	49.5%	49.5%
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O_2 Mole Percent in Boiler Exit, %	3.4%	3.4%	1.0%	1.0%
CO_2 Emissions (lb CO_2/MWh-gross)	1,617	1,490	1,353	1,353

Techno-economic Analysis Results Summary

Comparison of Baseline sCO_2 Plant with Rankine Plants

- **Compared to reference Case B12A, Baseline Case has:**
  - 5 MW increase in cycle output
  - 13 MW decrease in auxiliary power
    - Coal pulverizers
    - No wet FGD
    - Less cooling duty
  - 17 MW increase in net plant power

Power Summary	Reference Case B12A	AUSC Case 5	Baseline Case	Alternate Config
POWER GENERATION SUMMARY				
sCO_2/Steam Turbine Gross Power	588,516	586,305	741,272	740,316
sCO_2 Main Compressor	---	---	-85,654	-83,172
sCO_2 Bypass Compressor	---	---	-62,558	-64,096
Generator Loss	-8,828	-8,795	-8,896	-8,896
TOTAL POWER GENERATED	579,688	577,510	584,164	584,151
AUXILIARY LOAD SUMMARY				
Coal Handling	-430	-420	-399	-399
Sorbent Prep/Injection	-958	-890	-157	-157
Pulverizers	-2,690	-2,480	-72	-72
Ash Handling and Dewatering	-620	-580	-1,756	-1,756
Baghouse	-90	-80	-7	-7
Turbine Auxiliaries	-400	-400	-400	-400
Wet FGD	-2,830	-2,610	---	---
Condensate Pumps	-800	-640	---	---
SCR	-40	-40	---	---
Miscellaneous Balance of Plant	-2,000	-2,000	-2,000	-2,000
Circulating Water Pump	-4,980	-4,290	-3,636	-3,636
Cooling Tower Fans	-2,340	-2,010	-2,122	-2,122
Air & Flue Gas Fan Power	-9,690	-8,950	-4,647	-4,647
Transformer Losses	-1,820	-1,800	-1,794	-1,794
TOTAL AUXILIARIES	-29,688	-27,190	-16,990	-16,990
NET POWER	550,000	550,320	567,174	567,162

Techno-economic Analysis Results Summary

Comparison of Baseline sCO_2 Plant with Rankine Plants

- Compared to reference AUSC Case 5, **Baseline Case** has:
  - 7 MW increase in cycle output
  - 10 MW decrease in auxiliary power
    - Coal pulverizers
    - No wet FGD
    - Less cooling duty
  - 17 MW increase in net plant power

Power Summary	Reference Case B12A	AUSC Case 5	Baseline Case	Alternate Config
POWER GENERATION SUMMARY				
sCO_2/Steam Turbine Gross Power	588,516	586,305	741,272	740,316
sCO_2 Main Compressor	---	---	-85,654	-83,172
sCO_2 Bypass Compressor	---	---	-62,558	-64,096
Generator Loss	-8,828	-8,795	-8,896	-8,896
TOTAL POWER GENERATED	579,688	577,510	584,164	584,151
AUXILIARY LOAD SUMMARY				
Coal Handling	-430	-420	-399	-399
Sorbent Prep/Injection	-958	-890	-157	-157
Pulverizers	-2,690	-2,480	-72	-72
Ash Handling and Dewatering	-620	-580	-1,756	-1,756
Baghouse	-90	-80	-7	-7
Turbine Auxiliaries	-400	-400	-400	-400
Wet FGD	-2,830	-2,610	---	---
Condensate Pumps	-800	-640	---	---
SCR	-40	-40	---	---
Miscellaneous Balance of Plant	-2,000	-2,000	-2,000	-2,000
Circulating Water Pump	-4,980	-4,290	-3,636	-3,636
Cooling Tower Fans	-2,340	-2,010	-2,122	-2,122
Air & Flue Gas Fan Power	-9,690	-8,950	-4,647	-4,647
Transformer Losses	-1,820	-1,800	-1,794	-1,794
TOTAL AUXILIARIES	-29,688	-27,190	-16,990	-16,990
NET POWER	550,000	550,320	567,174	567,162

Summary of Capital Costs/COE

Steam Rankine vs. sCO_2 Cases ($/kW)

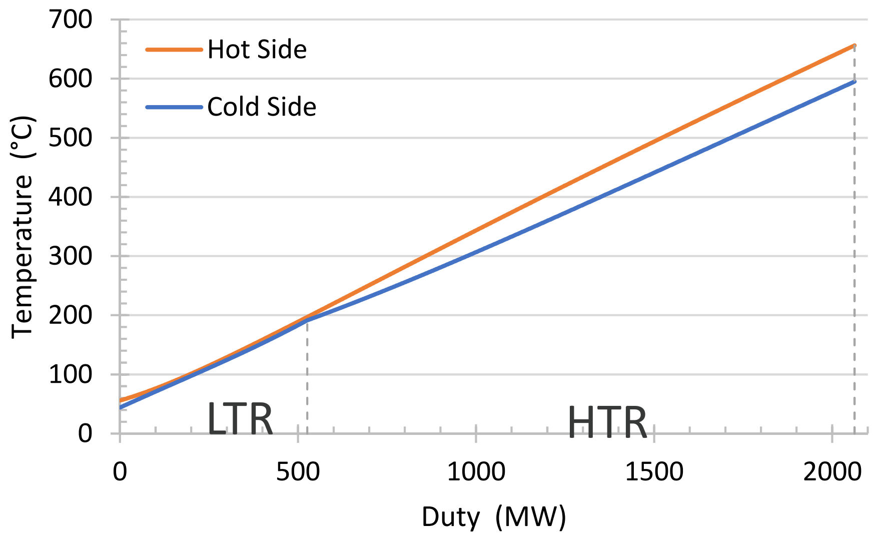
- **Compared to the reference Case B12A, Baseline Case had:**
  - 1.4 percent lower TOC
  - 3 percent lower COE
- **Compared to the reference AUSC Case 5, Baseline Case had:**
  - 1.5 percent greater TOC
  - 1.6 percent greater COE
- **Compared to the Alternate Config Case, Baseline Case had:**
  - $10/kW lower TOC. Differences due to:
    - Boiler & Power Cycle Accounts
    - Differences in relative HX duties
    - Lower HTR driving force
  - Slightly greater COE (0.2 $/MWh)
    - Difference not significant

Capital Cost Summary	Reference Case B12A	AUSC Case 5	Baseline Case	Alternate Config
Account	TPC ($/kW)			
Coal & Sorbent Handling	83	78	81	81
Coal & Sorbent Prep & Feed	39	37	43	43
Feedwater & Miscellaneous BOP Systems	170	146	37	37
Boiler & Accessories	621	611	669	635
Gas Cleanup & Piping	304	287	57	57
HRSG, Ducting, & Stack	83	82	86	86
Steam/sCO_2 Power Cycle	304	326	599	641
Cooling Water System	80	72	71	71
Ash & Spent Sorbent Handling Systems	31	29	52	52
Accessory Electric Plant	112	109	100	100
Instrumentation & Control	48	47	42	42
Improvements to Site	30	28	29	29
Buildings & Structures	122	119	121	121
Total Plant Costs	2,026	1,972	1,986	1,995
	Owner's Costs & TOC ($/kW)			
Owner's Costs	481	465	487	489
Total Overnight Cost (TOC)	2,507	2,437	2,473	2,483
Component	COE Summary (/MWh)			
Capital	39.0	38.0	41.2	41.4
Fixed O&M	9.6	9.5	9.7	9.7
Variable O&M	9.1	8.5	8.8	8.8
Fuel	24.6	22.7	20.2	20.2
Total (with T&S)	82.3	78.6	79.9	80.1

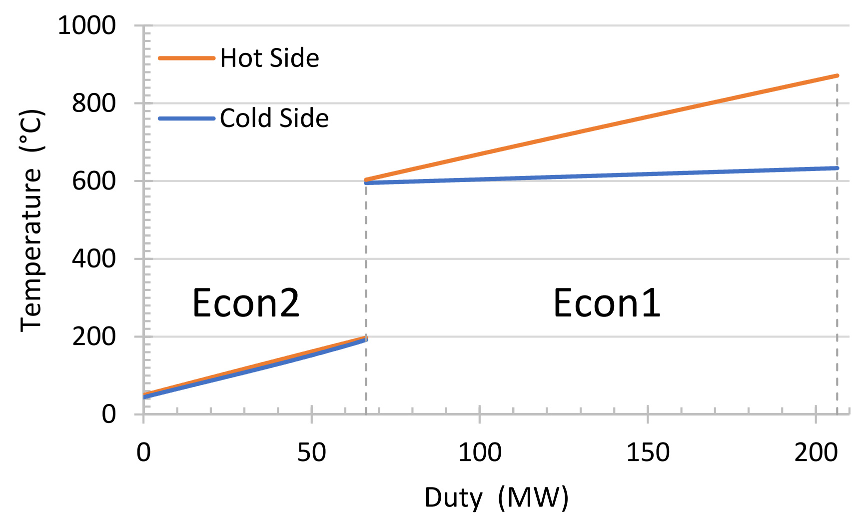
Heat Integration Analysis Results Summary

T-Q Economizer Diagram for Baseline sCO_2 plant

- **LTR has an internal pinch point:**
  - Minimum Tapp = 3.7 °C
  - Cold end T_{app} = 11.9 °C
  - Average T_{app} = 5.6 °C
- **HTR has considerably larger average T_{app}:**
  - Cold end T_{app} = 5.6 °C
  - Hot end T_{app} = 61.2 °C



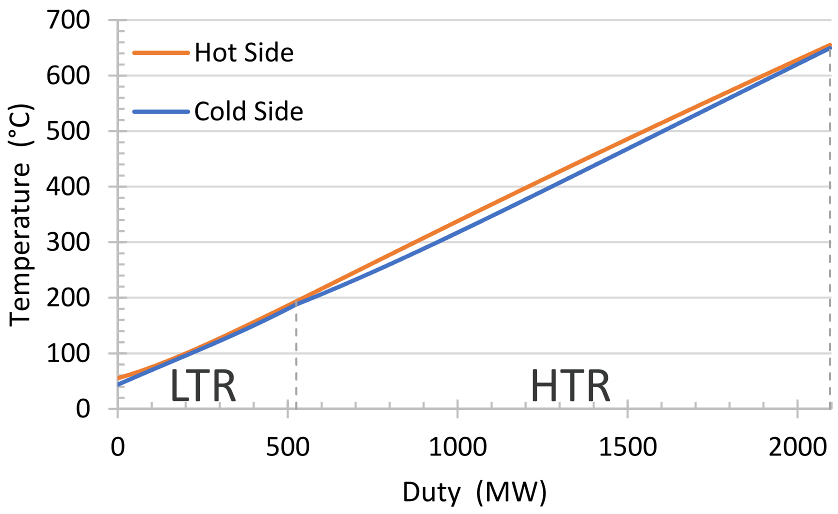
- **Low temperature economizer (Econ2):**
  - Cold end T_{app} = 5.6 °C
  - Hot end T_{app} = 5.6 °C
  - Average T_{app} = 8.3 °C
- **High temperature economizer (Econ1):**
  - Cold end T_{app} = 5.6 °C
  - Hot end T_{app} = 237 °C

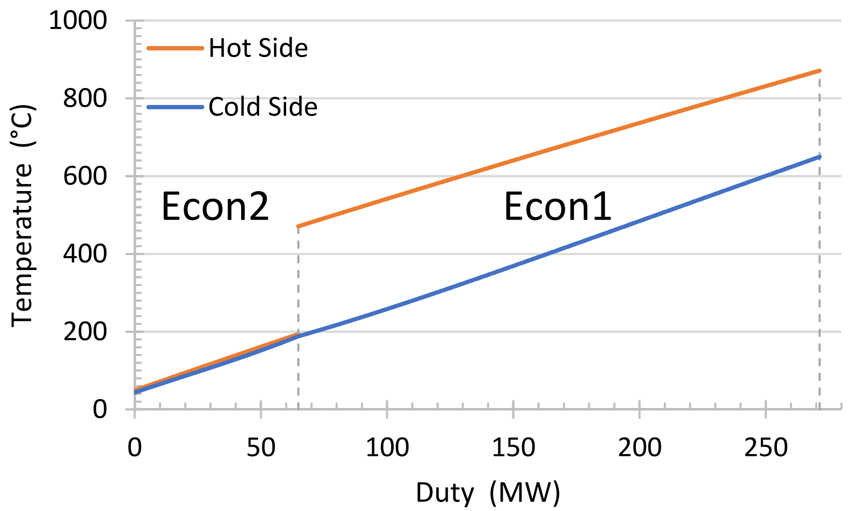


Heat Integration Analysis Results Summary

T-Q Recuperator Diagram for Alternate Configuration sCO_2 plant

- **LTR has an internal pinch point**
  - Minimum Tapp = 3.7 °C
  - Cold end T_{app} = 11.7 °C
  - Average T_{app} = 5.6 °C
- **HTR has modestly larger average T_{app}**
  - Cold end T_{app} = 5.6 °C
  - Hot end T_{app} = 5.6 °C
  - Average T_{app} = 15.5 °C
- **Low temperature economizer (Econ2)**
  - Cold end T_{app} = 5.6 °C
  - Hot end T_{app} = 5.6 °C
  - Average T_{app} = 8.3 °C
- **High temperature economizer (Econ1)**
  - Cold end T_{app} = 283 °C
  - Hot end T_{app} = 222 °C

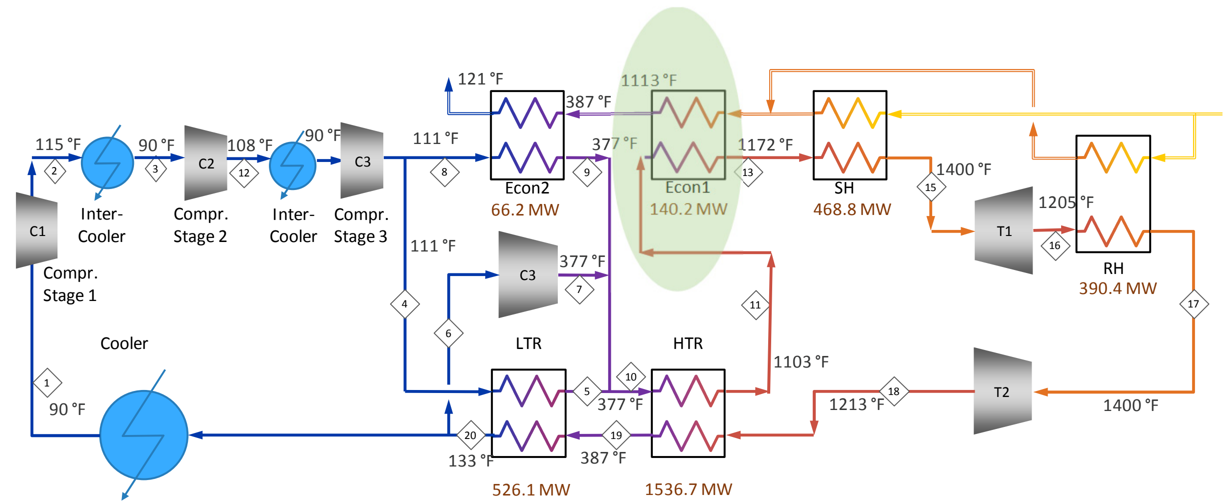




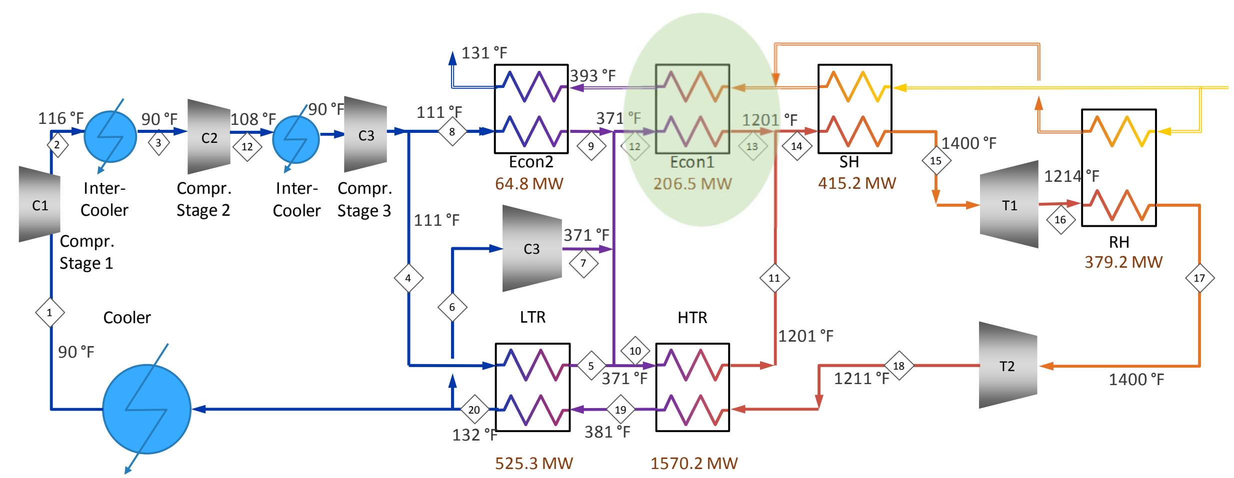
Heat Integration Analysis Results Summary

Comparing Heat Integration - Baseline Case vs. Alternate Configuration Case

- **Baseline Case**
  - Maximum LTR performance
  - Moderate HTR performance
  - Moderate Econ1 performance
  - Maximum Econ2 performance



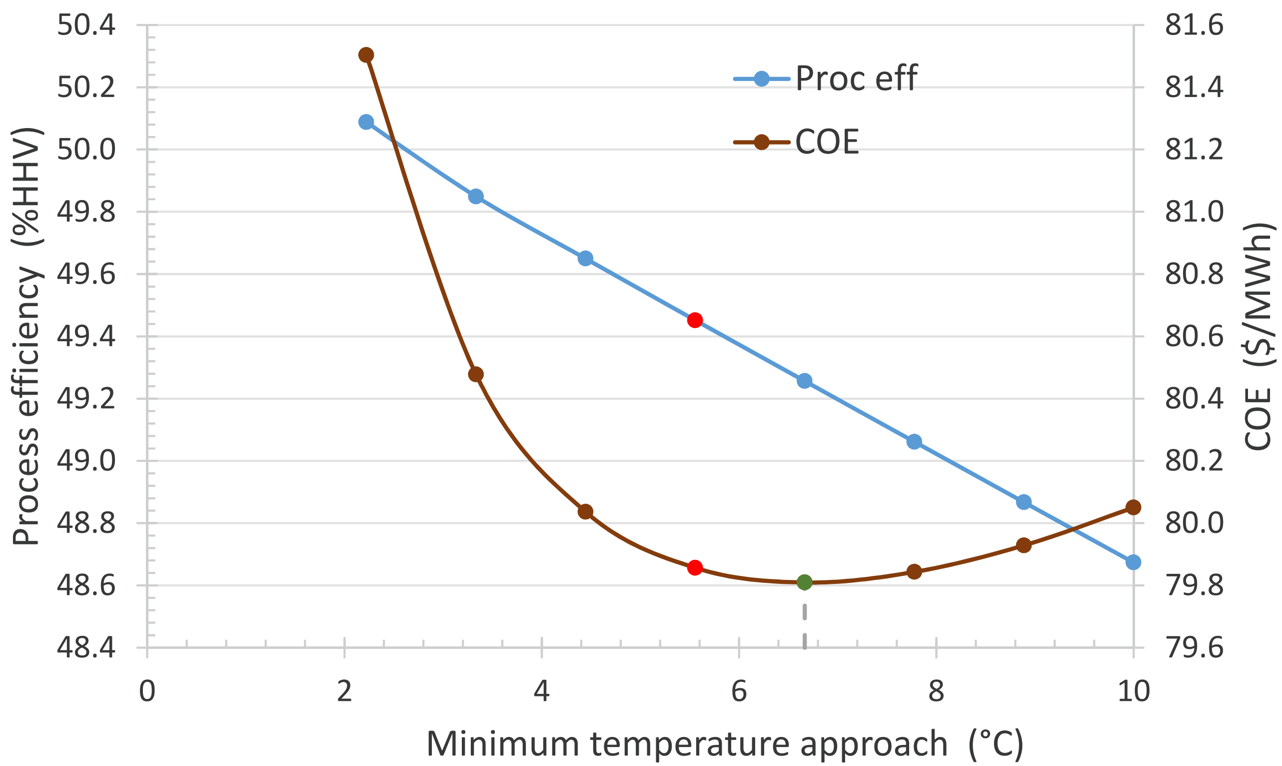
- **Alternate Configuration Case**
  - Maximum LTR performance
  - Near maximum HTR performance
  - Poor Econ1 performance
  - Maximum Econ2 performance



Sensitivity Analysis Results Summary

Efficiency and COE versus Minimum Recuperator T_{app}

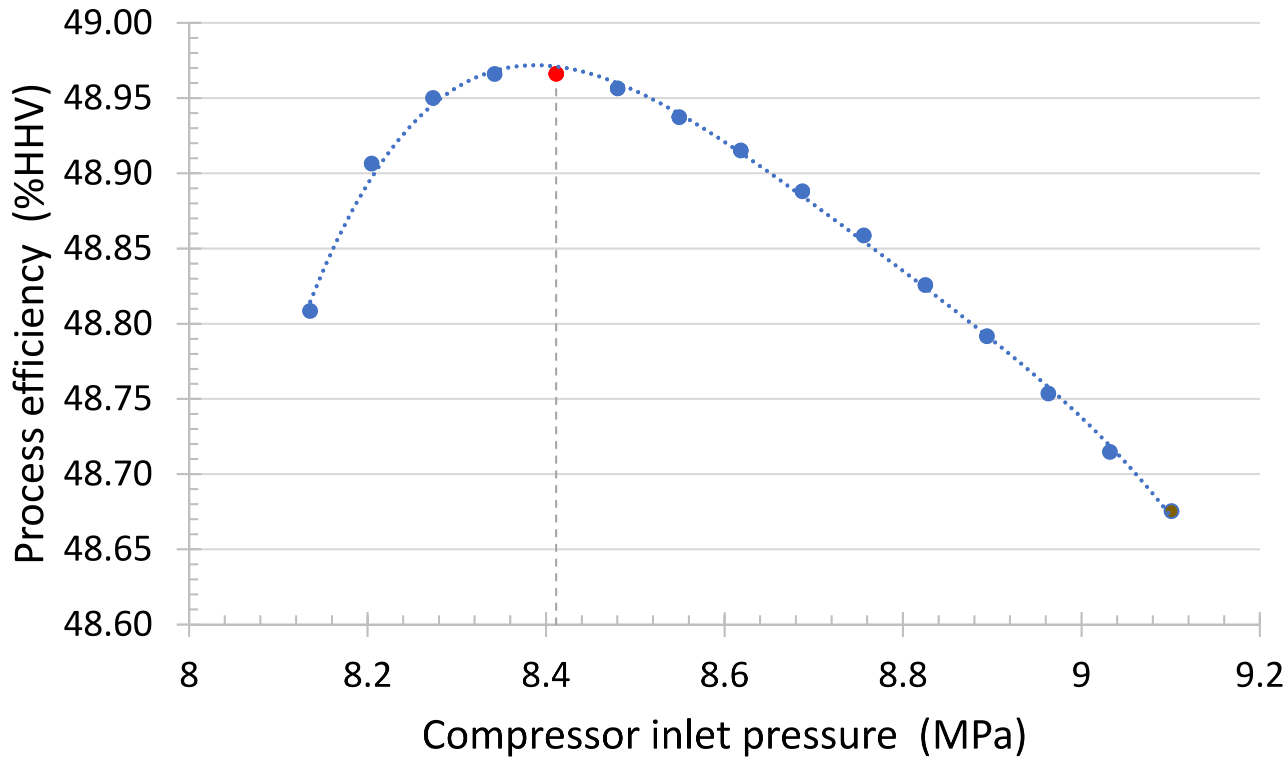
- **Process efficiency decreases monotonically and almost linearly with increasing minimum T_{app}**
- **COE passes through a minimum at a T_{app} of 6.7 °C**
  - Gray dashed vertical line and green marker
- **Result suggests that a lower COE could be attained with a higher minimum T_{app} of 6.7 °C**
  - However the 0.2 percentage point drop in process efficiency was deemed more significant than the negligible drop in COE



Sensitivity Analysis Results Summary

Main Compressor Inlet Pressure – Reference Case RhtIC760A

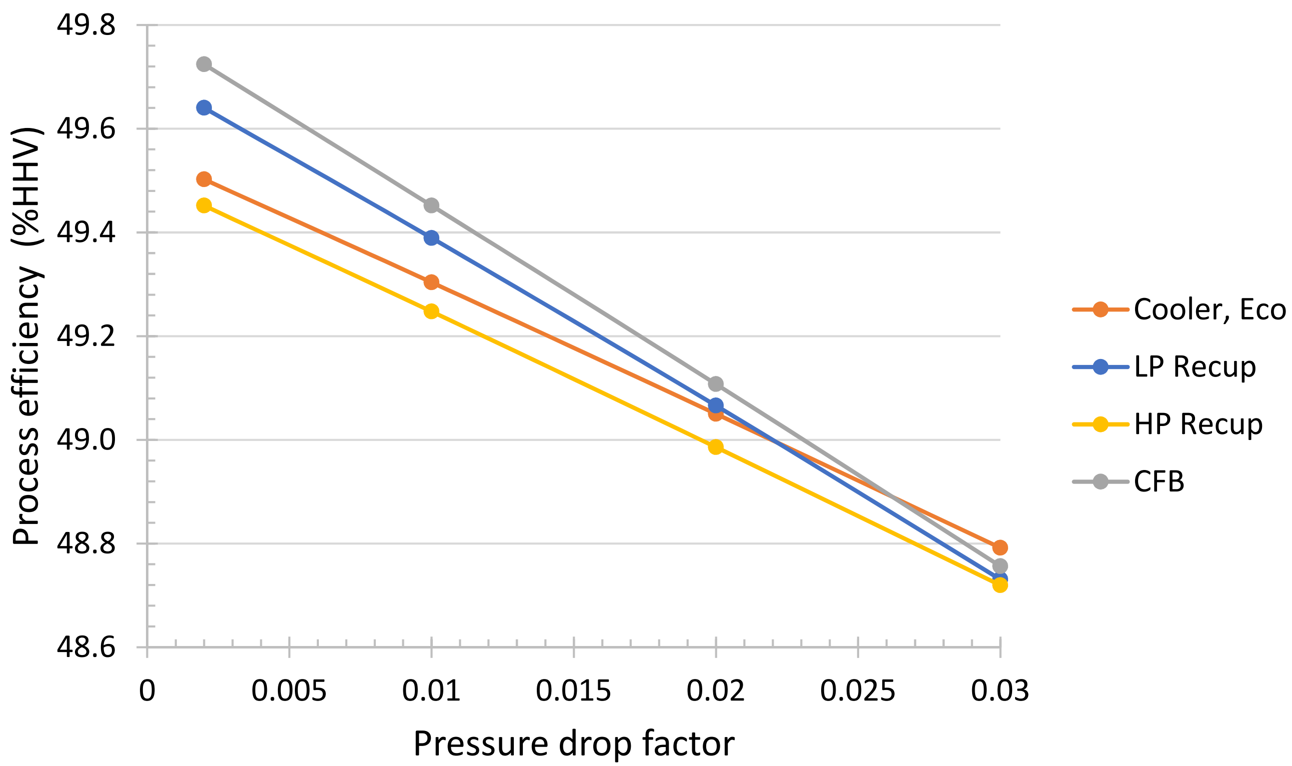
- **For any sCO_2 power cycle there is an optimum:**
  - Turbine inlet pressure
  - CO_2 compressor inlet pressure
- **Sensitivity analysis was performed on reference Case RhtIC760A to determine optimum cycle pressures**
- **Optimum turbine inlet pressure exceeds the maximum turbine inlet pressure constraint**
  - 34.5 MPa
- **Optimum compressor inlet pressure found to be 8.41 MPa**
  - Yielded maximum process efficiency
- **Optimum cycle pressure ratio = 4.1**



Sensitivity Analysis Results Summary

Unit Operation Pressure Drop – Reference Case RhtIC760A

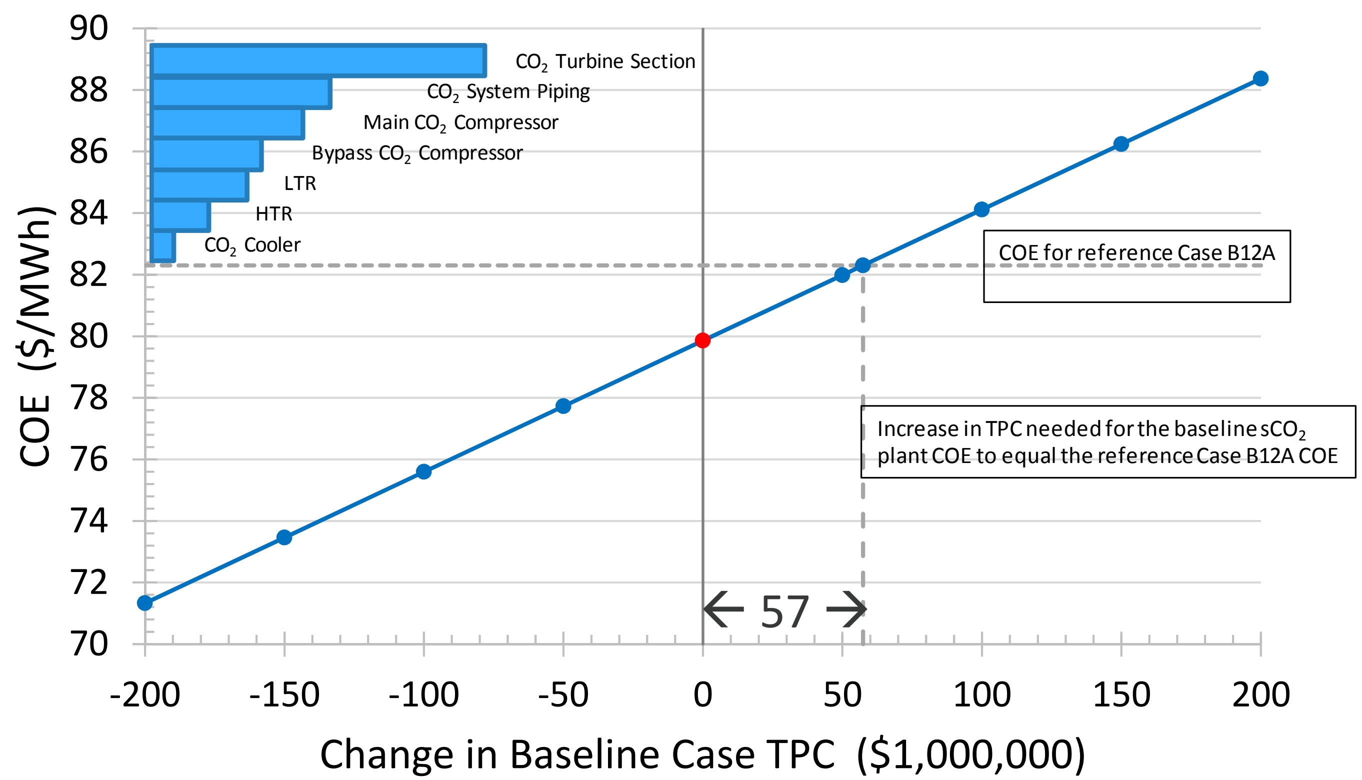
- **Pressure drops used for power cycle should be considered optimistic targets that were based on the desire to maximize process efficiency**
- **A performance only sensitivity analysis was performed on reference Case RhtIC760A to quantify the impact of pressure drop on process efficiency**
- **Independent variables were the pressure drop factors**
  - $\Delta P = P_{in} * \text{Factor}$
- **Pressure drop factors used were:**
  - 0.008 for the CO_2 cooler, CO_2 side of economizers and LP side of recuperators
  - 0.002 for HP side of recuperators
  - 0.01 for CO_2 side of the CFB
- **Process efficiency for sCO_2 power cycle is moderately sensitive to the pressure drop**
  - Particularly on the low-pressure side of the cycle
- **If more conservative pressure drop factors had been used (triple the optimistic values) the efficiency benefit of the Baseline Case compared to reference AUSC Case 5 would have been cut by 30%**



Sensitivity Analysis Results Summary

sCO_2 Power Cycle Component TPC, COE versus ΔTPC

- It is a study goal that the COE for the advanced technology power plants not exceed COE for reference Case B12A
- Horizontal bars are drawn to scale with respect to the horizontal axis
- For Baseline Case COE to equal reference Case B12A requires either:
  - 57 $MM increase in the aggregate TPC
  - 5 percent increase in the aggregate TPC
  - 17 percent increase in power cycle TPC
  - 49 percent increase in turbine TPC
  - 107 percent increase in recuperator TPC



Summary & Conclusions

- **This paper has presented the results of a preliminary examination of the potential benefits of the indirect sCO_2 power cycle for improving the efficiency and cost of non-capture coal-fired power plants**
- **Results have shown that the sCO_2 power cycle can achieve much higher efficiencies than SOA PC/Rankine systems with no increase in COE**
- **Compared to prior NETL systems studies on advanced power generation technologies (e.g., PC power plant with an AUSC Rankine cycle) the sCO_2 power cycle offers a significant increase in overall efficiency of greater than 5 percentage points**
- **Full-load, steady-state carbon dioxide (CO_2) emissions of 1353 lbs CO_2/MWh gross nominally meets the current EPA's 1400 lbs CO_2/MWh gross for new coal plants**
    - However, the EPA's standard is based on average annual emissions – additional analyses are required to assess system performance under realistic annual operating profiles, including part-load
- **The study has also shown that plants based on the sCO_2 power cycle have significantly lower (22-33%) water consumption than comparable reference Rankine cycle plants**
    - Due to higher thermal efficiencies of the sCO_2 plants
    - Elimination of intrinsic water losses arising from the Rankine cycle such as from blowdown

Ongoing and Future sCO_2 System Analysis

FY18-FY19

- **Continue to explore the indirect sCO_2 power cycle with the goals of**
  - Expanding its range of application
  - Further optimizing its performance and cost
  - Reducing the current level of uncertainty in the performance and cost models
  - Exploring more complex aspects of the cycle development related to system dynamics
- **One current study is exploring in greater detail the impacts of various cooling technology options on the cycle and overall plant performance**
  - Goal is to optimize the cooling technology choice for any given ambient condition or site location
- **Other concepts planned for near-term examination are based on the results of the sensitivity analyses performed in this study and include:**
  - Investigations of condensing cycles
  - Conducting a more thorough optimization of the cycle parameters including individual minimum temperature approaches for each end of every recuperator, economizer, and intercooler
  - Better defining the trade-off between process efficiency gains and capital cost results from pressure drops in the cycle unit operations

For More Information …

- **National Energy Technology Laboratory (NETL), "Development of Coal-Fueled Indirect sCO_2 Systems without CO_2 Capture", DOE/NETL report in preparation.**

- Charles W. White, Principal Engineer, KeyLogic, Charles.W.White@netl.doe.gov
- Walter W. Shelton, General Engineer, U.S.DOE-NETL, Walter.Sheltons@netl.doe.gov
- Nathan T. Weiland, General Engineer, U.S.DOE-NETL, Nathan.Weiland@netl.doe.gov
- Travis R. Shultz, Supervisor, EPAT, U.S.DOE-NETL, Travis.Shultz@netl.doe.gov