Use of Waste Heat and CO_2 Compression Heat to Reduce Penalty due to Post-Combustion CO_2 Capture

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Presentation Outline

- *Project goals and objectives*
- *Modeling and optimization of MEA CO_2 capture process using ASPEN Plus.*
- *Boiler-Turbine Cycle Integration*
  - *Feedwater Heating (FWH)*
  - *Advanced Air Preheating*
  - *Steam turbine cycle modeled by PEPSE*
- *Integration of CO_2 scrubber with waste heat sources.*
- *Integration of CO_2 compression train and turbine cycle.*
- *Partial CO_2 scrubbing*
- *Conclusions*

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Project Goals and Objectives

- Determine efficiency improvements that can be achieved at **existing power plants** by using heat recovered from flue gas and CO_2 compression heat to partially offset efficiency and capacity losses due to post-combustion CO_2 capture retrofit.
  - Optimize MEA CO_2 capture process to reduce reboiler thermal duty and cooling loads.
  - Use heat recovered from flue gas and CO_2 compression heat to improve performance of steam cycle.
  - Integrate CO_2 stripper with plant waste heat sources to reduce steam extraction from LP turbine for solvent regeneration and process energy requirements for CO_2 capture.
    - Investigate thermal integration options
  - Investigate partial CO_2 scrubbing and determine its effect on unit efficiency and capacity.
- Analyses performed for 600 MW subcritical PC-fired unit

Modeling and Optimization of MEA CO_2 Capture Process Using Aspen Plus

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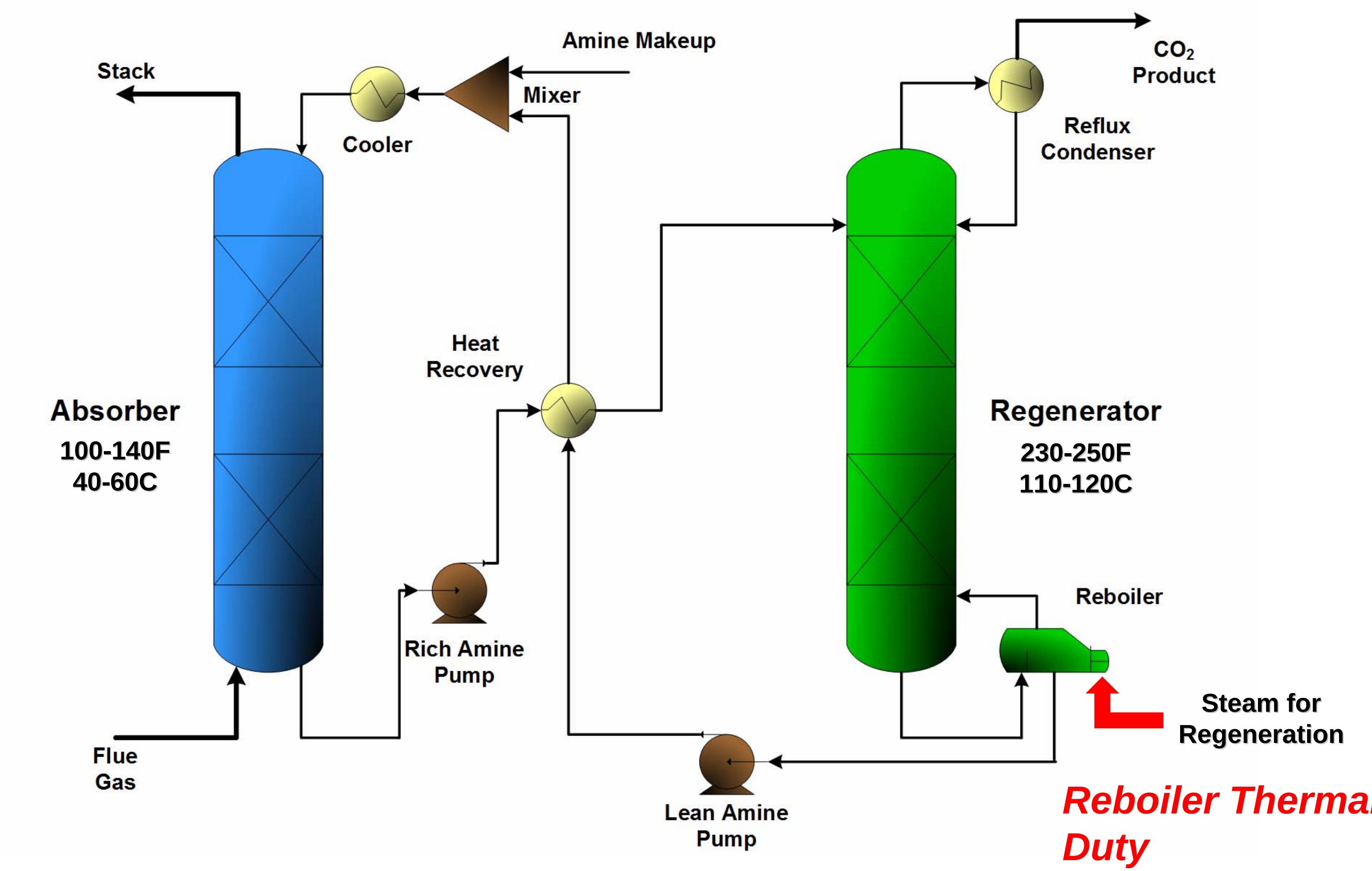
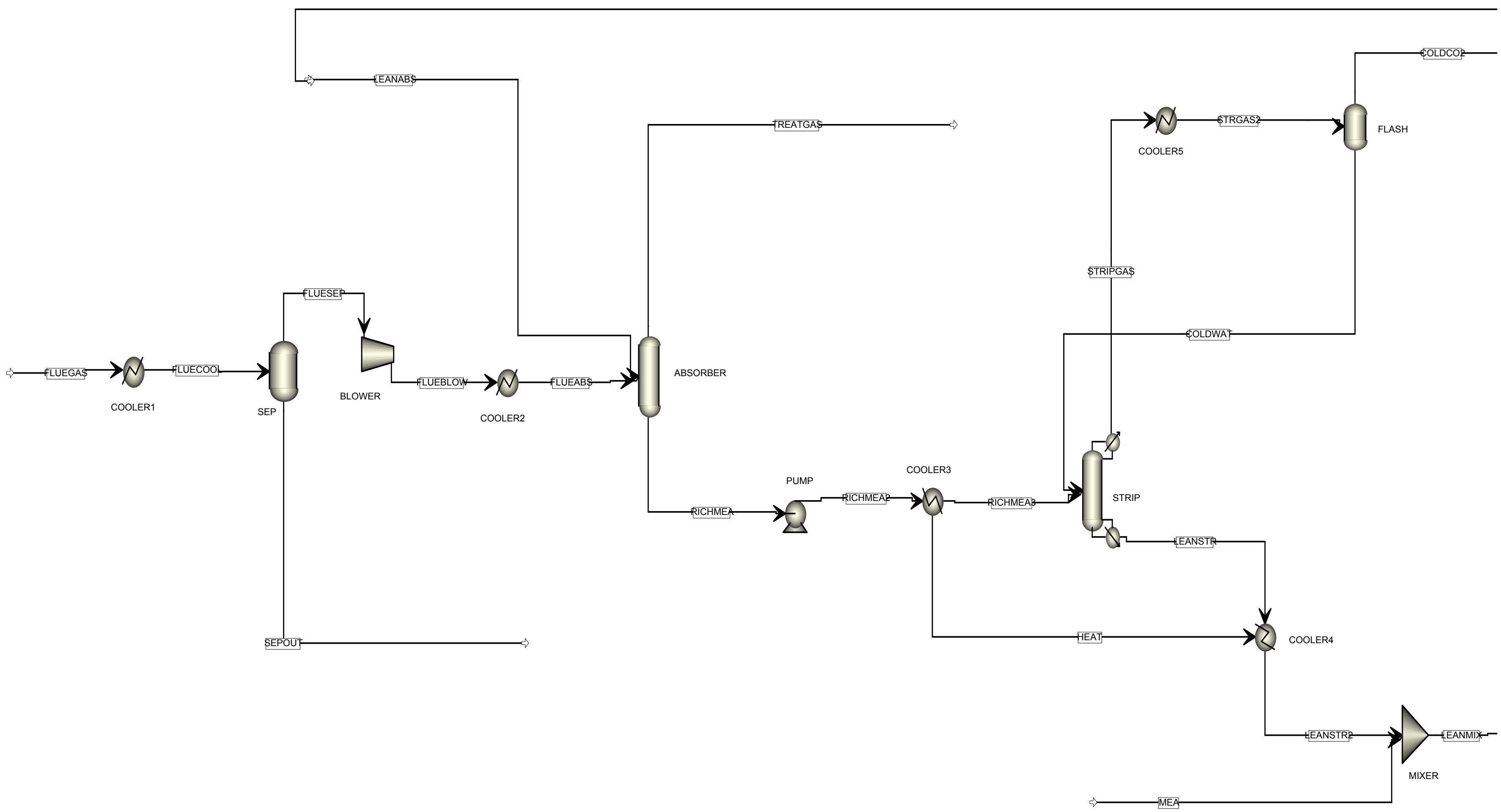
Conventional Amine (MEA) CO_2 Capture Process



Reboiler Thermal Duty

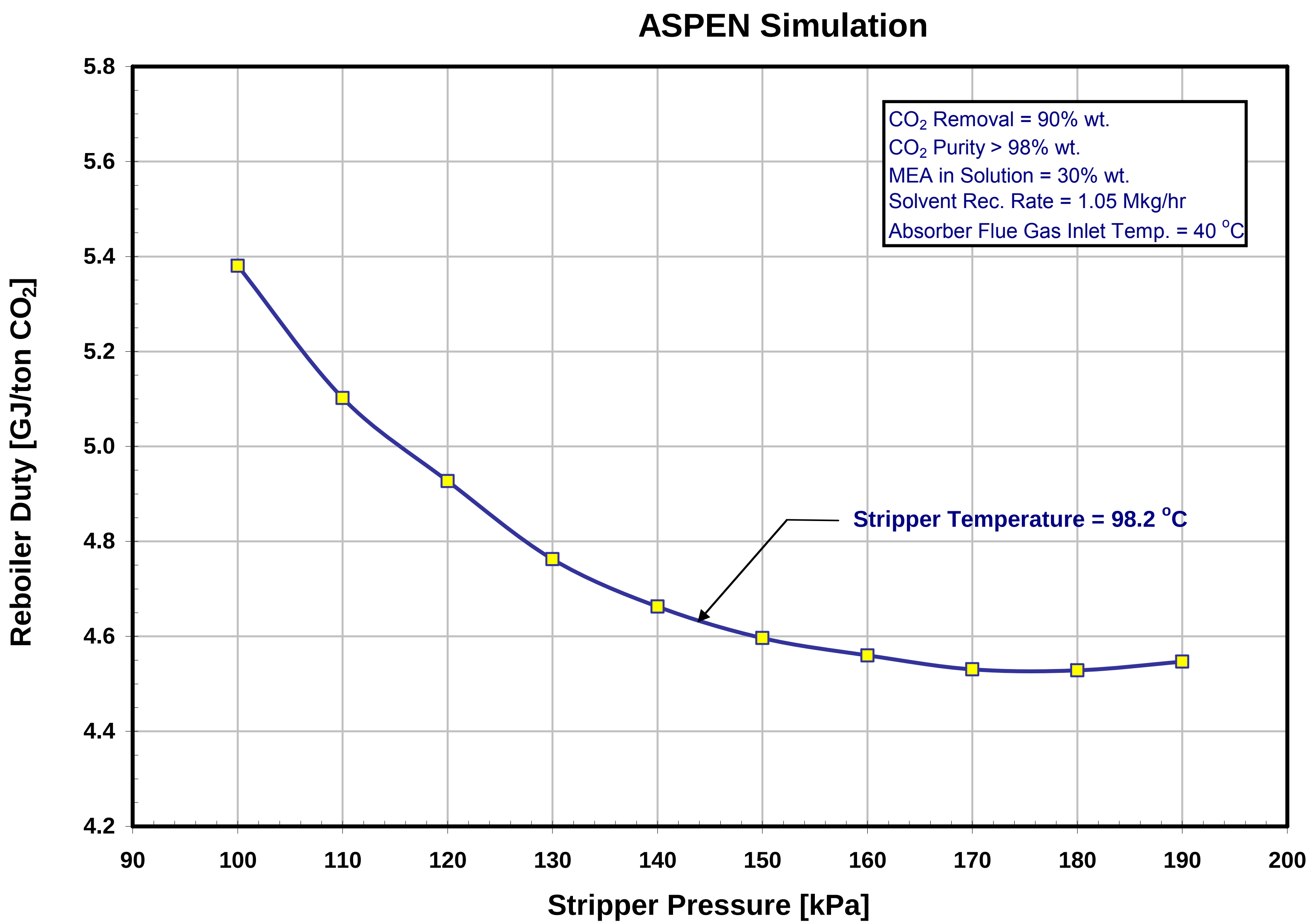
ASPEN Plus Model Diagram of MEA-CO_2 Capture Process



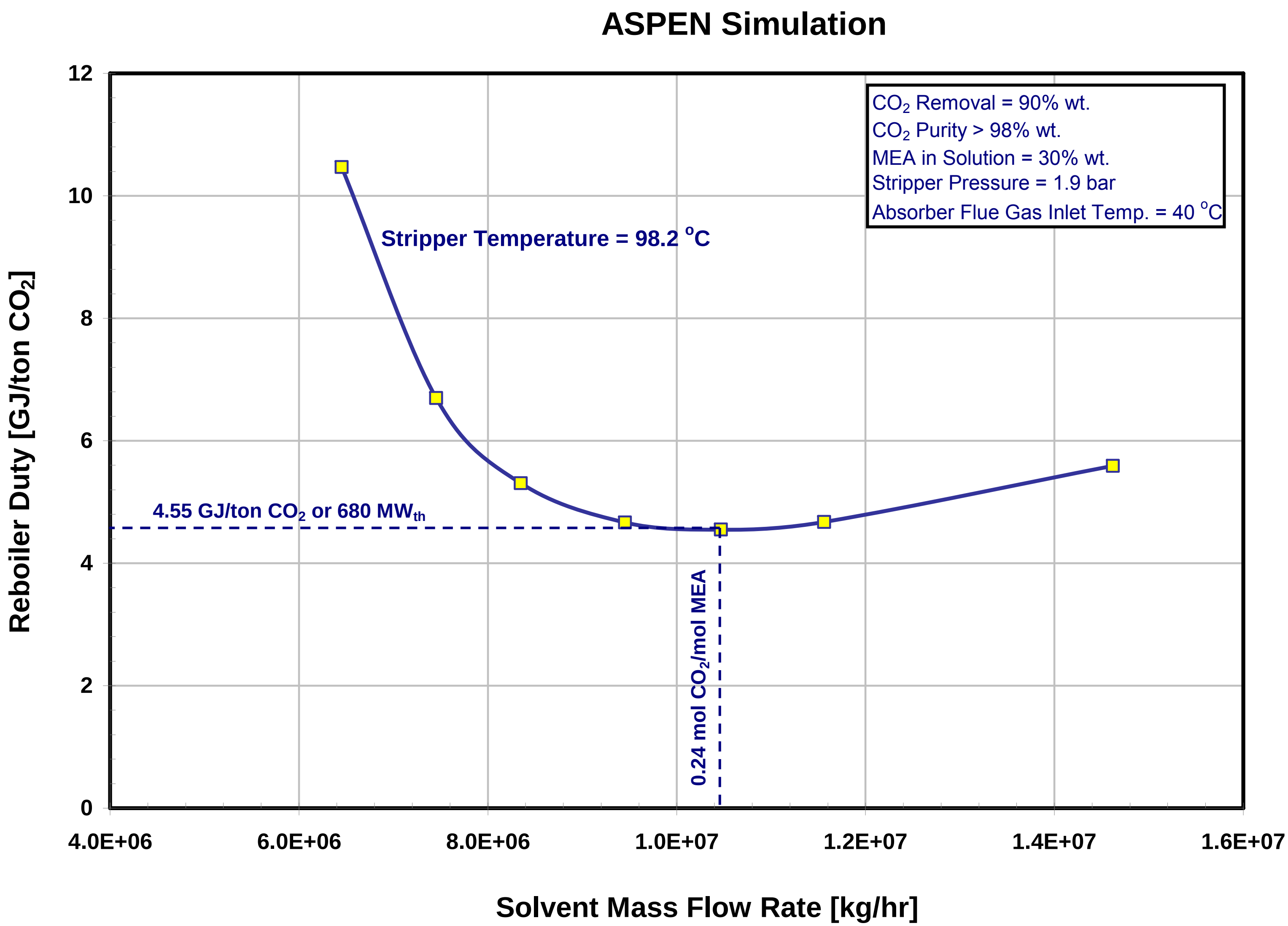
Parametric Study: Minimization of Reboiler Thermal Duty

- *Sensitivity analysis was performed where parameters affecting performance of CO_2 capture process were varied to improve performance of MEA CO_2 capture process and **minimize reboiler thermal duty**.*
- *The following process parameters were varied:*
  - *CO_2 stripper operating pressure.*
  - *Solvent circulation rate/CO_2 lean solvent loading (mol CO_2/mol MEA).*
  - *MEA weight percentage in absorption solvent.*
  - *CO_2 removal percentage.*
  - *Flue gas/lean solvent temperature.*

Effect of CO_2 Stripper Pressure on Reboiler Thermal Duty



Effect of Solvent Mass Flow Rate on Reboiler Thermal Duty



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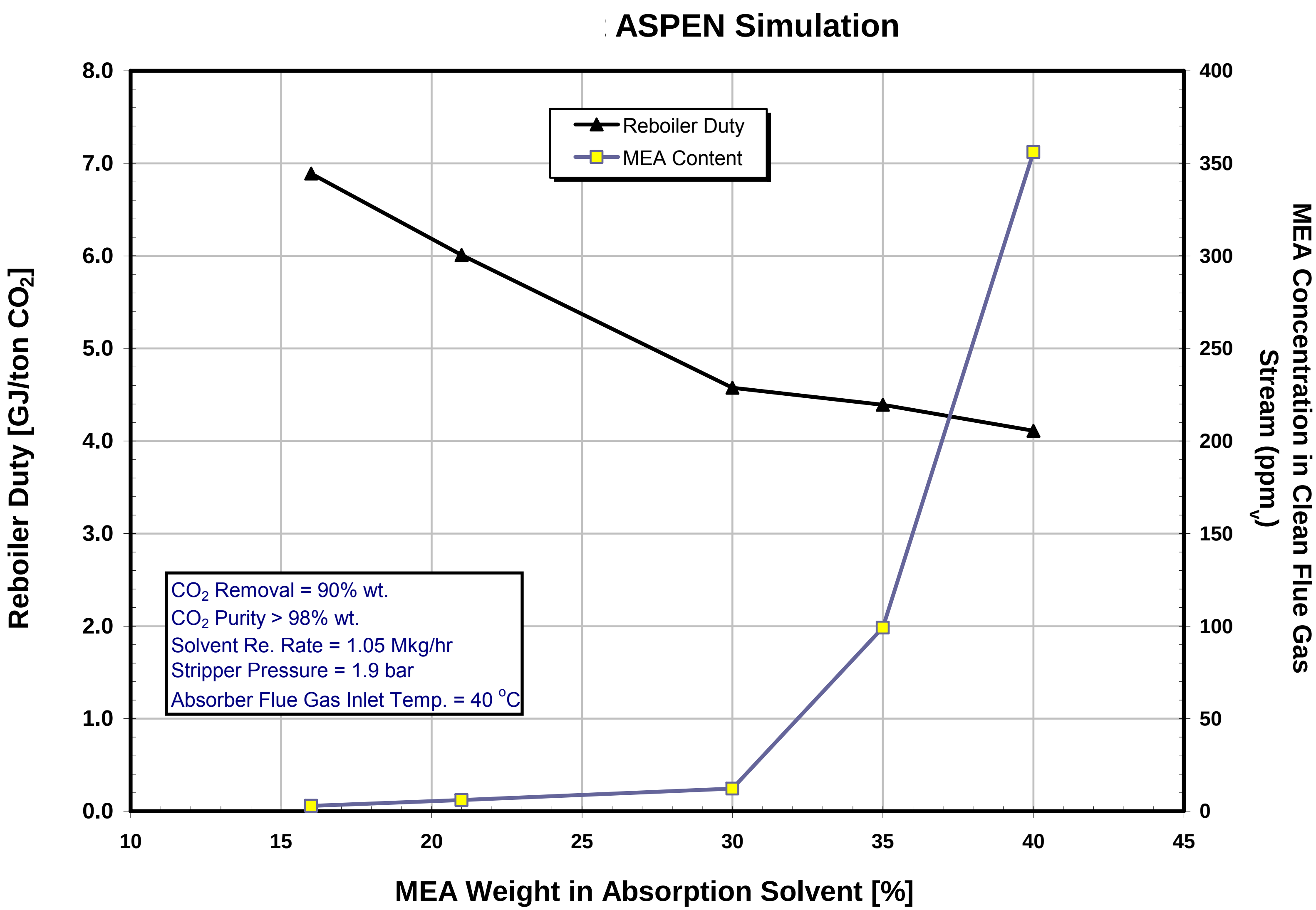
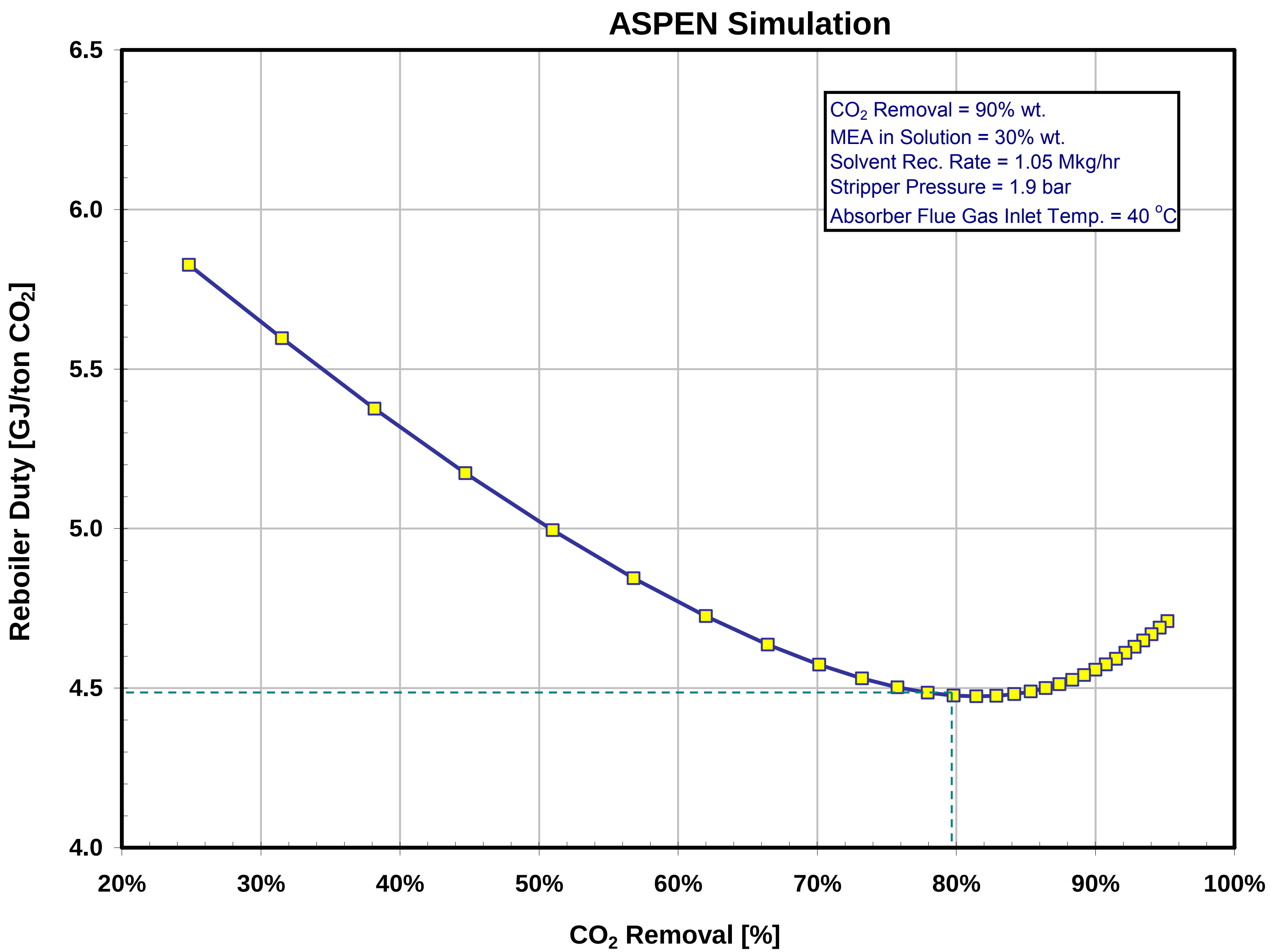
Effect of MEA Concentration in Solvent on Reboiler Thermal Duty



Effect of CO_2 Removal on Reboiler Thermal Duty



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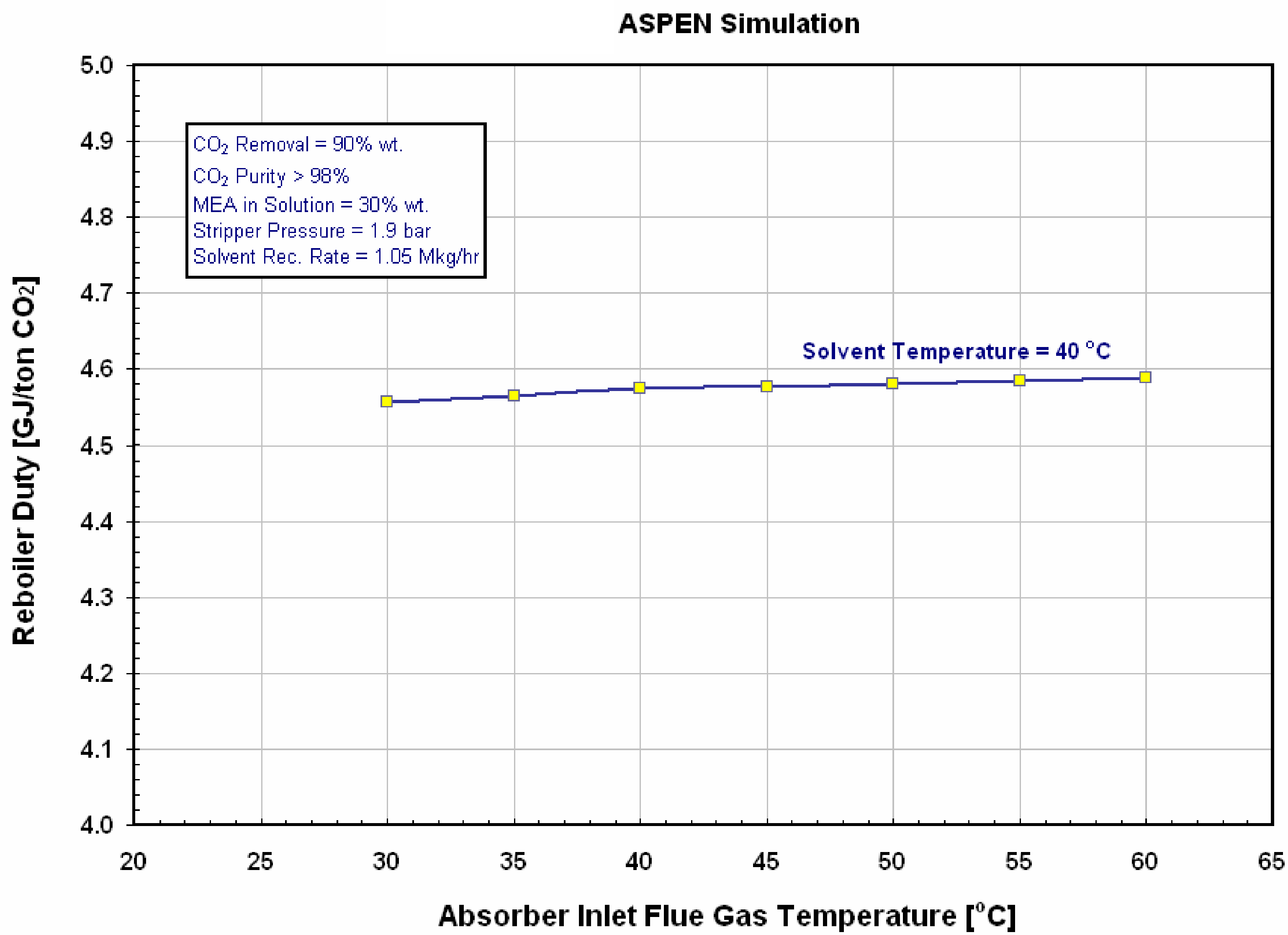
Effect of Absorber Inlet Flue Gas Temp. on Reboiler Thermal Duty



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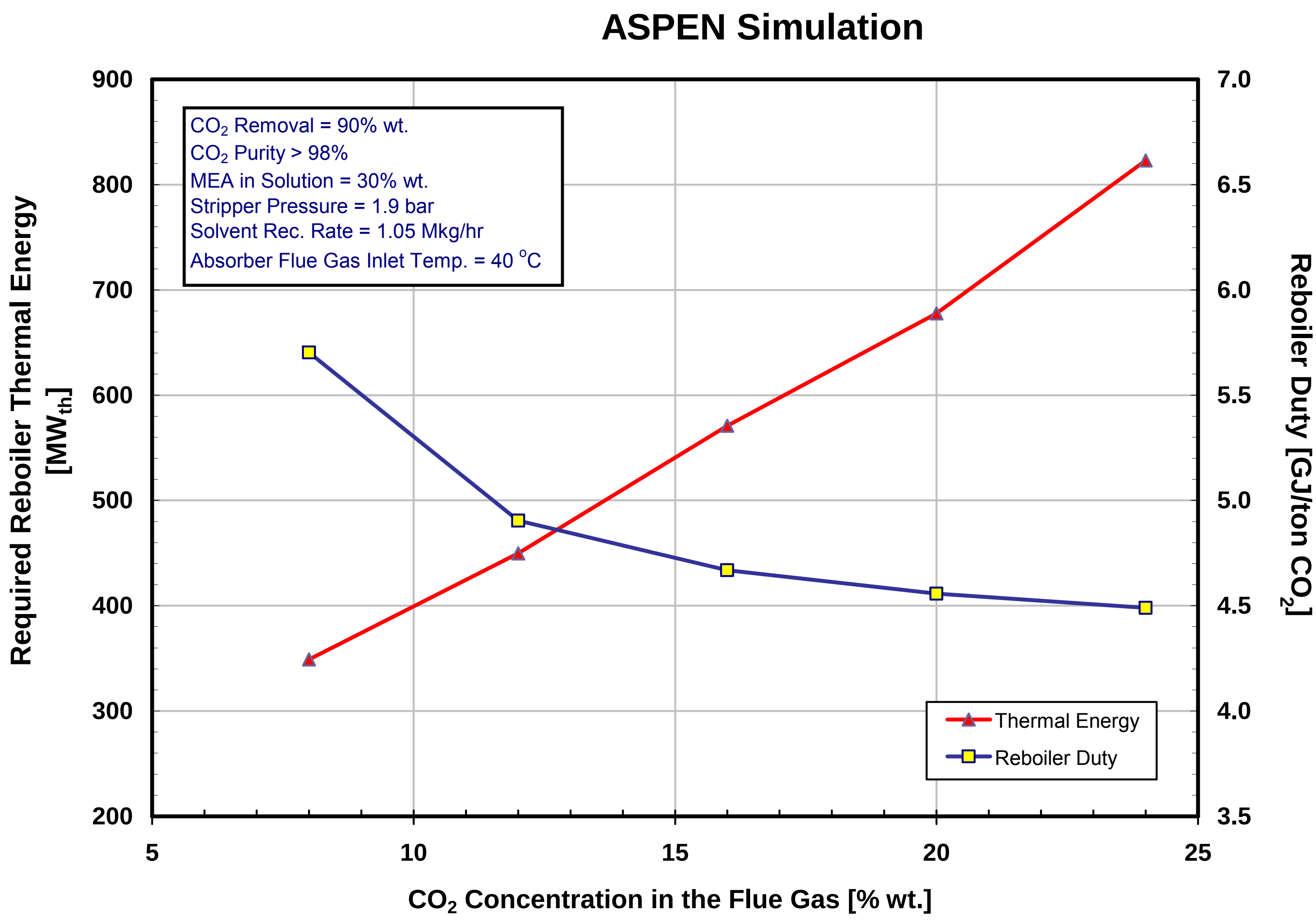
Effect of CO_2 Concentration in Flue Gas on Reboiler Thermal Duty



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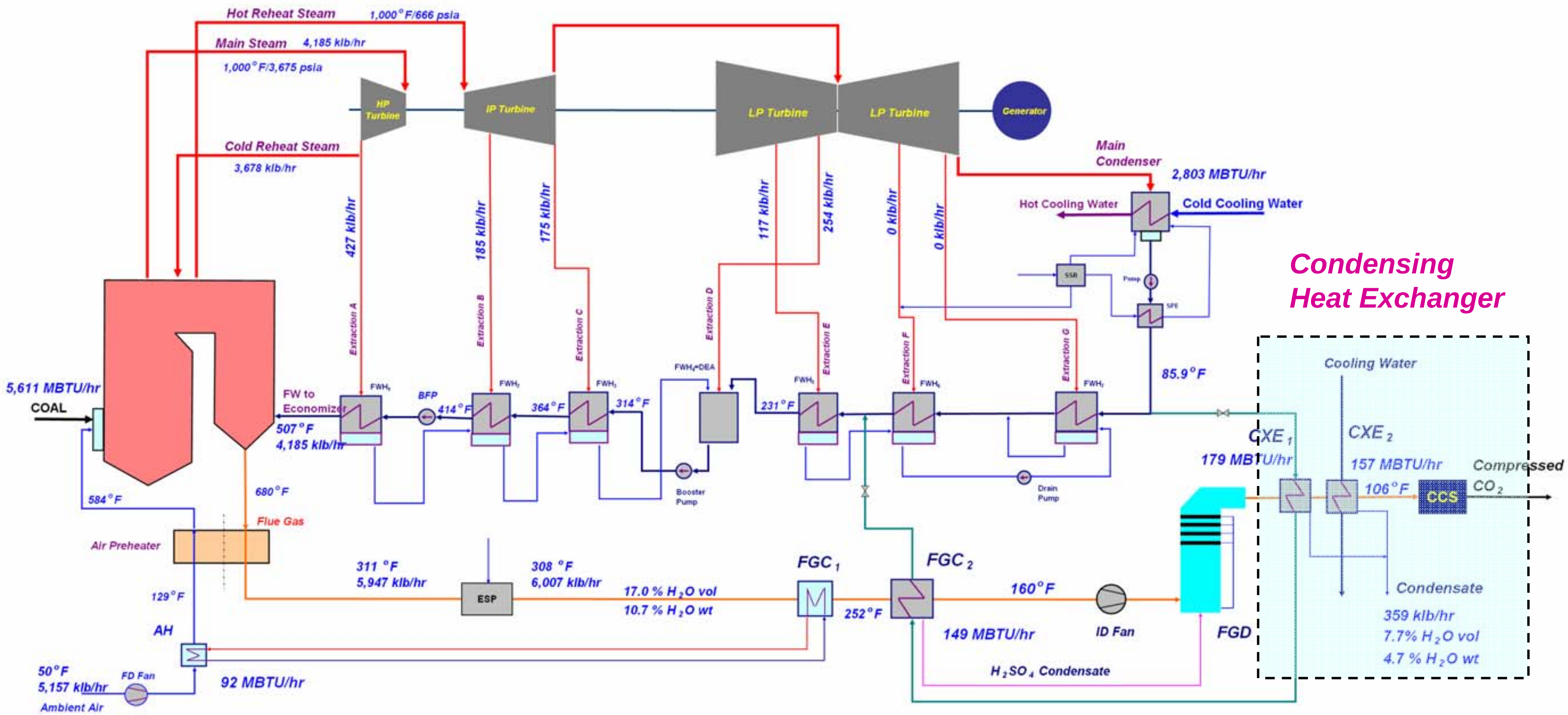
Feedwater Heating & Advanced Air Preheating with Two-Stage CXE for CCS



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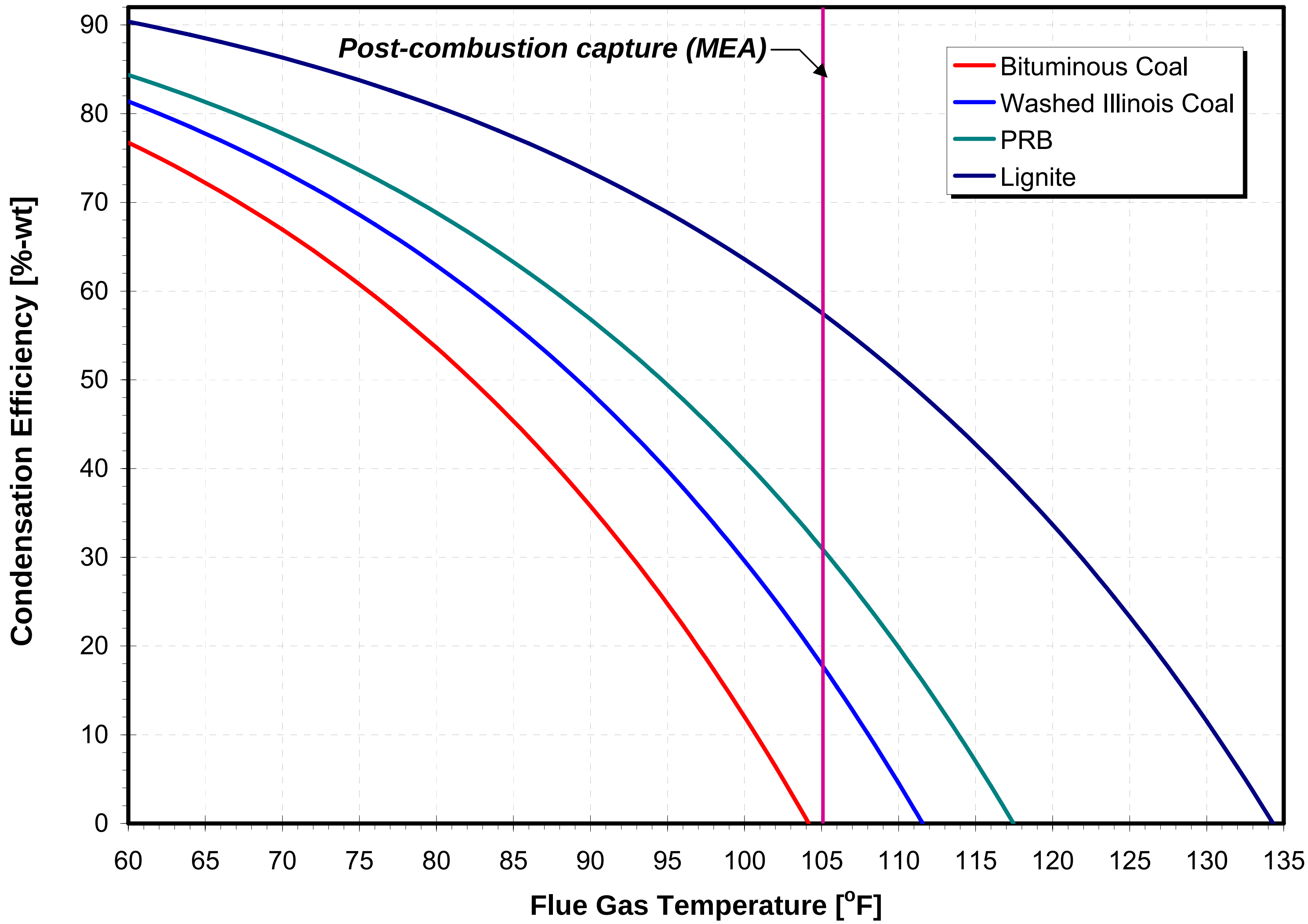
CXE: Condensation Efficiency

Condensation Efficiency = Percentage of flue gas moisture condensed out the flue gas stream



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Optimization Results

MEA System Optimal Operating Point	
Flue Gas Mass Flow Rate (t/h)	3049.9
Solvent Mass Flow Rate (t/h)	10827.4
MEA Conc. n Absorption Liquid (wt. %)	30.0
Amine Rich Loading (mol CO2/mol MEA)	0.480
Amine lean Loading(mol CO2/mol MEA)	0.240
Stripper Reboiler Temperature (deg. C)	121.1
Stripper Condenser Temperature (deg. C)	100.3
Stripper pressure (bar)	1.9
Bottom to Feed Molar Ratio	0.975
Reboiler Heat Required (MW)	677.6
Reboiler Duty (GJ/hr)	2439.3
Reboiler Duty (GJ/t CO2)	**4.56**
CO2 Removal (wt. %)	90.0%
CO2 Purity (wt.%)	98.4%
Mass Flow Rate of CO2 Captured (t/hr)	535.3
MEA Conc. on Clean Flue Gas (ppm)	122.0
CO2 Conc. on Clean Flue Gas (ppm)	1.01

MEA System Worst Operating Point	
Flue Gas Mass Flow Rate (t/h)	3049.9
Solvent Mass Flow Rate (t/h)	10792.9
MEA Conc. n Absorption Liquid (wt. %)	30.0
Amine Rich Loading (mol CO2/mol MEA)	0.480
Amine lean Loading(mol CO2/mol MEA)	0.240
Stripper Reboiler Temperature (deg. C)	103.0
Stripper Condenser Temperature (deg. C)	96.3
Stripper pressure (bar)	1.0
Bottom to Feed Molar Ratio	0.905
Reboiler Heat Required (MW)	855.5
Reboiler Duty (GJ/hr)	2794.0
Reboiler Duty (GJ/t CO2)	**5.76**
CO2 Removal (wt. %)	90.0%
CO2 Purity (wt.%)	98.4%
Mass Flow Rate of CO2 Captured (t/hr)	534.4
MEA Conc. on Clean Flue Gas (ppm)	330.1
CO2 Conc. on Clean Flue Gas (ppm)	1.01

- *26.3% reduction in reboiler thermal duty*

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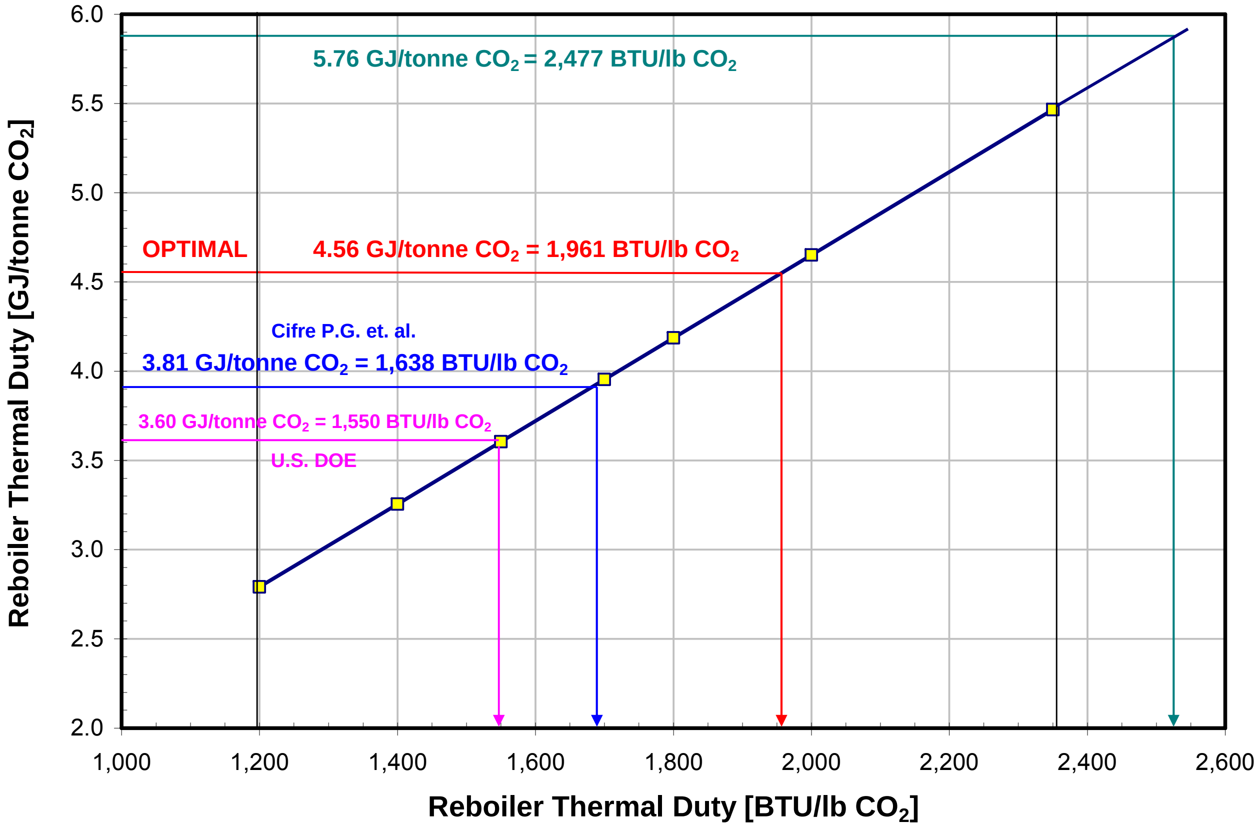
Integration of CO_2 Scrubber with Heat Sources:

600 MW Subcritical PC-Fired Unit

Heat Integration of CO_2 Scrubber

- *Analysis performed over range of reboiler thermal duties*

Reboiler Thermal Duty	
BTU/lb CO_2	GJ/tonne CO_2
2,350	5.47
2,000	4.65
1,800	4.19
1,700	3.95
1,550	3.60
1,400	3.26
1,200	2.79



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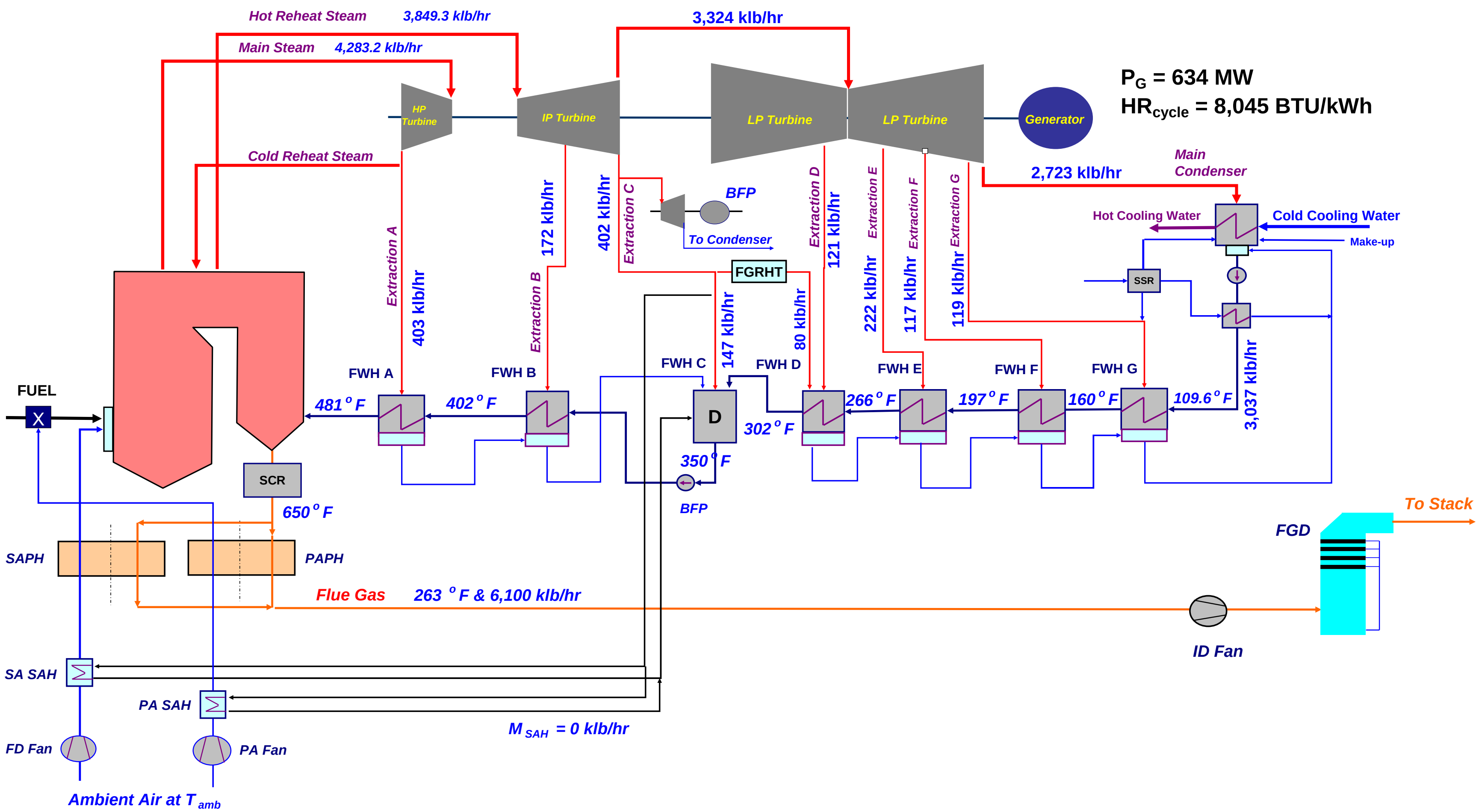
Baseline Unit Configuration



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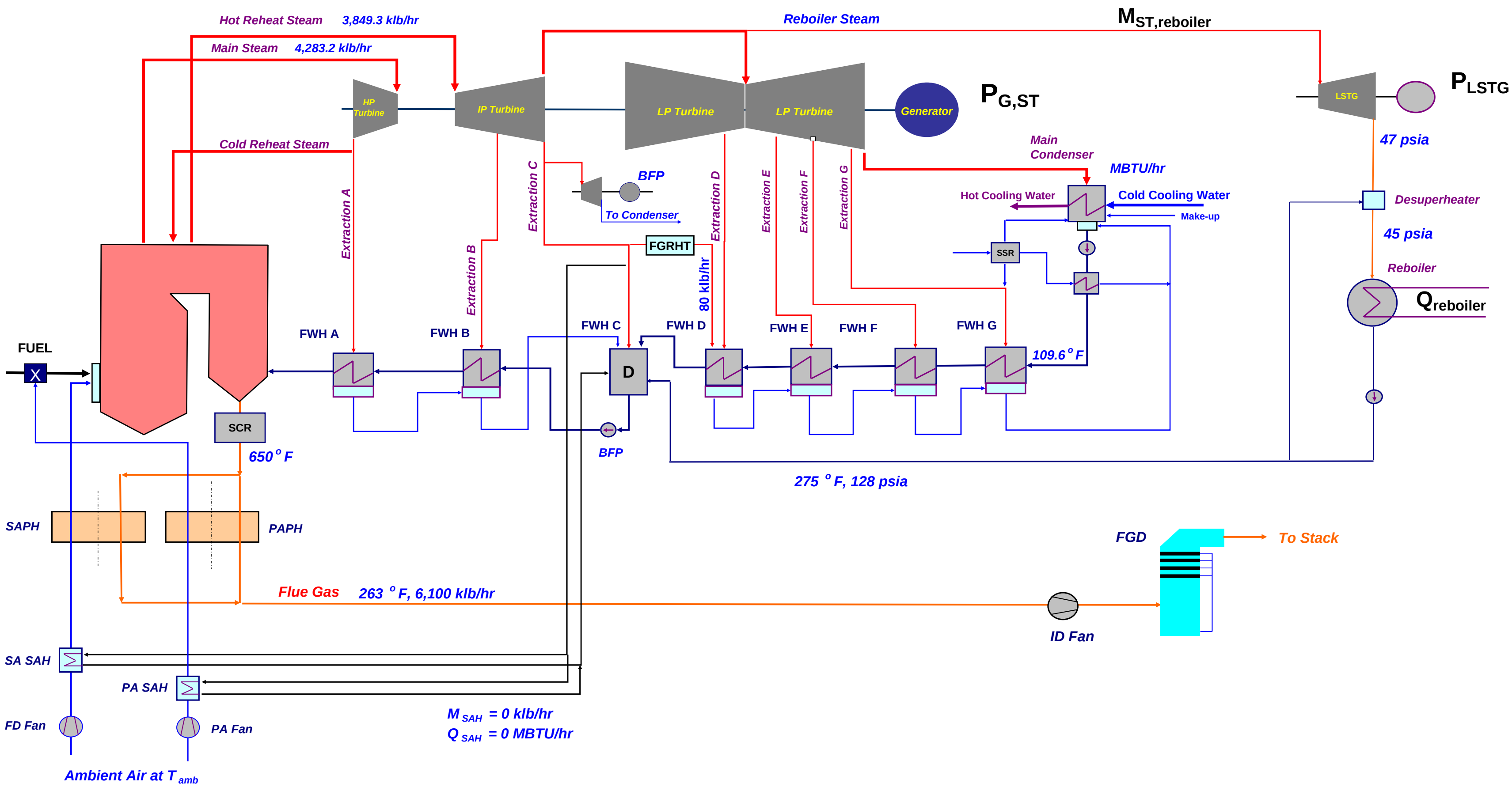
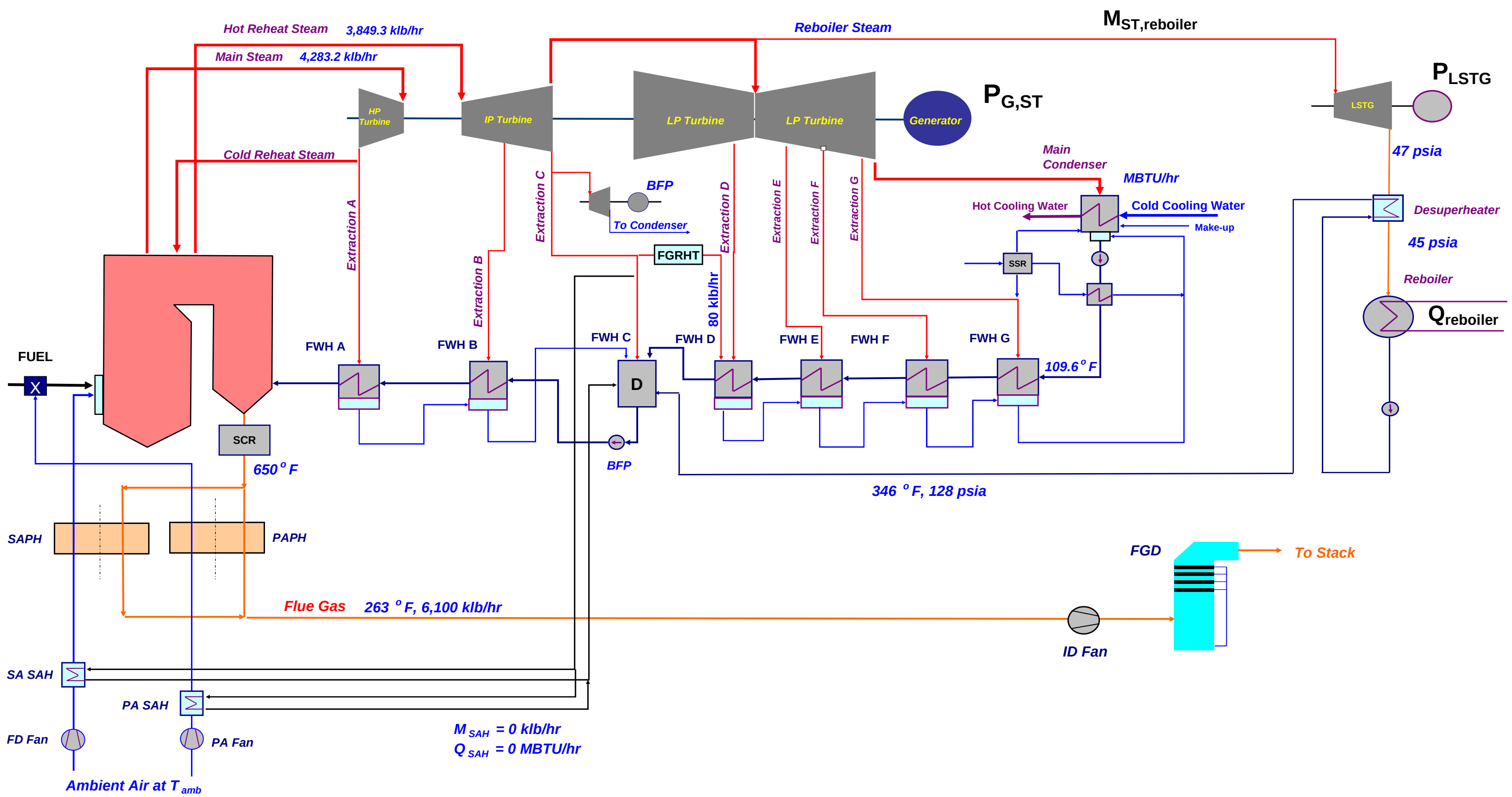
Case 1: Conventional Reboiler Integration with Steam Turbine Cycle



Case 2: Advanced Reboiler Integration with Steam Turbine Cycle



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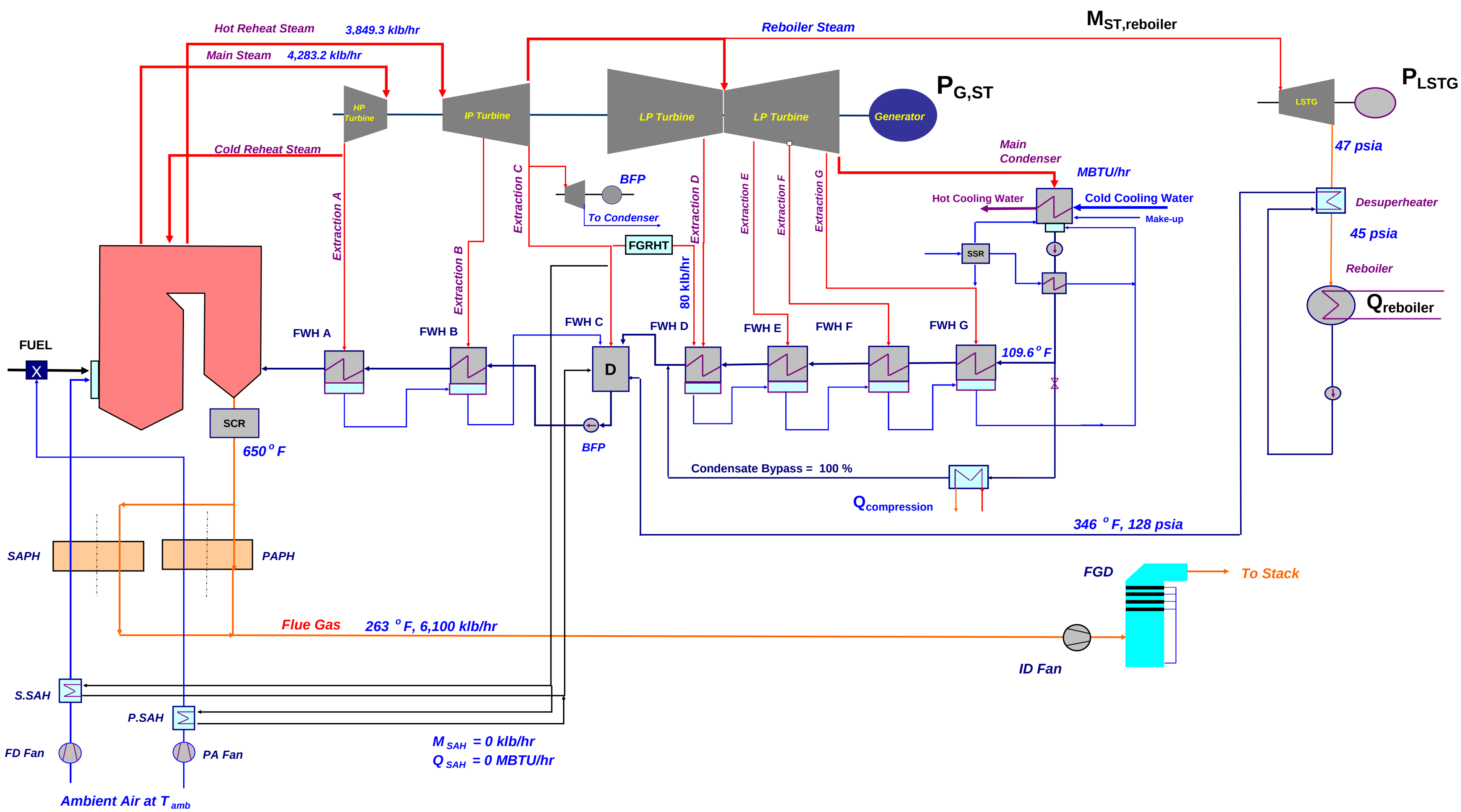
Case 3: Integration of Reboiler and CO_2 Compression with Steam Turbine Cycle



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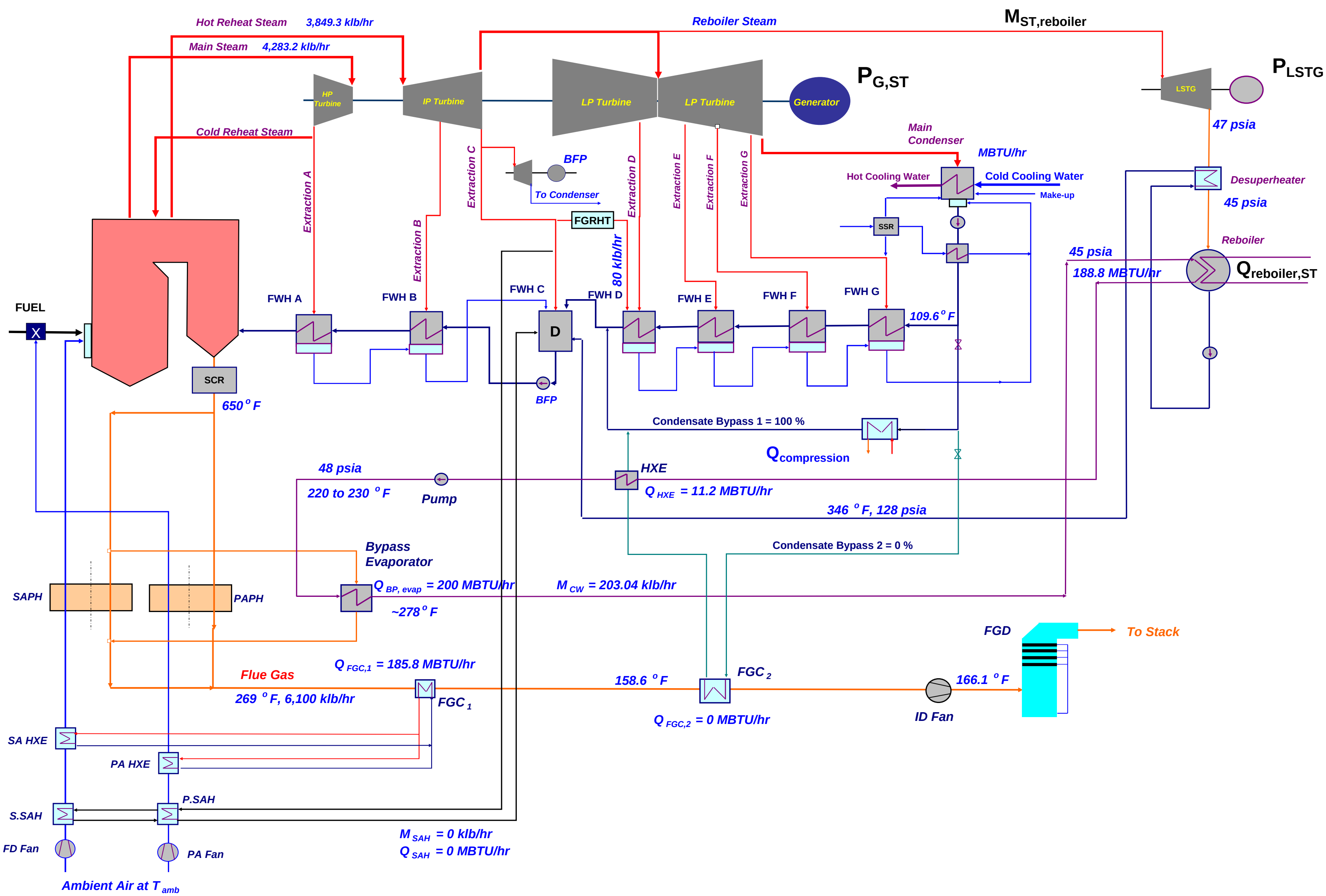
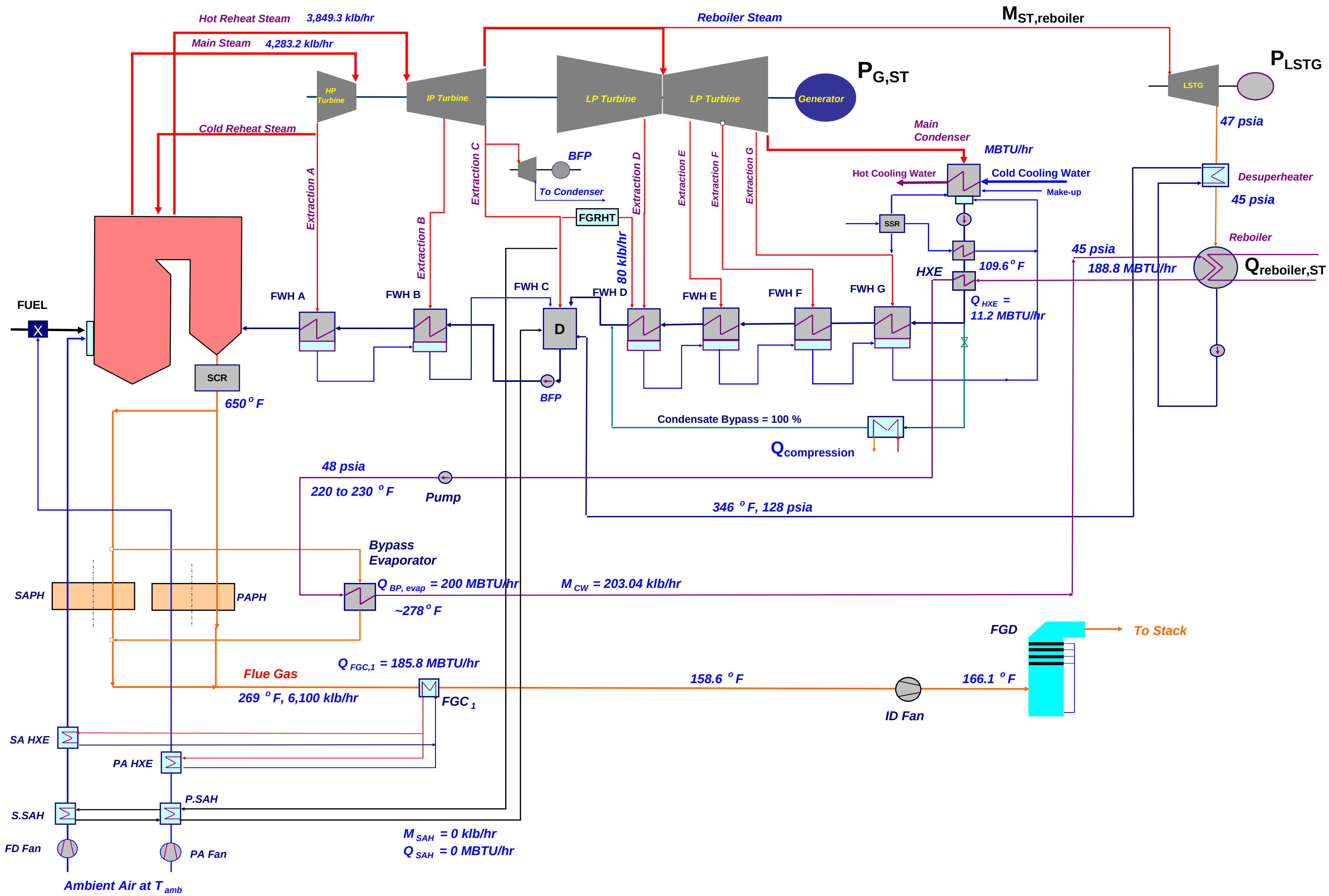
Case 4: Integration of Boiler, Reboiler and CO_2 Compression with Steam Turbine Cycle



Case 4a: Integration of Boiler, Reboiler and CO_2 Compression with Steam Turbine Cycle



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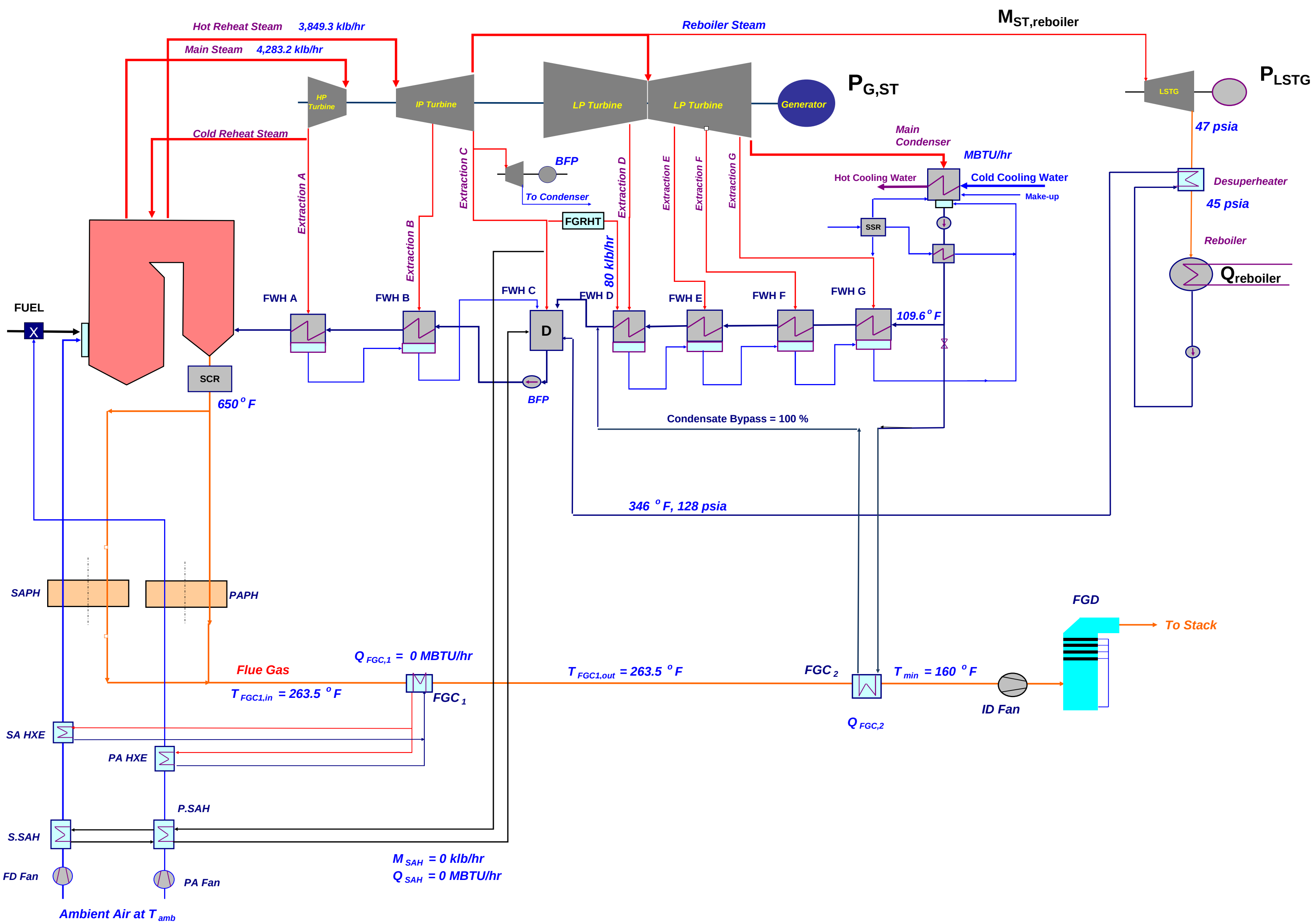
Case 5: Integration of Boiler and Reboiler with Steam Turbine Cycle



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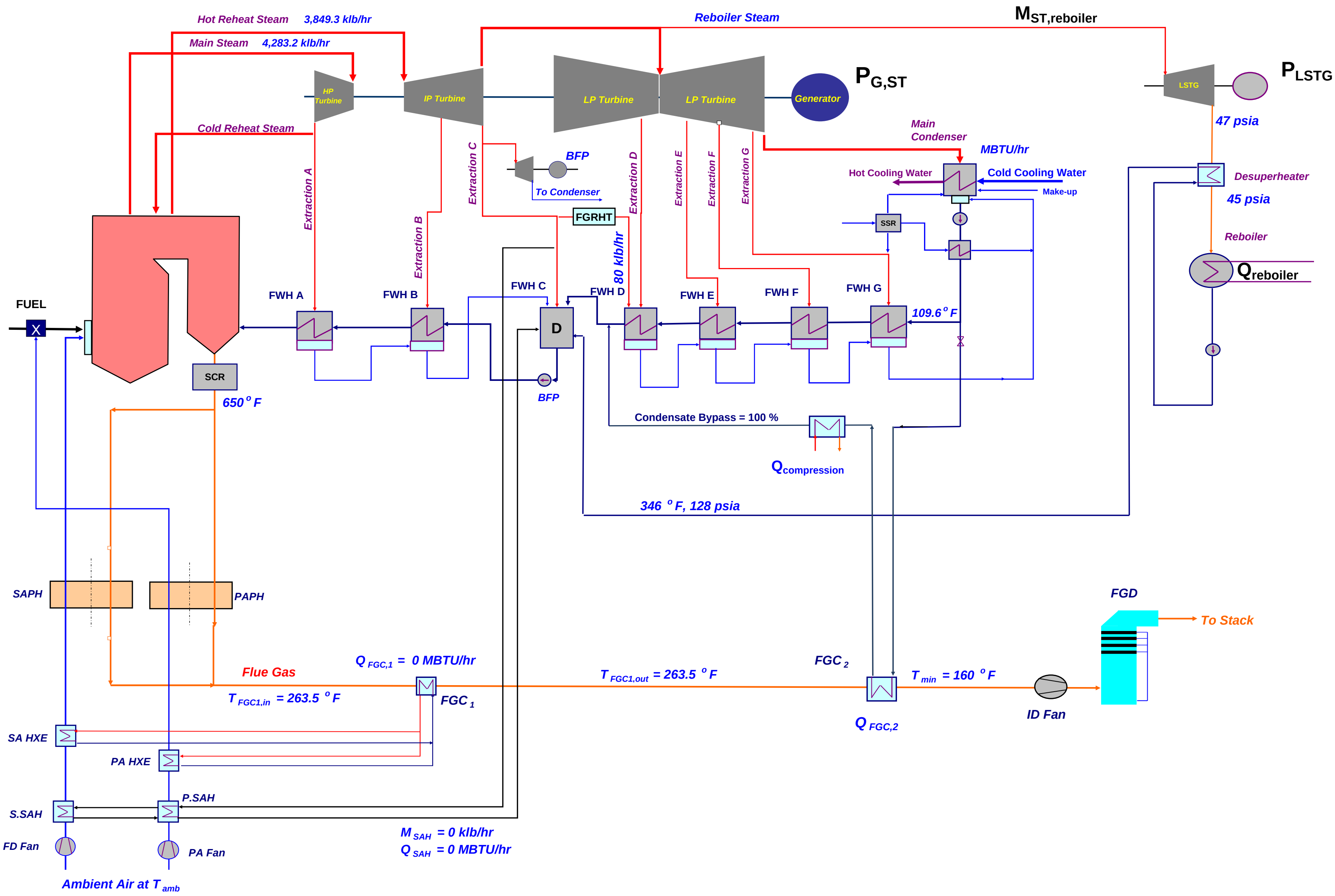
Case 6: Integration of Boiler, Reboiler and CO_2 Compression with Steam Turbine Cycle



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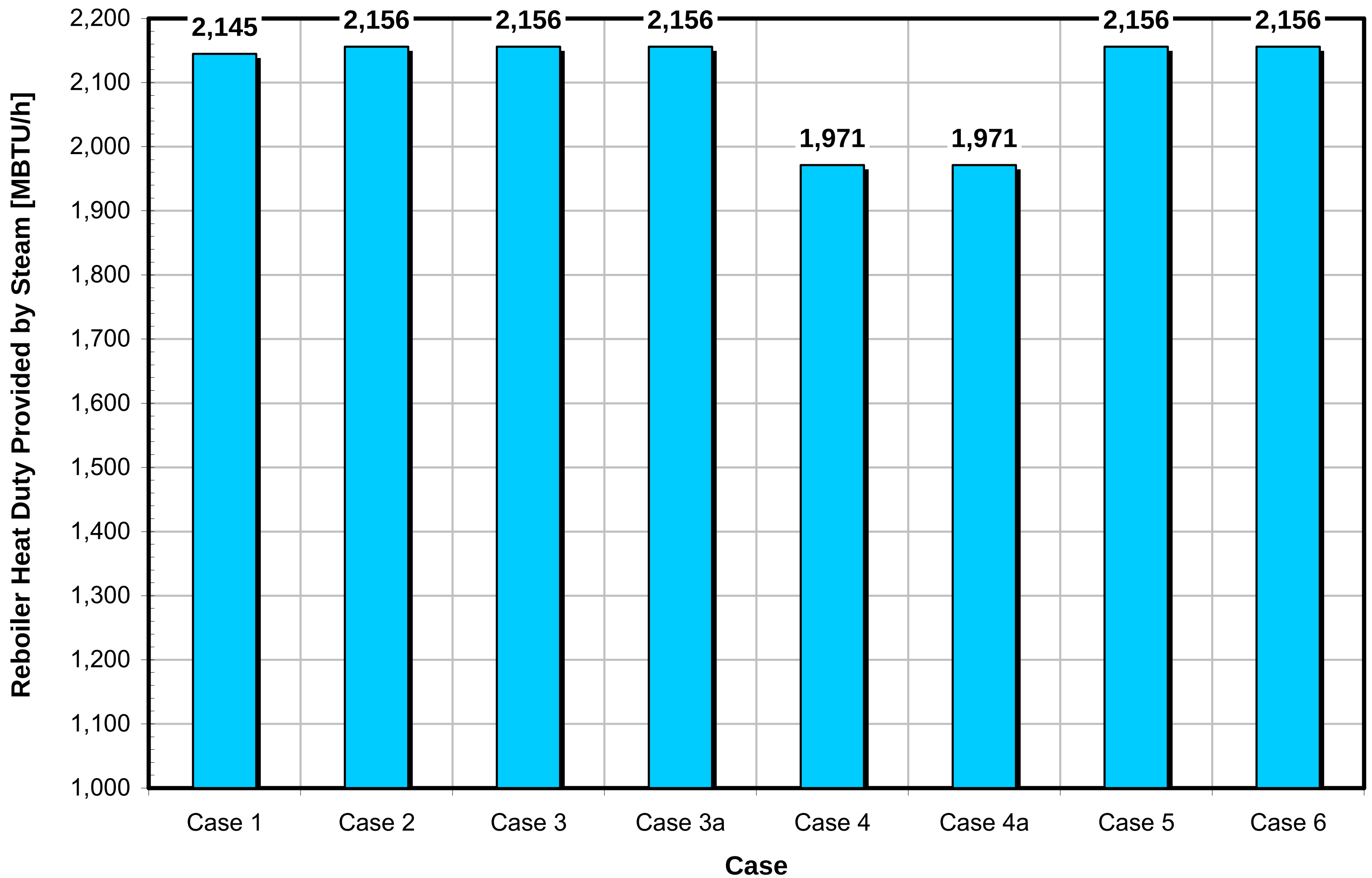
Results for q_{reb} = 2,000 BTU/lb



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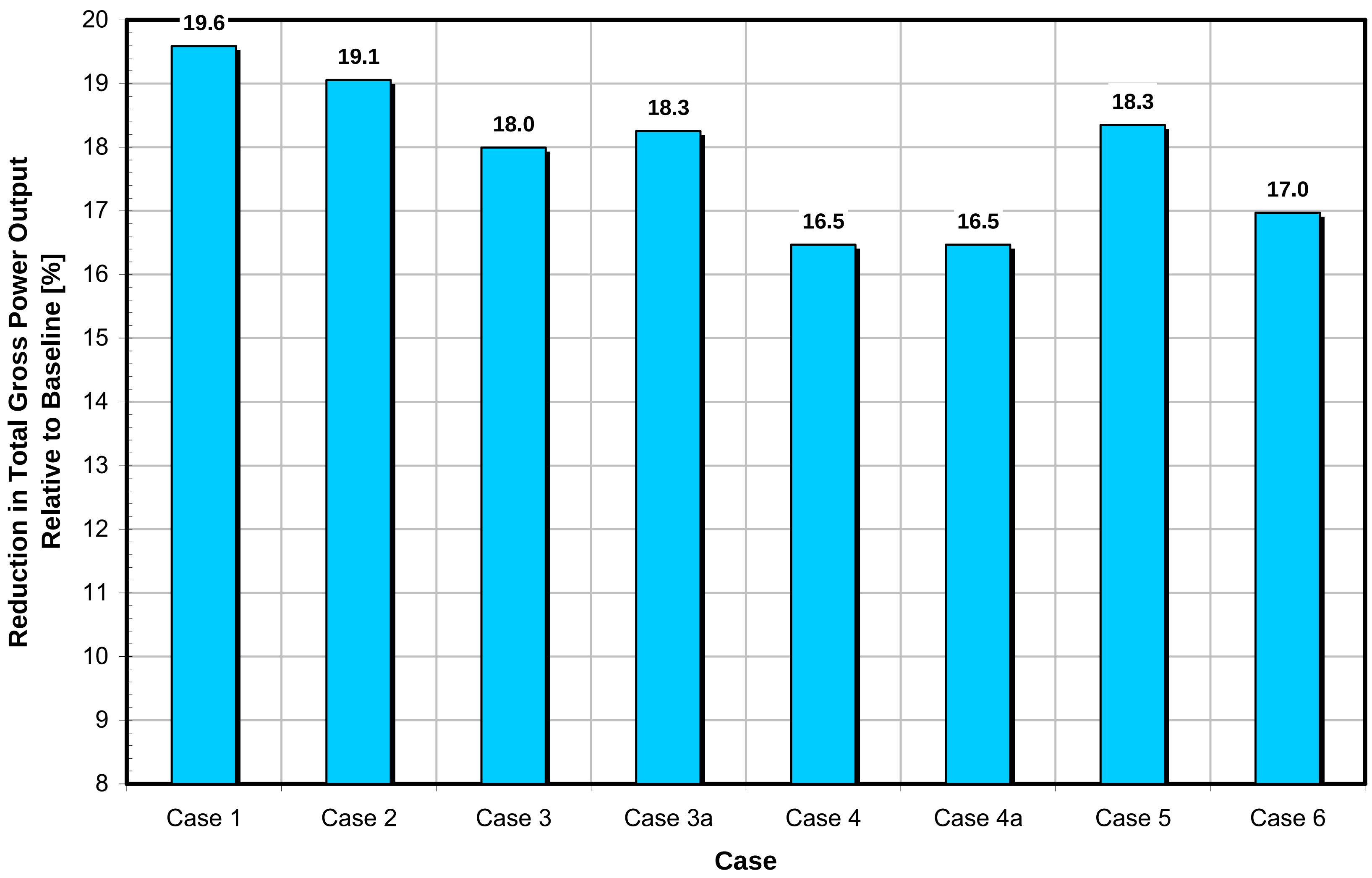

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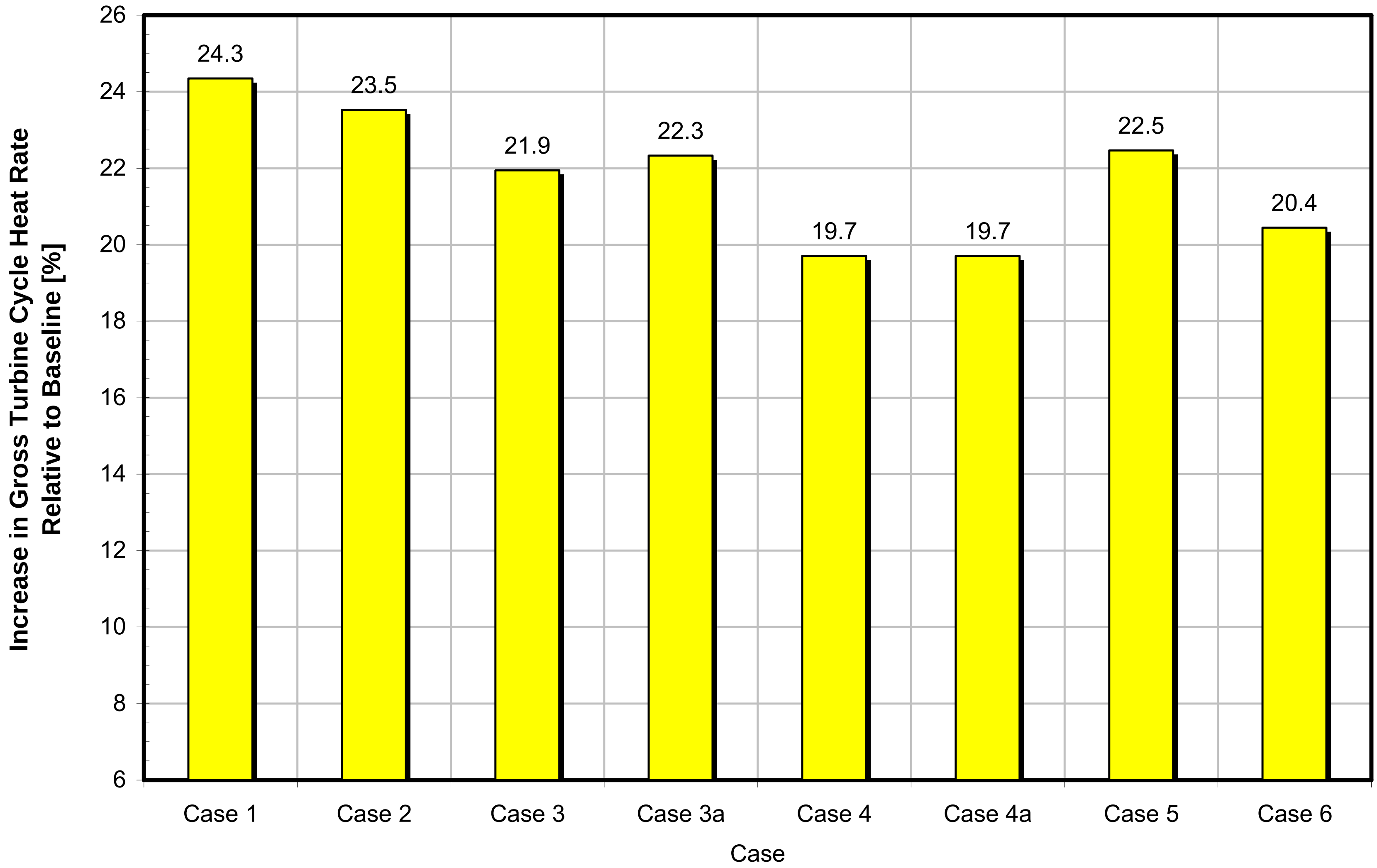

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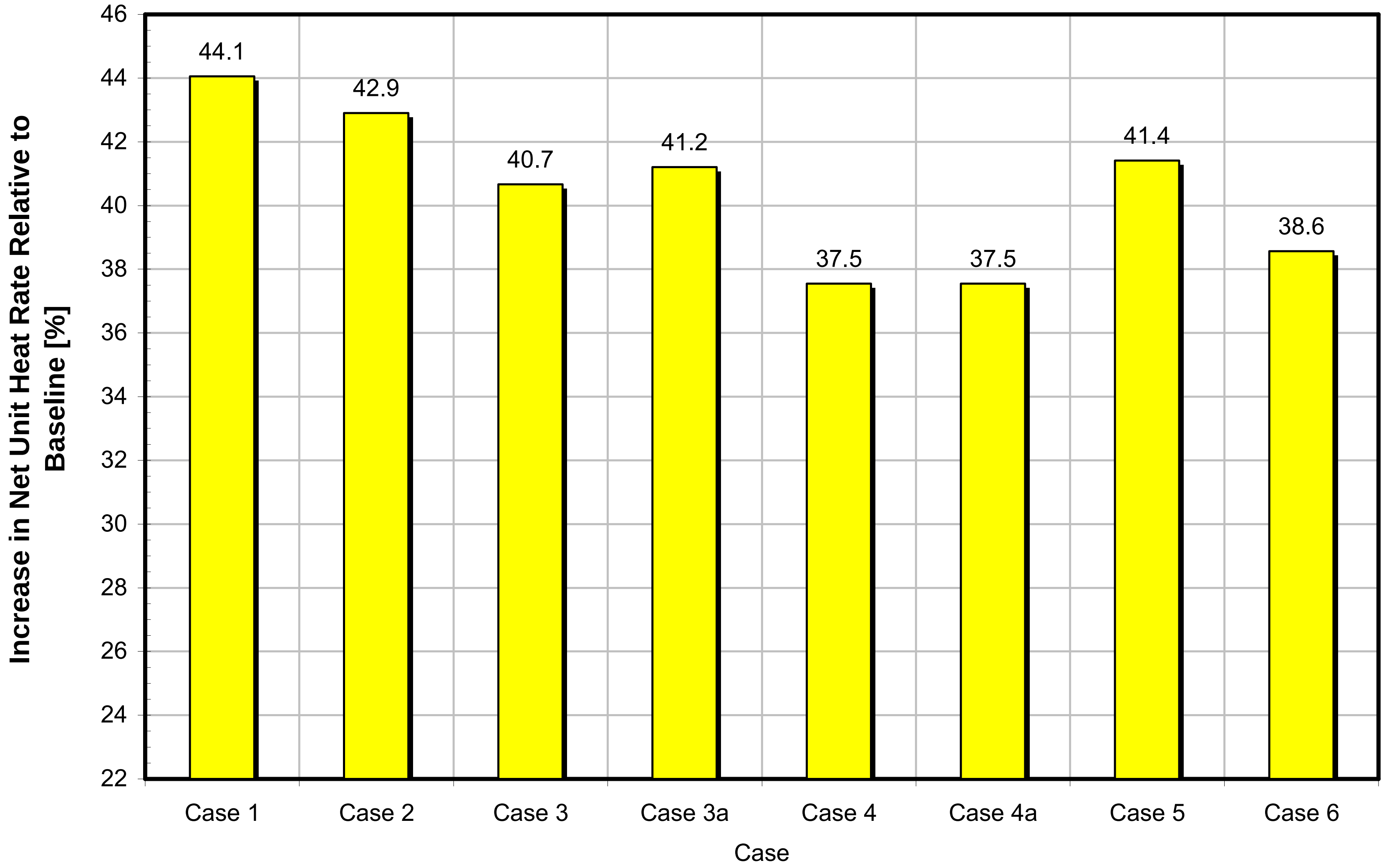

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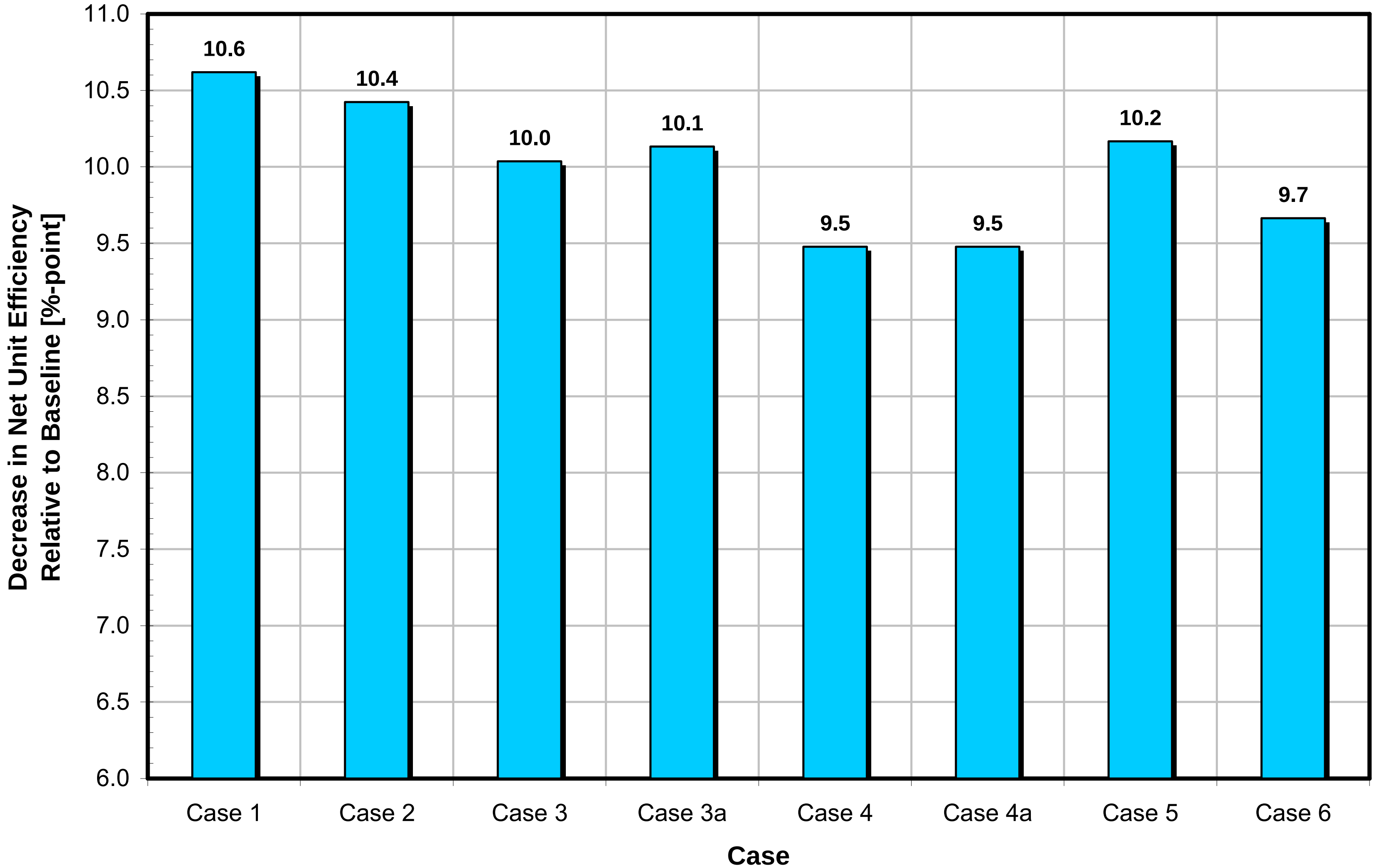

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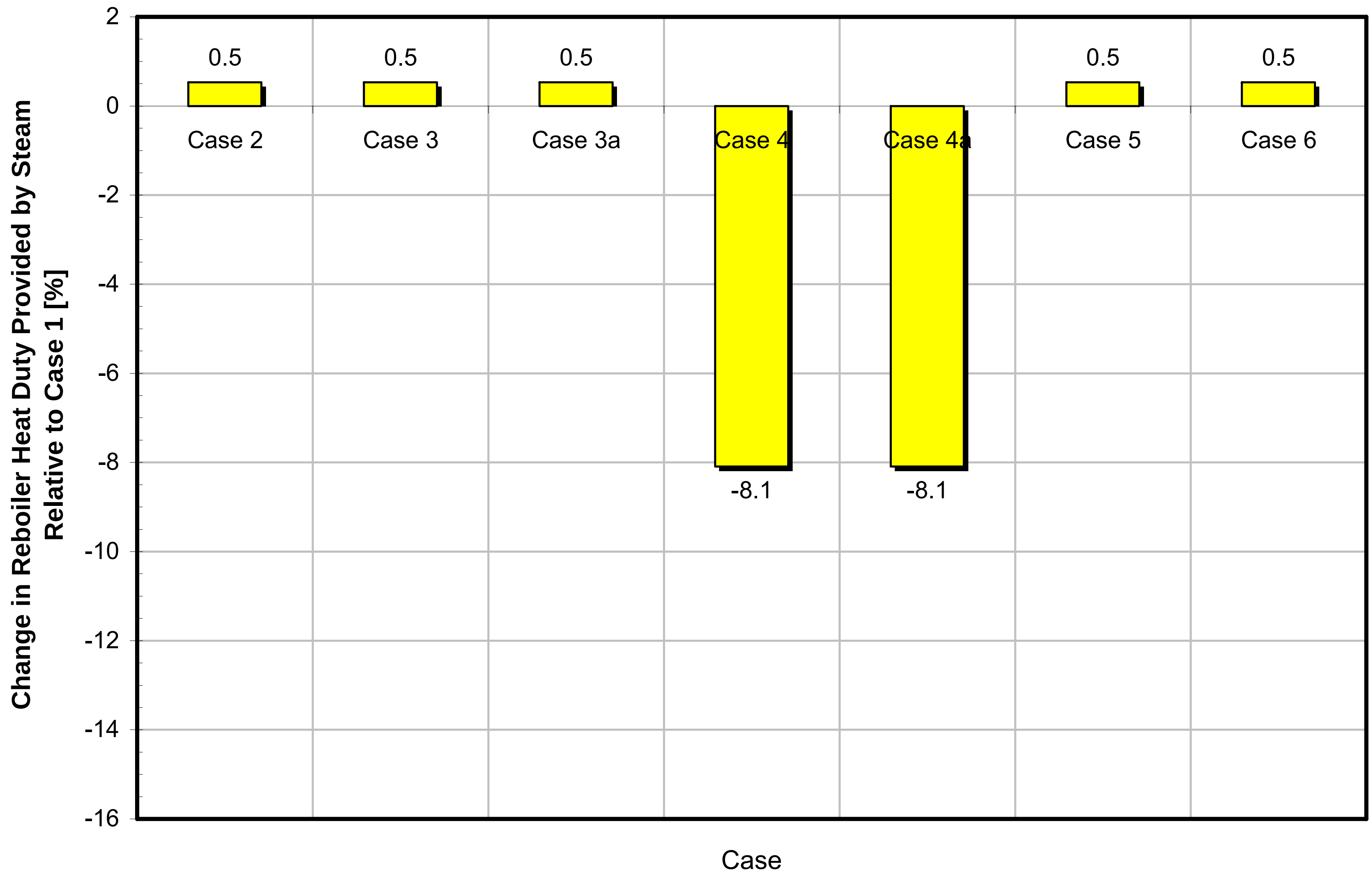

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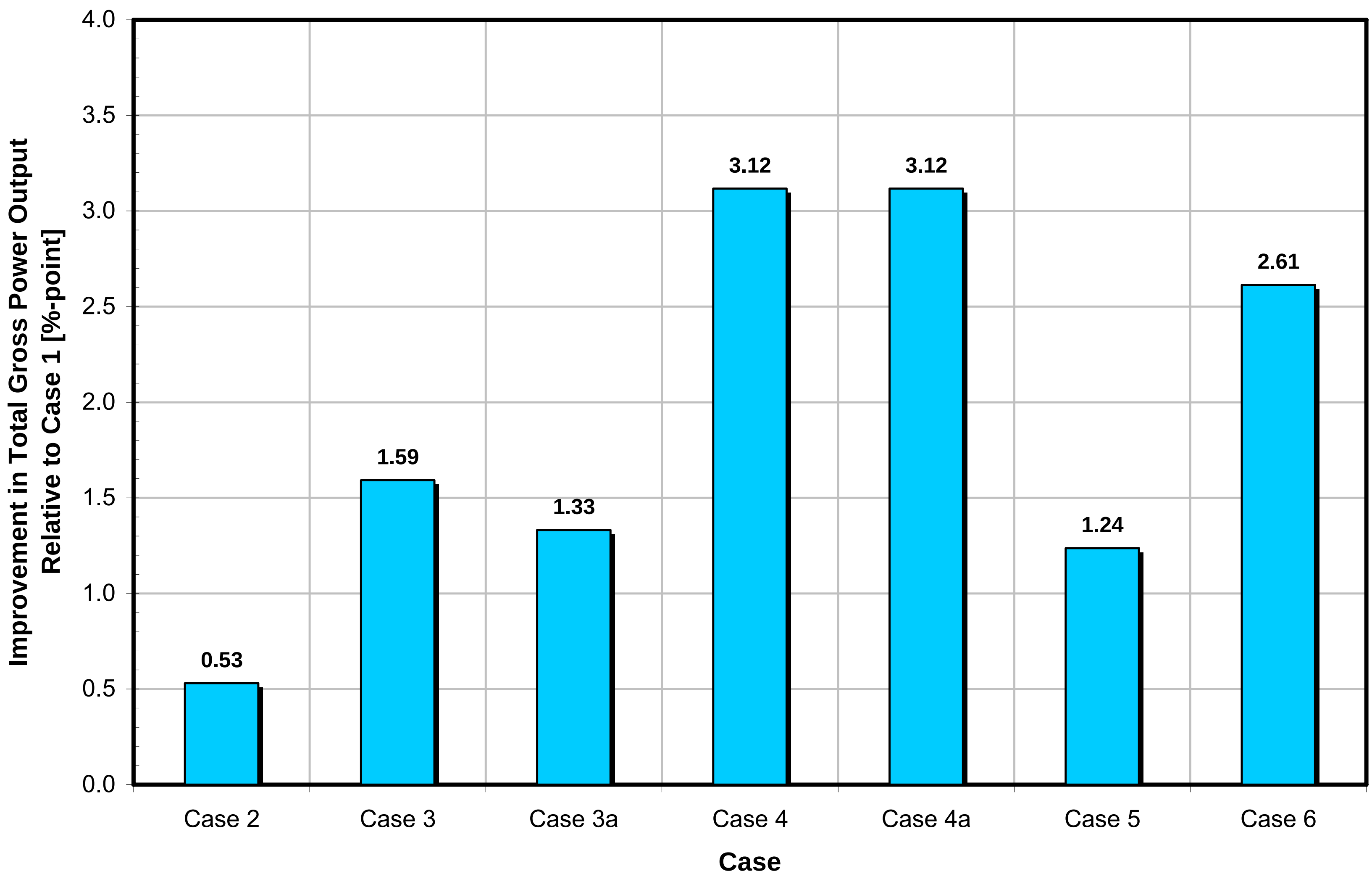

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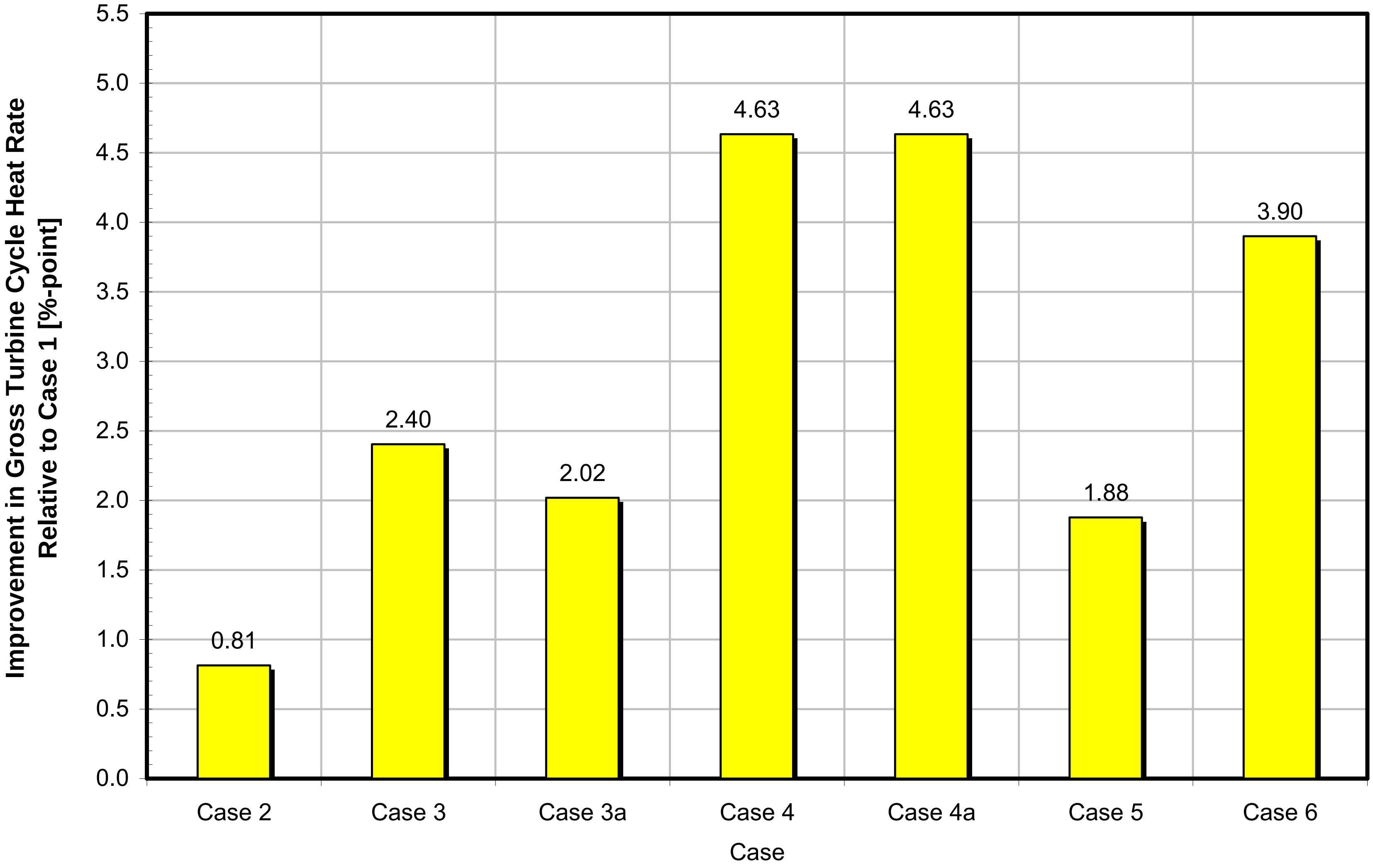

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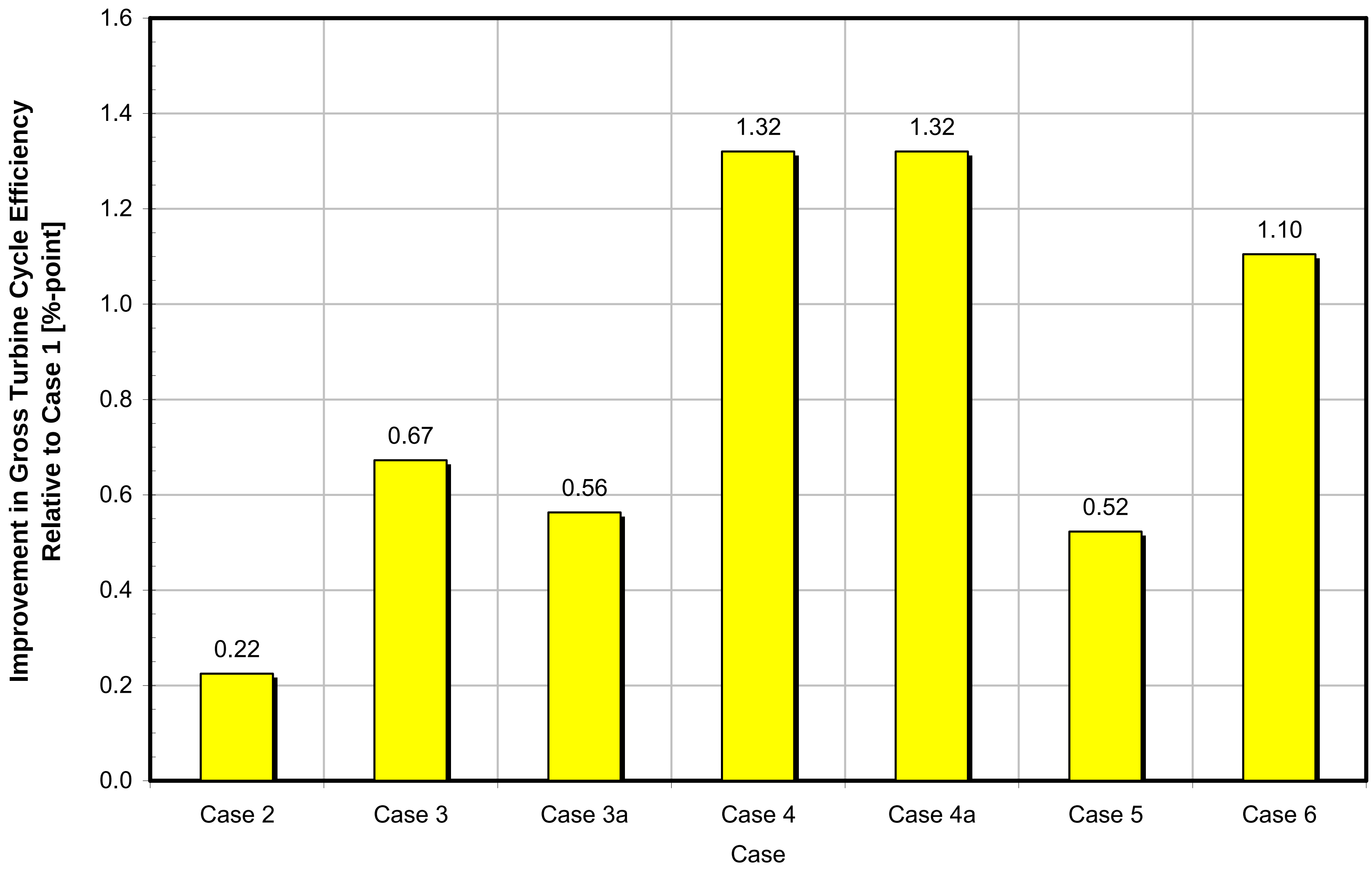

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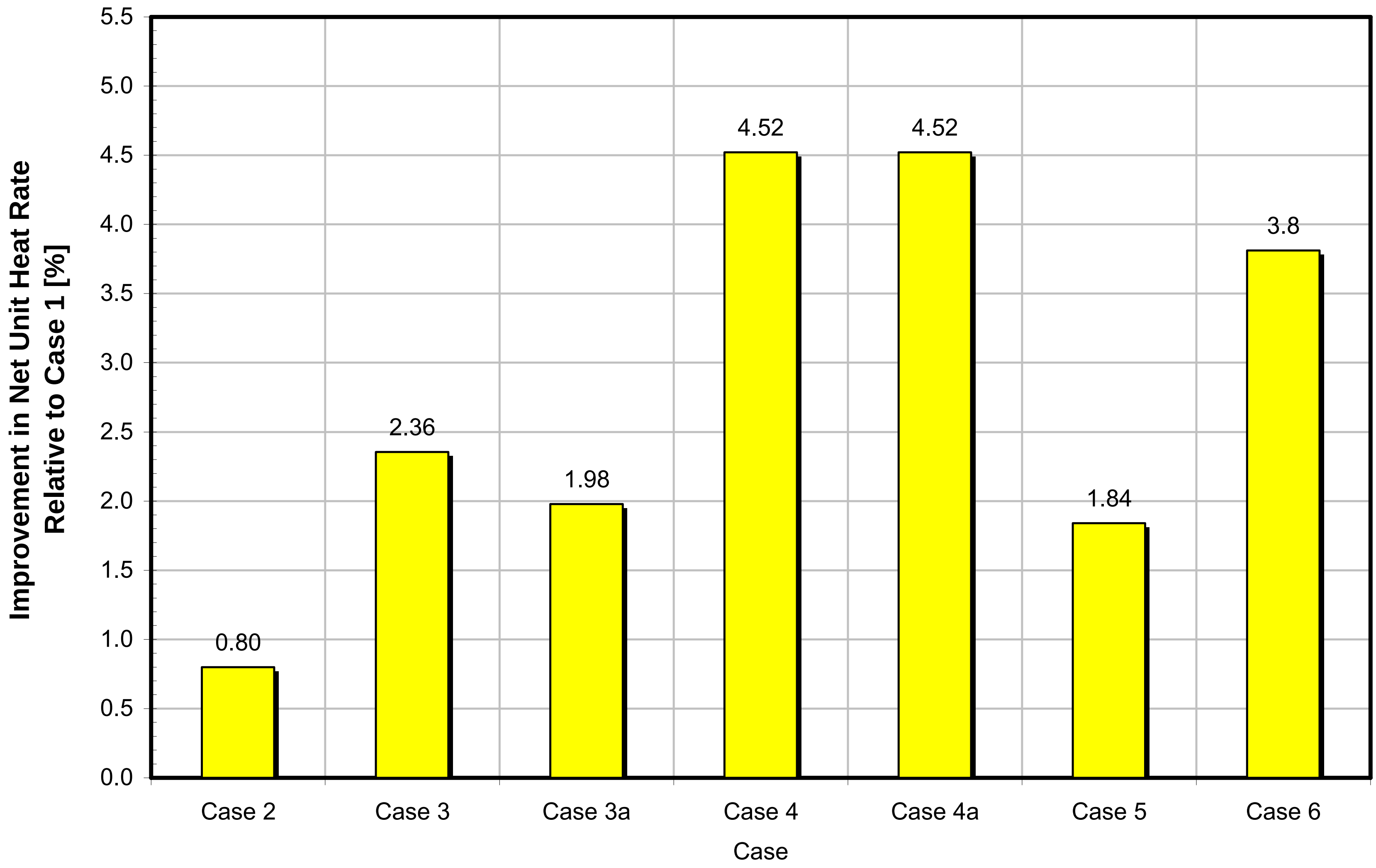

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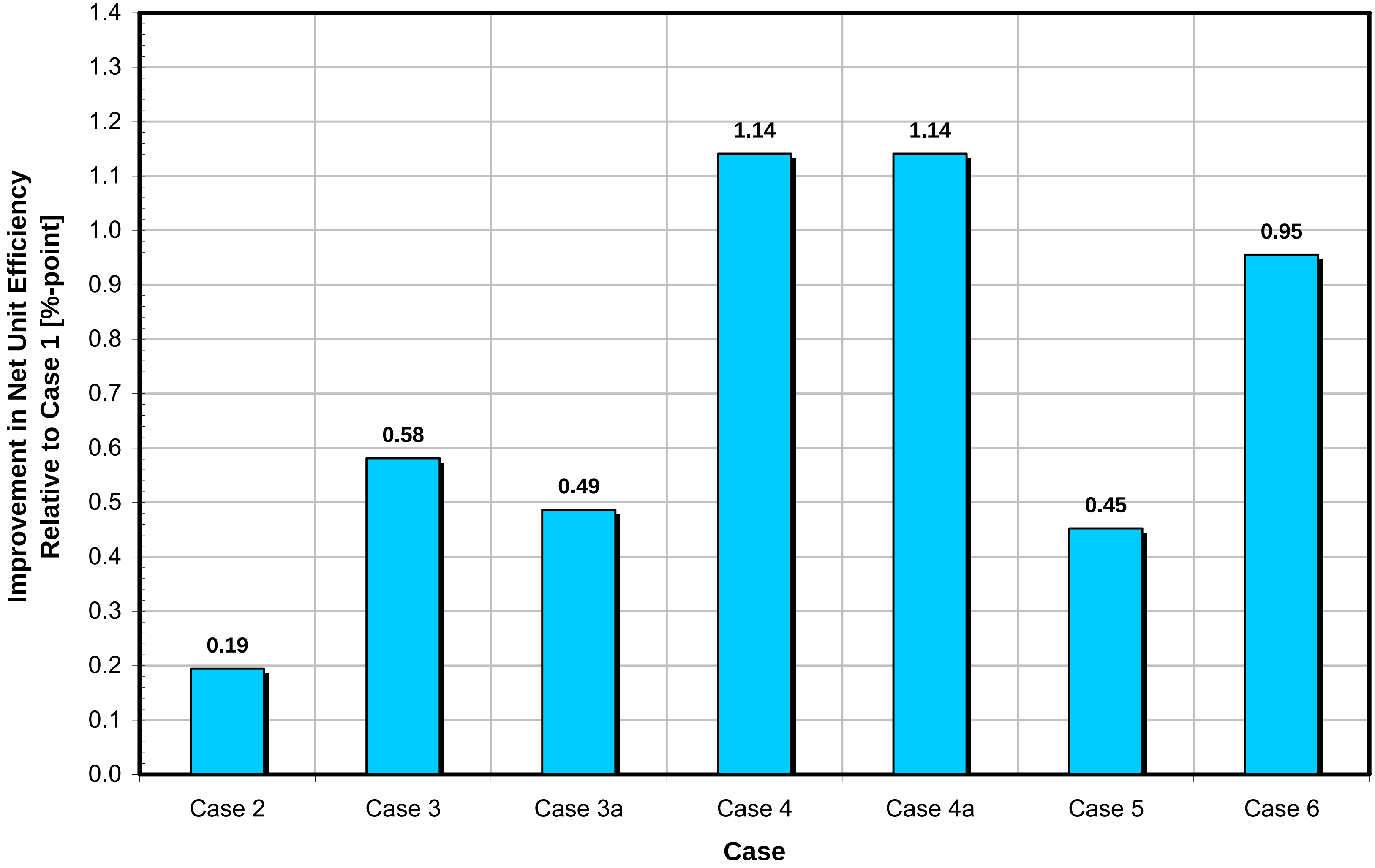
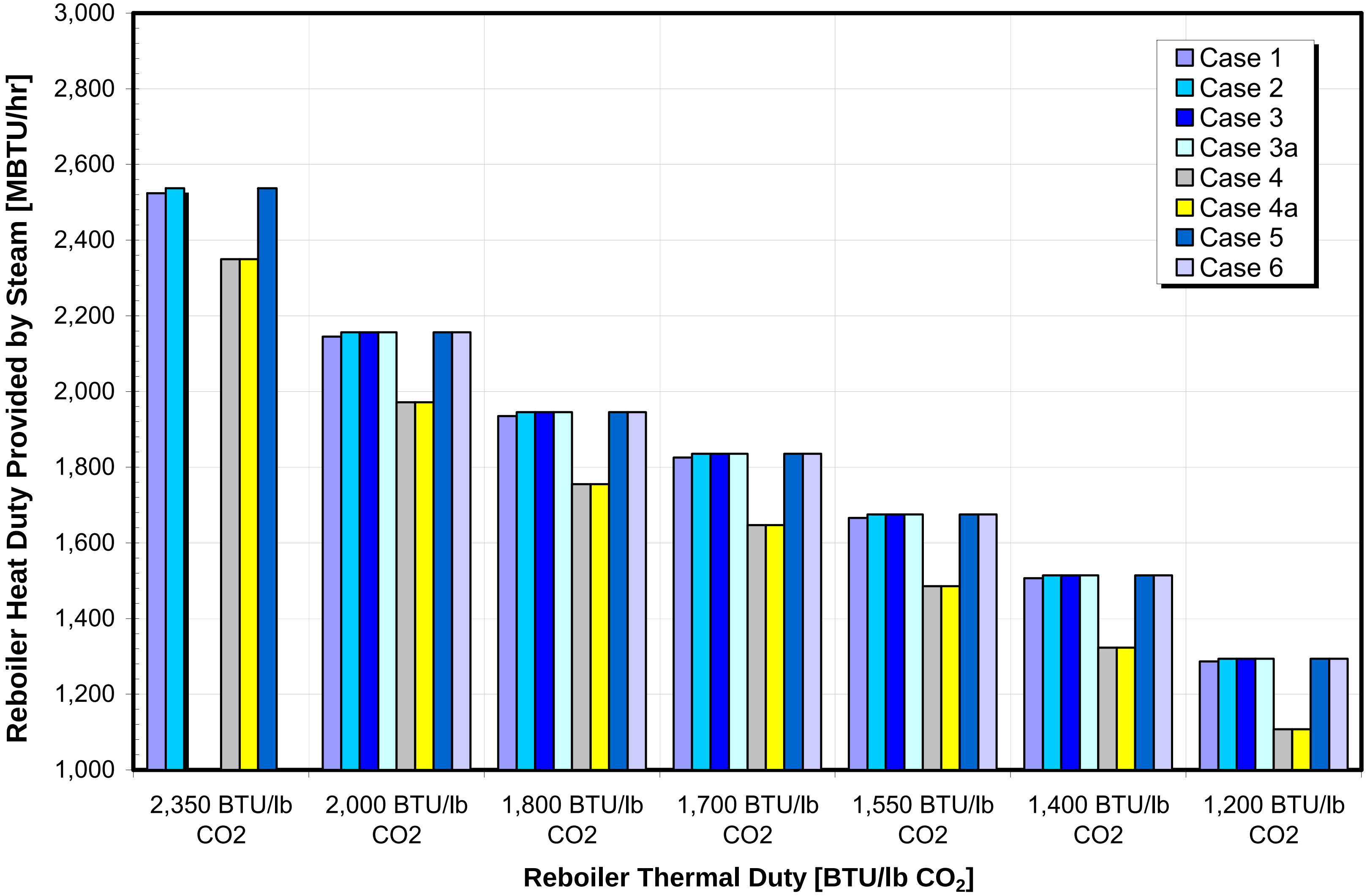


Summary of Results



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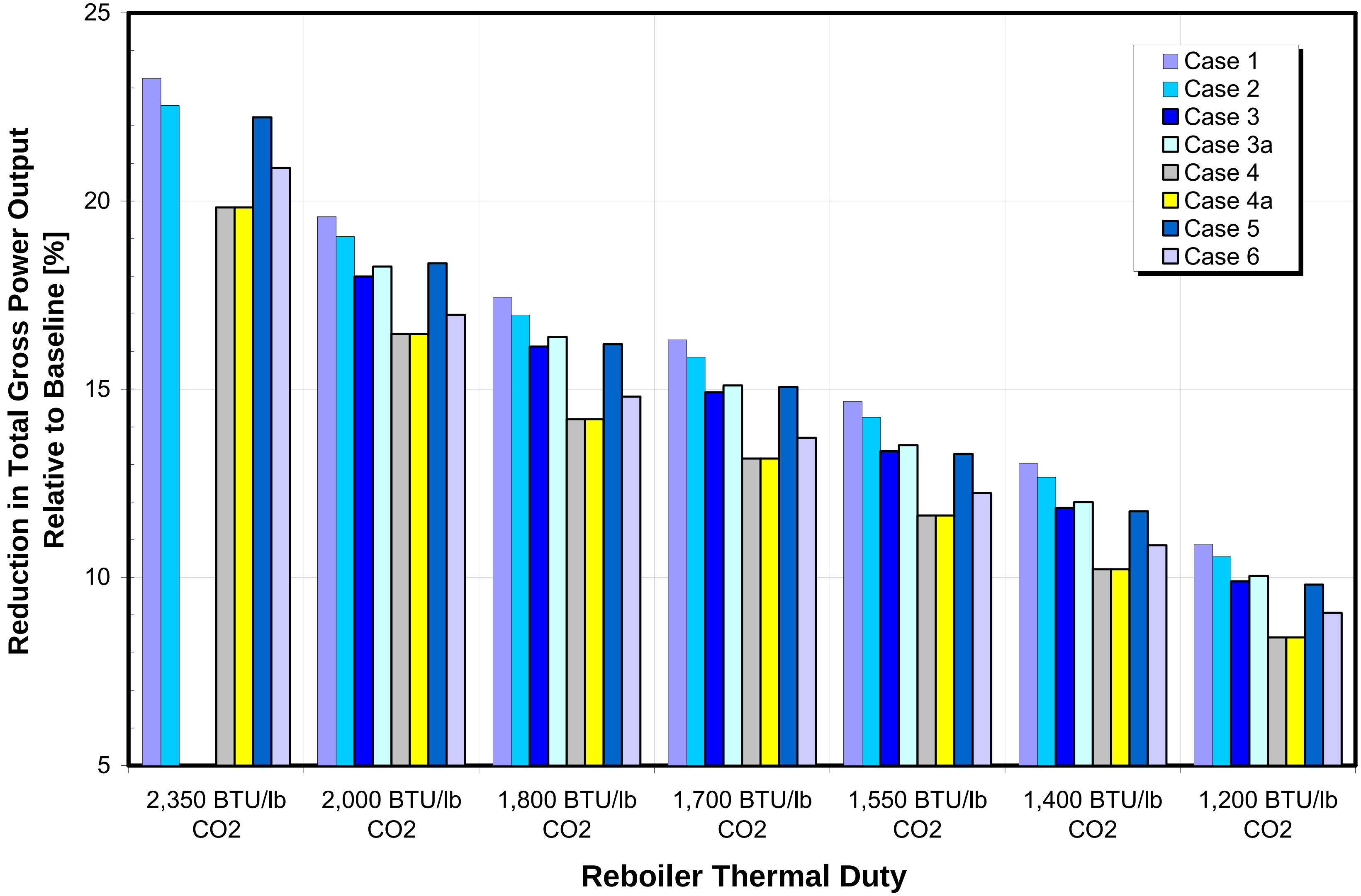

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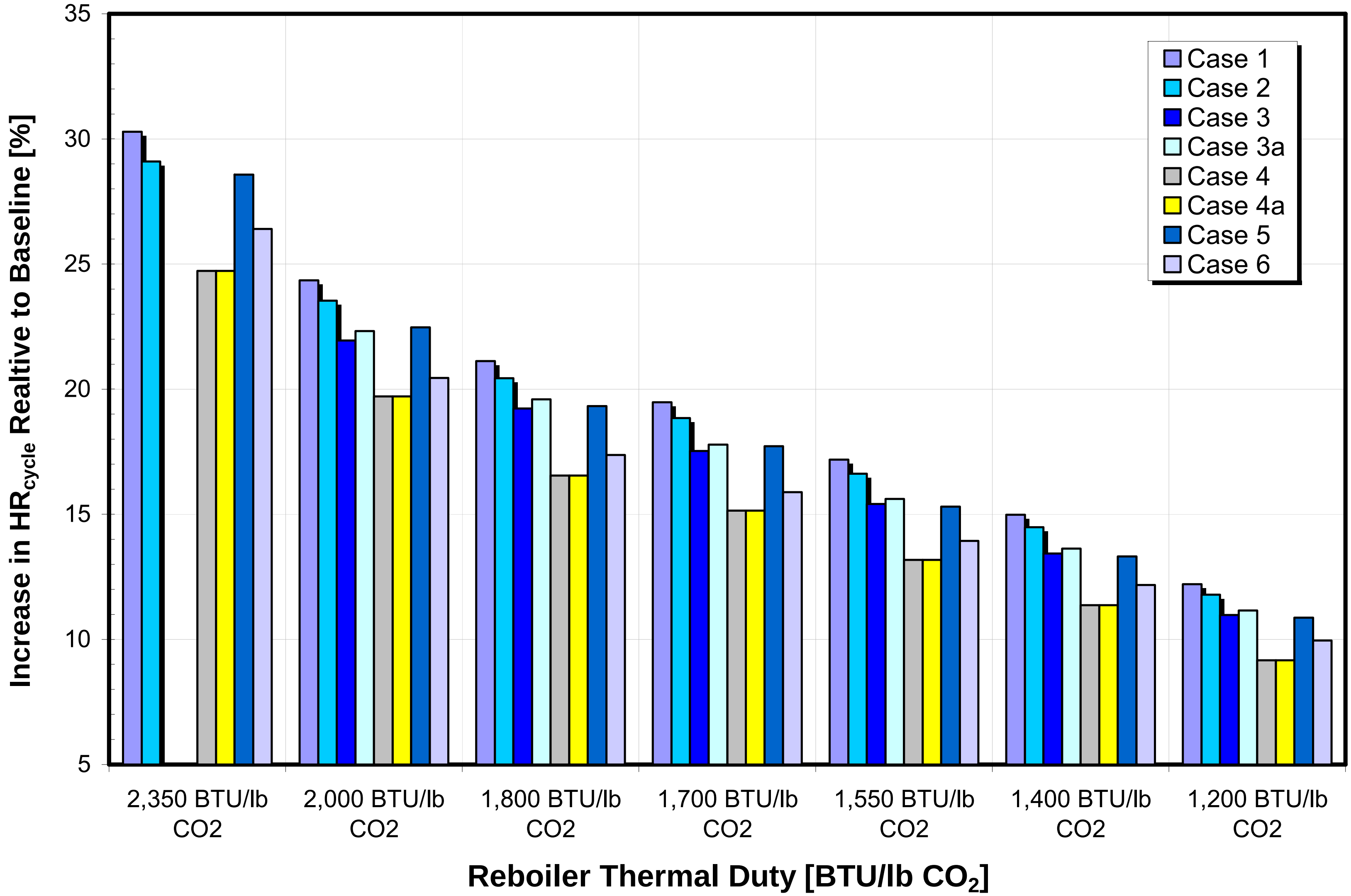

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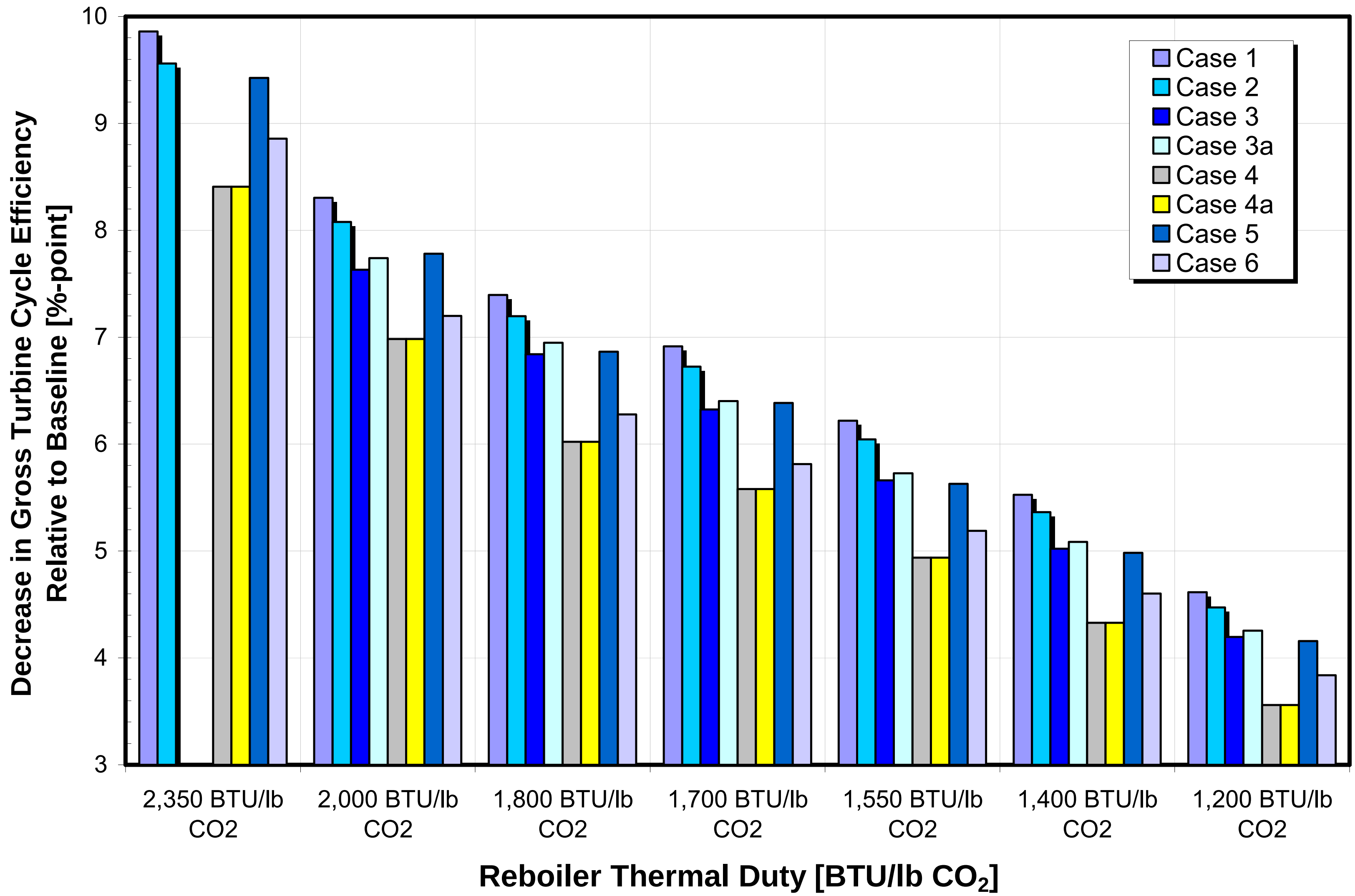

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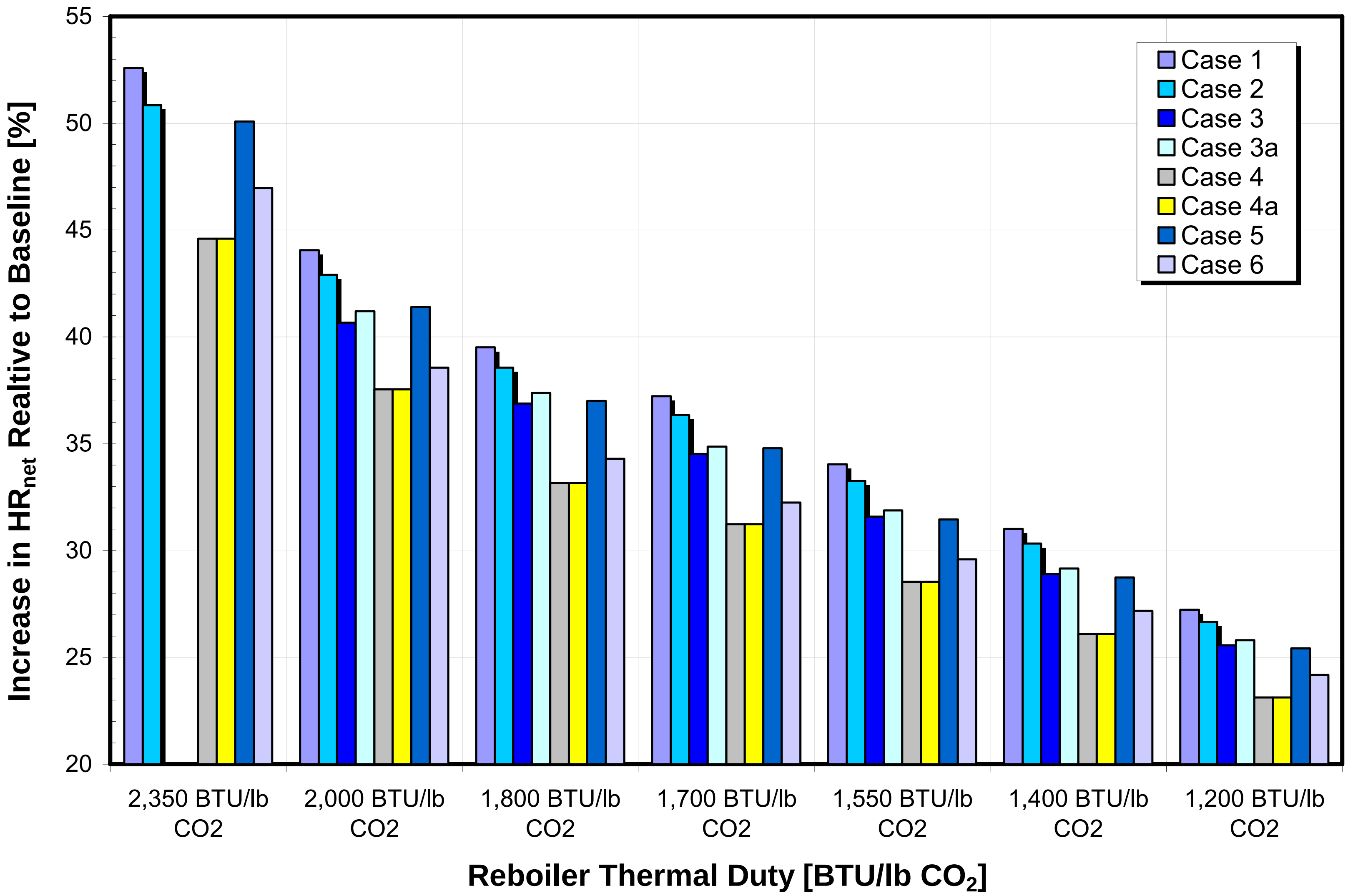

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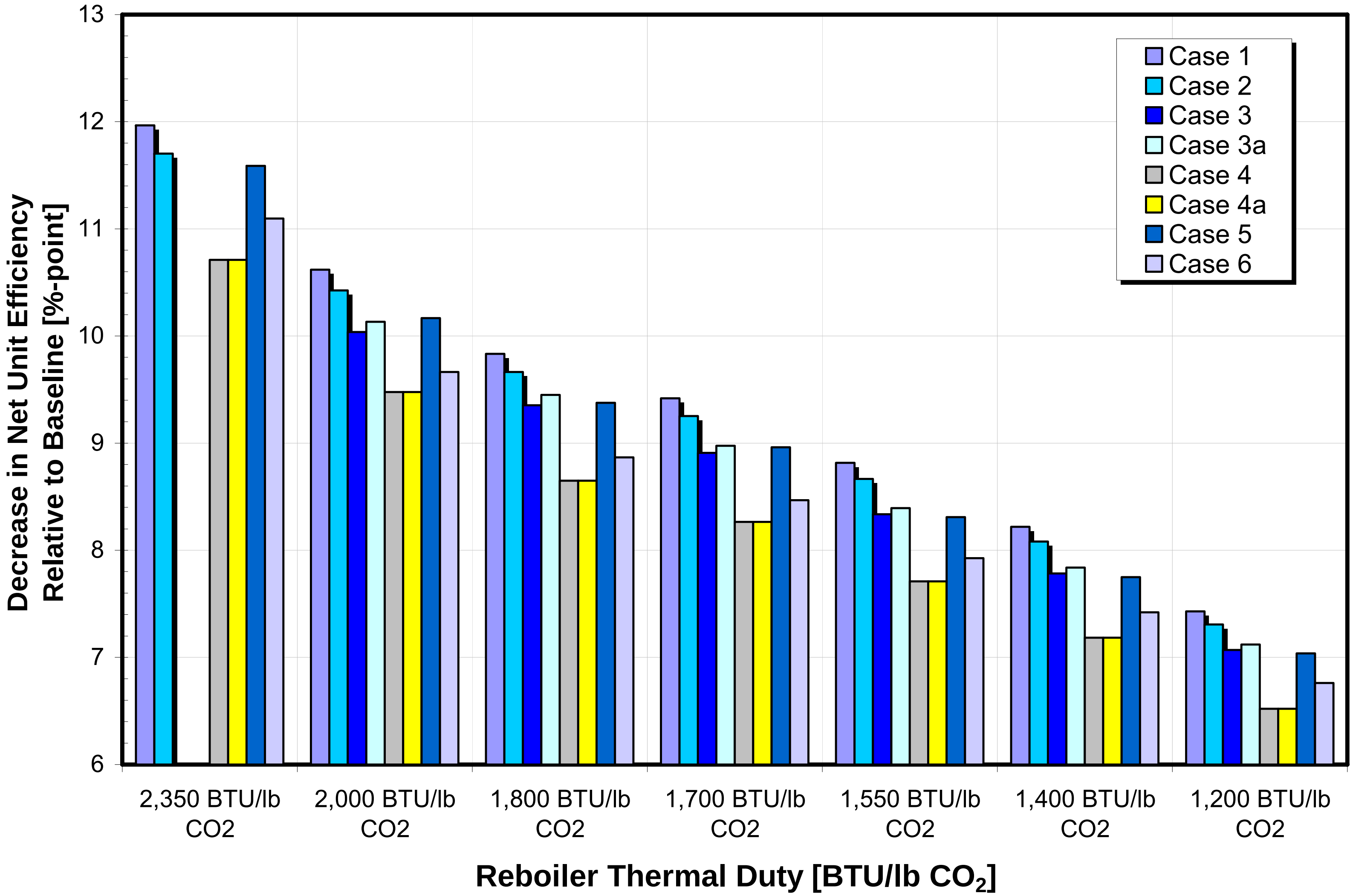

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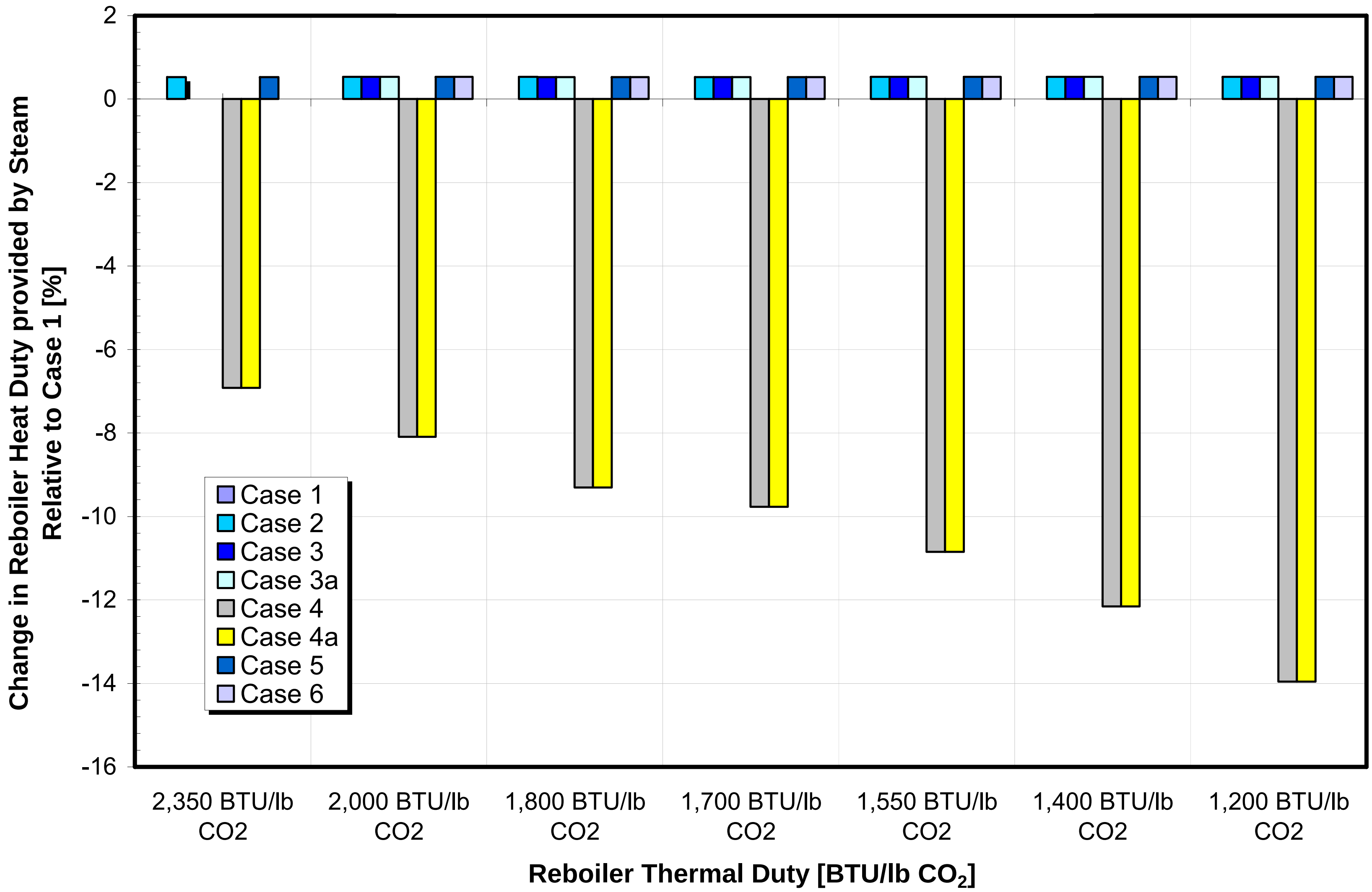

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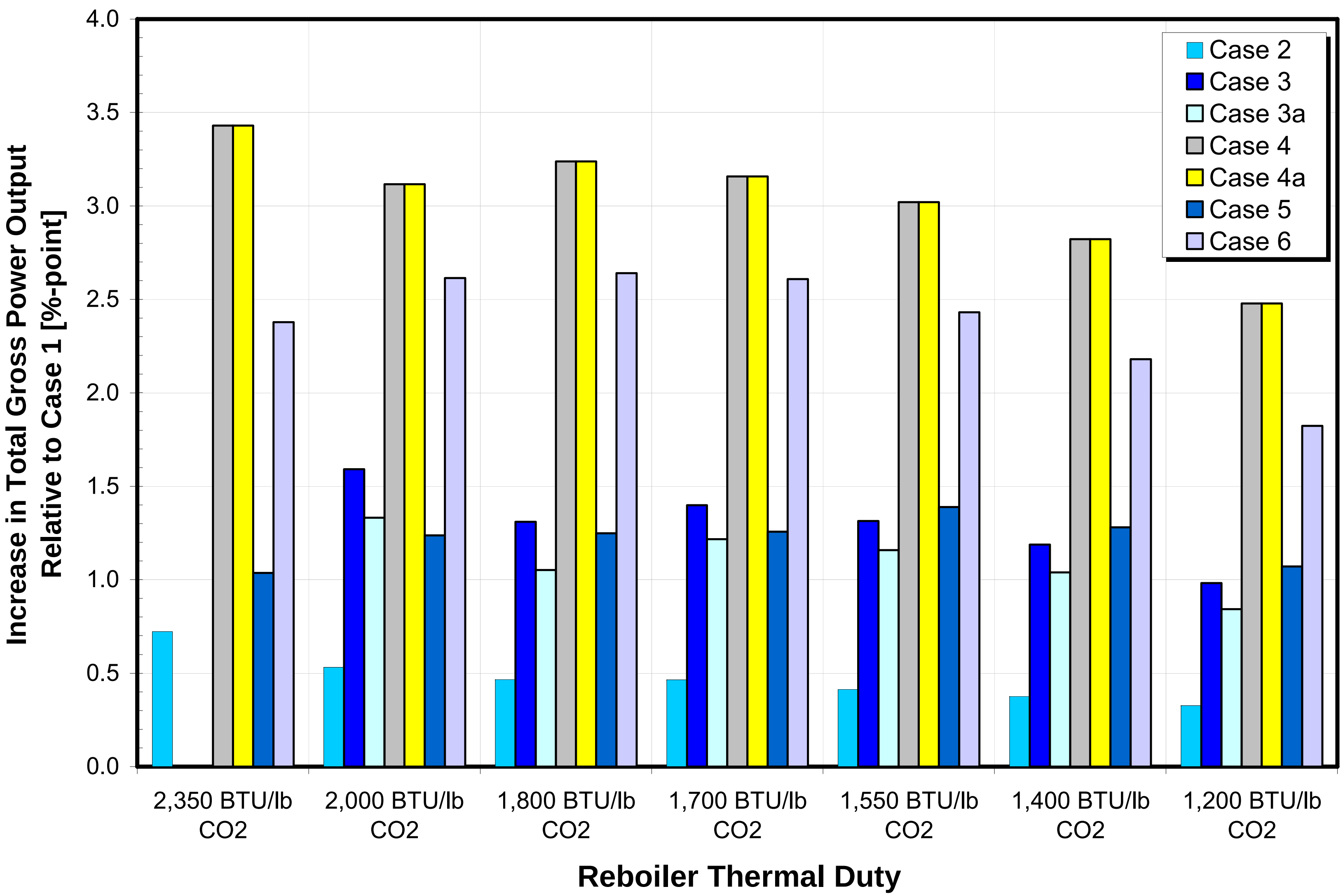

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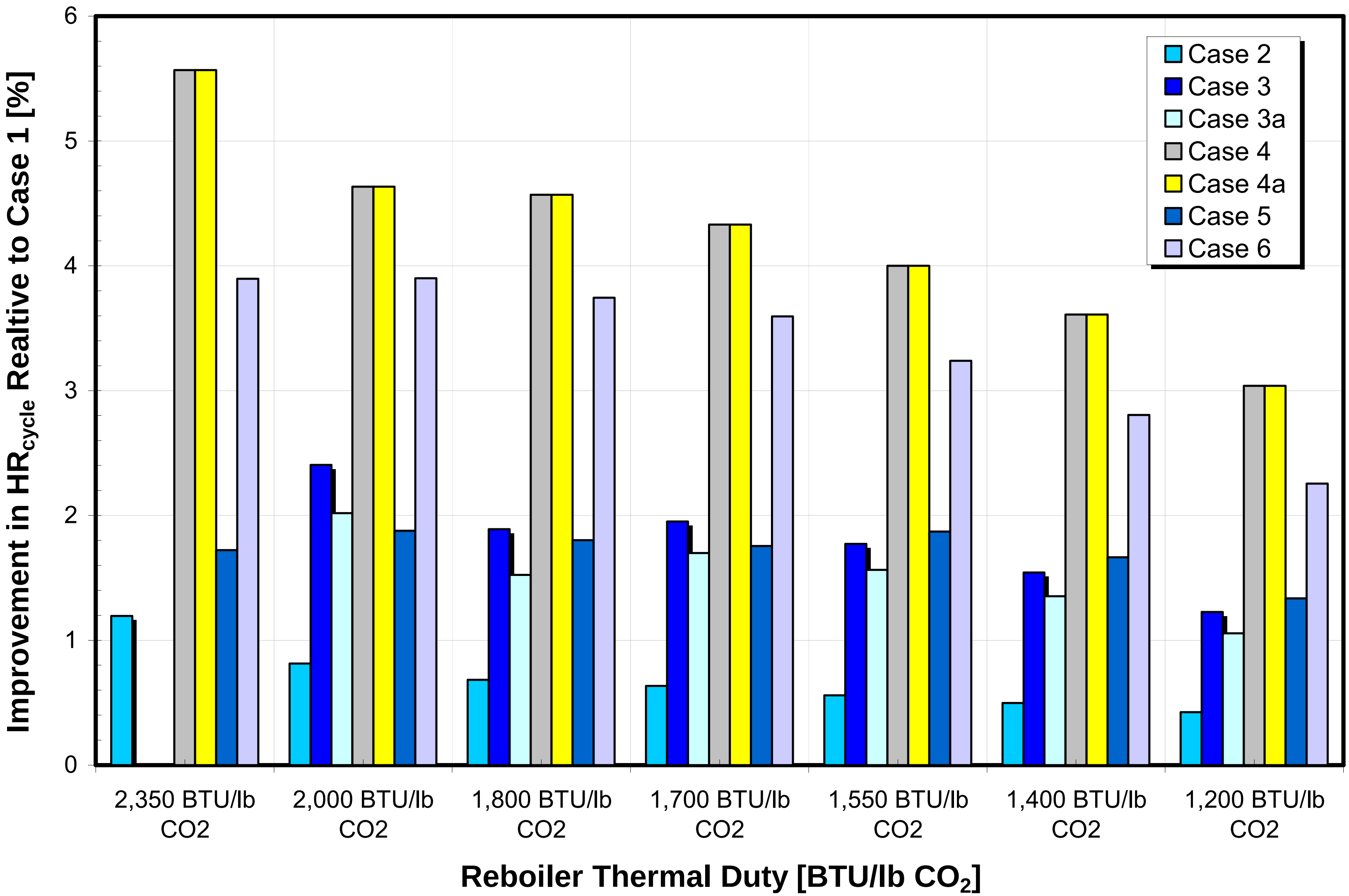

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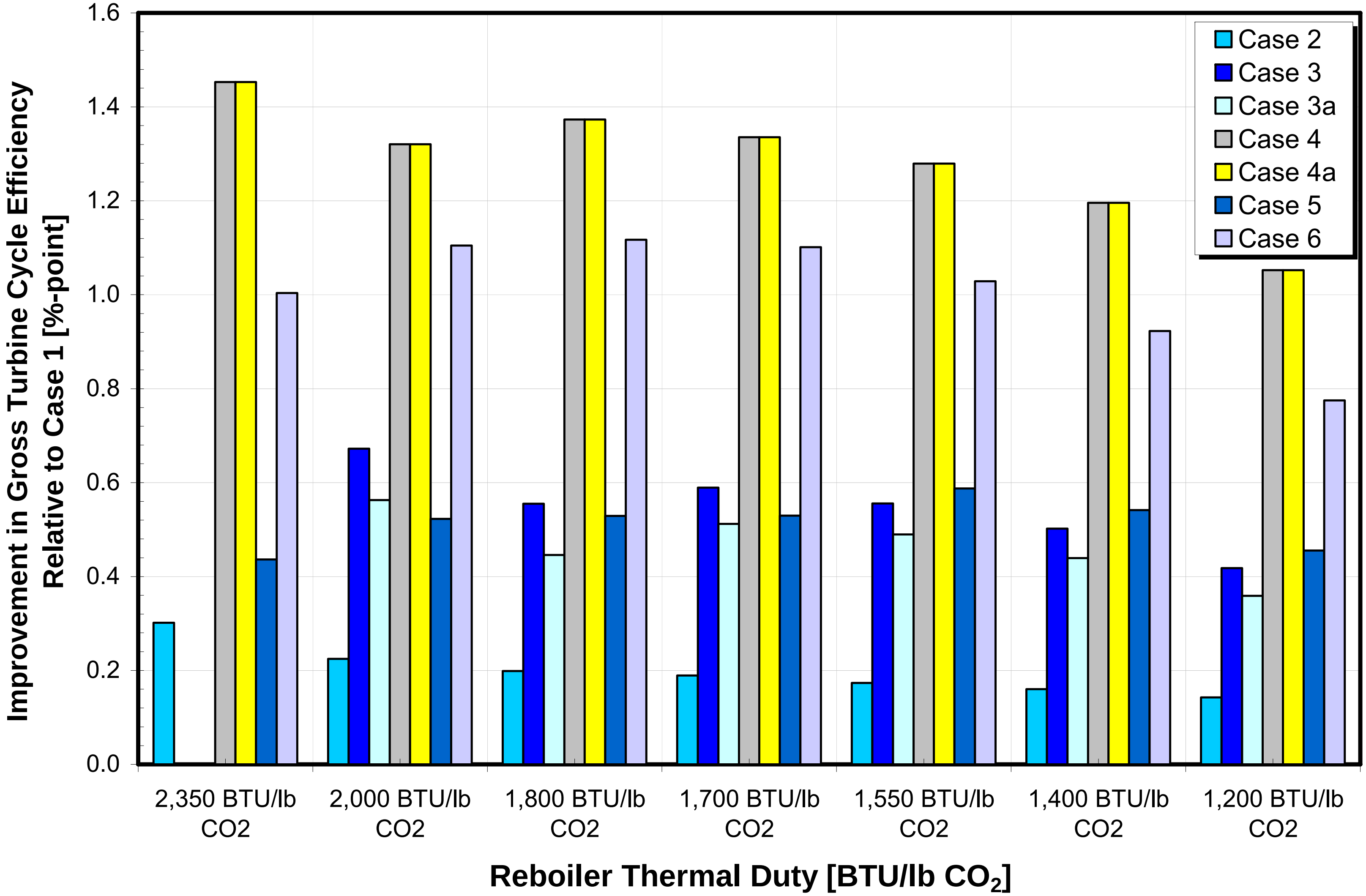

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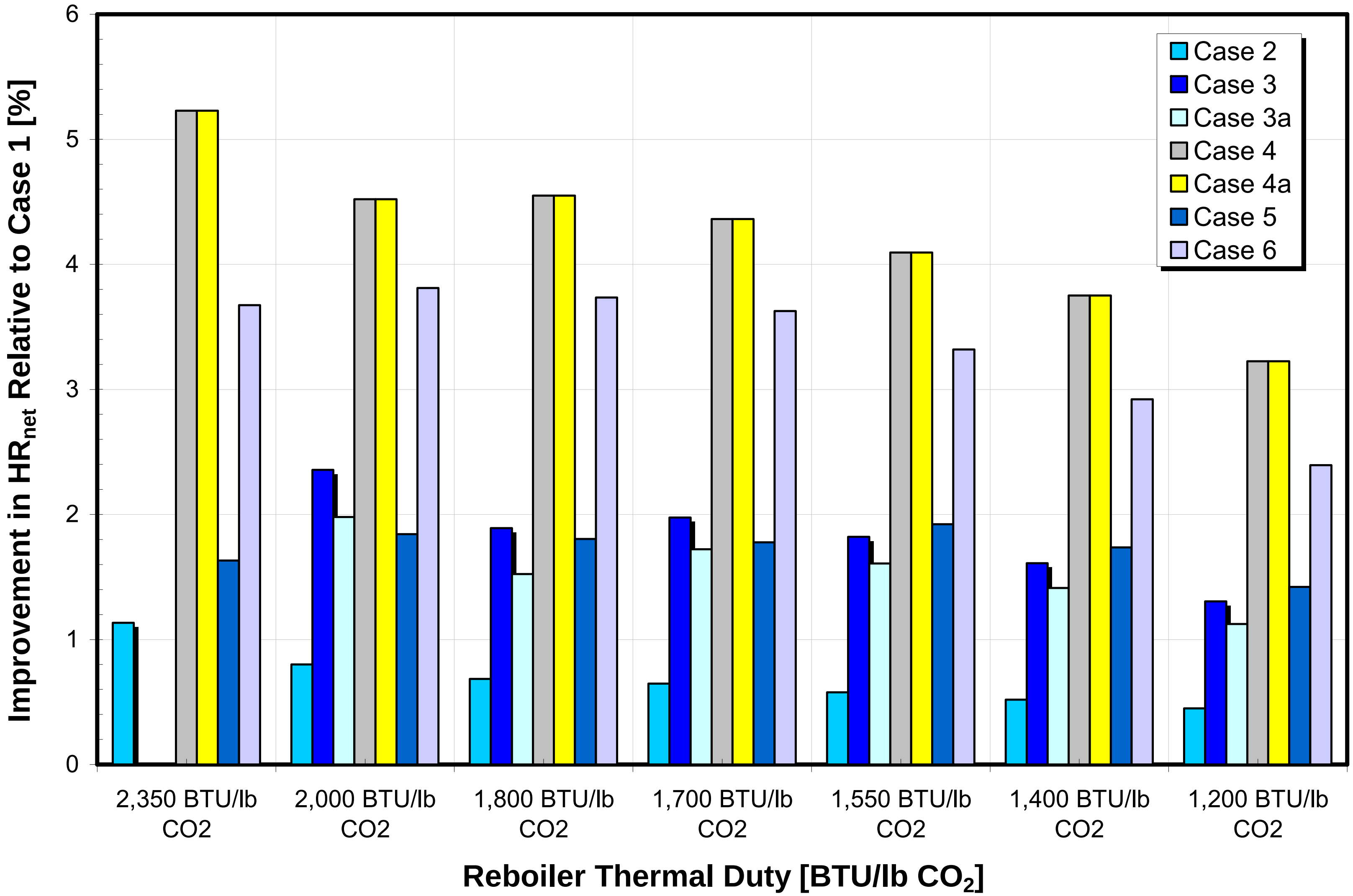

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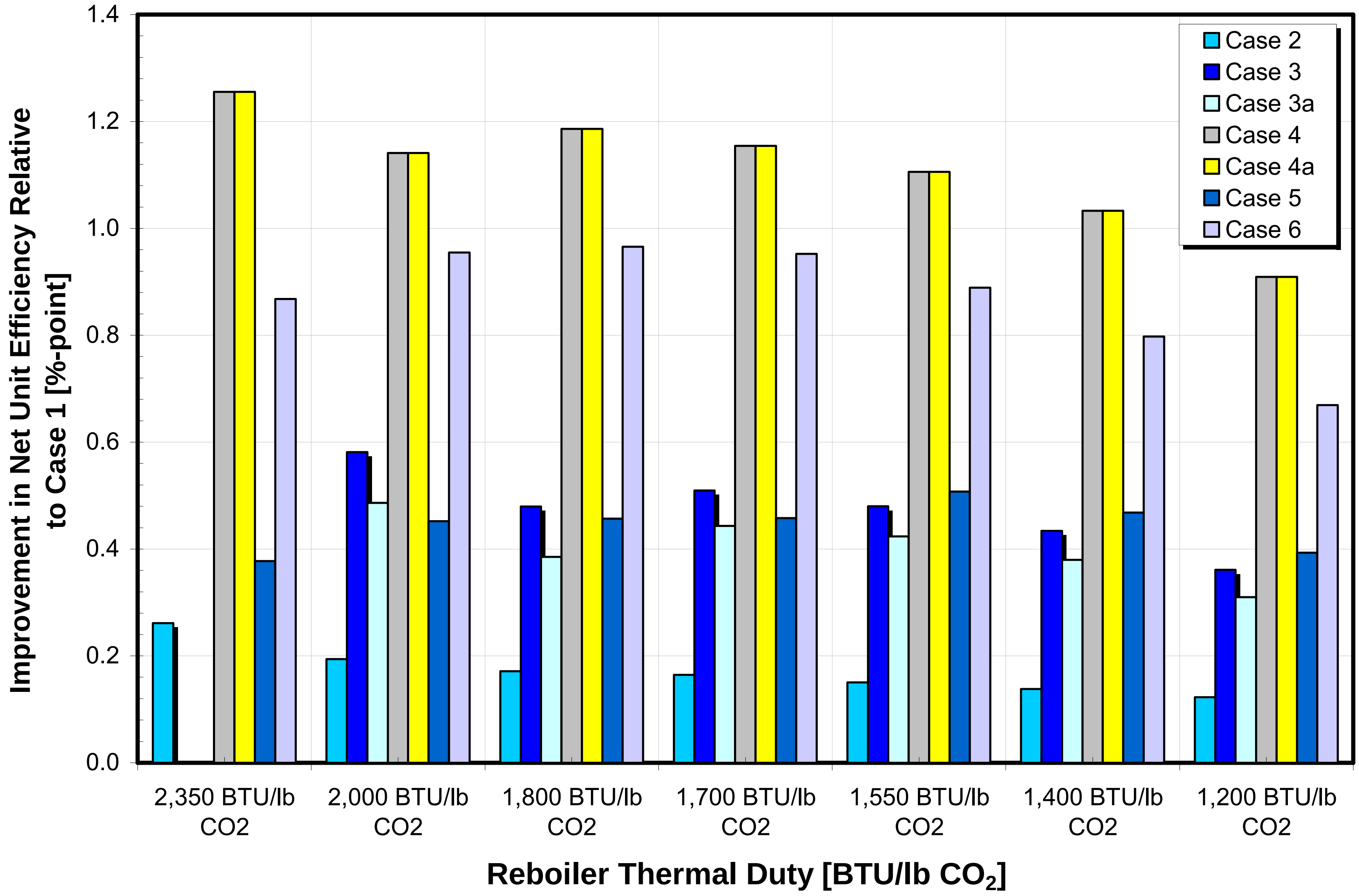

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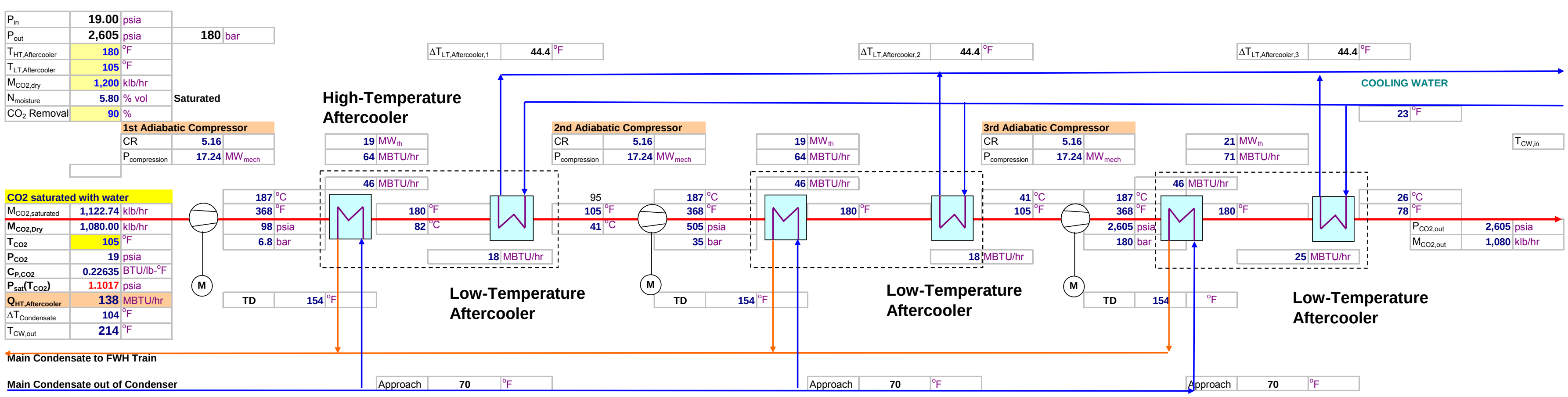
Integration of CO_2 Compression with Steam Turbine Cycle

Integration of CO_2 Compression with Steam Turbine Cycle

- *Conventional CO_2 compression process involves multiple adiabatic compressors with inter-cooling to reach pressure required for delivery and underground storage.*
- *High-grade compression heat is used for FWH to improve performance of steam turbine cycle, and allow steam normally used for FWH to be used in reboiler.*

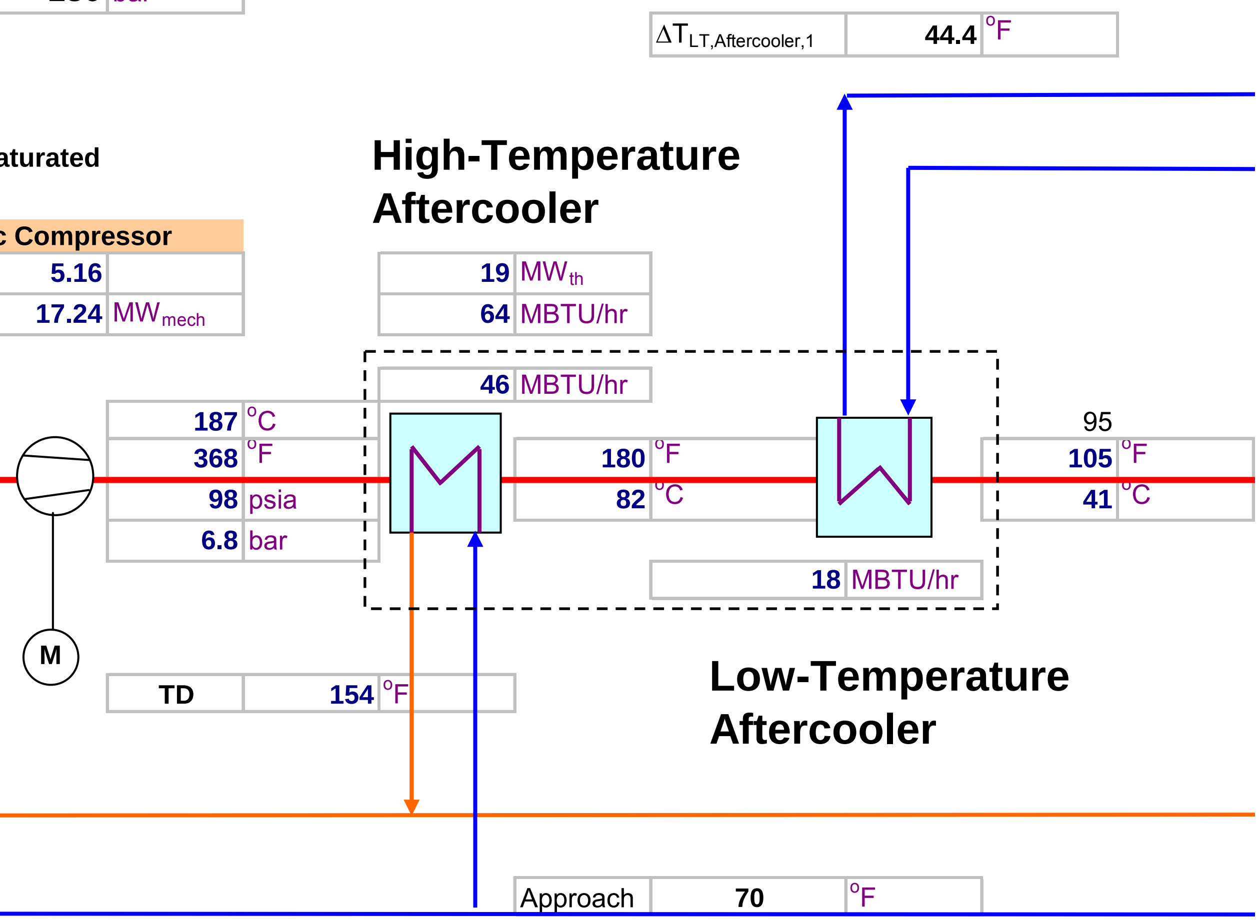


Integration of CO_2 Compression with Steam Turbine Cycle: Detail

P_{in}	19.00	psia		
P_{out}	2,605	psia	180	bar
$T_{HT,Aftercooler}$	180	°F		
$T_{LT,Aftercooler}$	105	°F		
$M_{CO2,dry}$	1,200	klb/hr		
$N_{moisture}$	5.80	% vol	Saturated	
CO_2 Removal	90	%		

1st Adiabatic Compressor		
CR	5.16	
$P_{compression}$	17.24	MW_{mech}

CO2 saturated with water		
$M_{CO2,saturated}$	1,122.74	klb/hr
$M_{CO2,Dry}$	1,080.00	klb/hr
T_{CO2}	105	°F
P_{CO2}	19	psia
$C_{P,CO2}$	0.22635	BTU/lb-°F
$P_{sat}(T_{CO2})$	1.1017	psia



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Integration of CO_2 Compression with Steam Turbine Cycle: Summary

CO_2 Compression Layout	Note
Compression Train 1	Dry CO_2
Compression Train 2	Dry CO_2
Compression Train 3	CO_2 Saturated by Moisture
Compression Train 4	CO_2 Saturated by Moisture
Compression Train 5	CO_2 Saturated by Moisture + Moisture Knockout
Compression Train 6	CO_2 Saturated by Moisture + Moisture Knockout, Air Products-Doosan Babcock-Imperial College

CO_2 Compression Layout	T_{in}	P_{in}	P_{out}		$CR_{Overall}$	$M_{CO2,dry}$	$M_{CO2,wet}$	$Q_{HT\ Aftercooler}$	$Q_{LT\ Aftercooler}$	$P_{Compression}$
	°F	psia	psia	bar		klb/hr	klb/hr	MBTU/hr	MBTU/hr	MW_{mech}
Compression Train 1	105	14.7	**1,595**	110	108.5	1,080	1,080	**128**	55	55
Compression Train 2	105	14.7	**2,605**	180	177.2	1,080	1,080	**149**	55	62
Compression Train 3	105	19.0	**2,605**	180	137.1	1,080	1,123	**138**	62	52
Compression Train 4	105	19.0	**2,200**	152	115.8	1,080	1,123	**130**	62	50
Compression Train 5	105	19.0	**2,015**	139	106.1	1,080	1,123	**136**	61	60
Compression Train 6	105	19.0	**1,595**	110	83.9	1,080	1,123	**143**	67	63

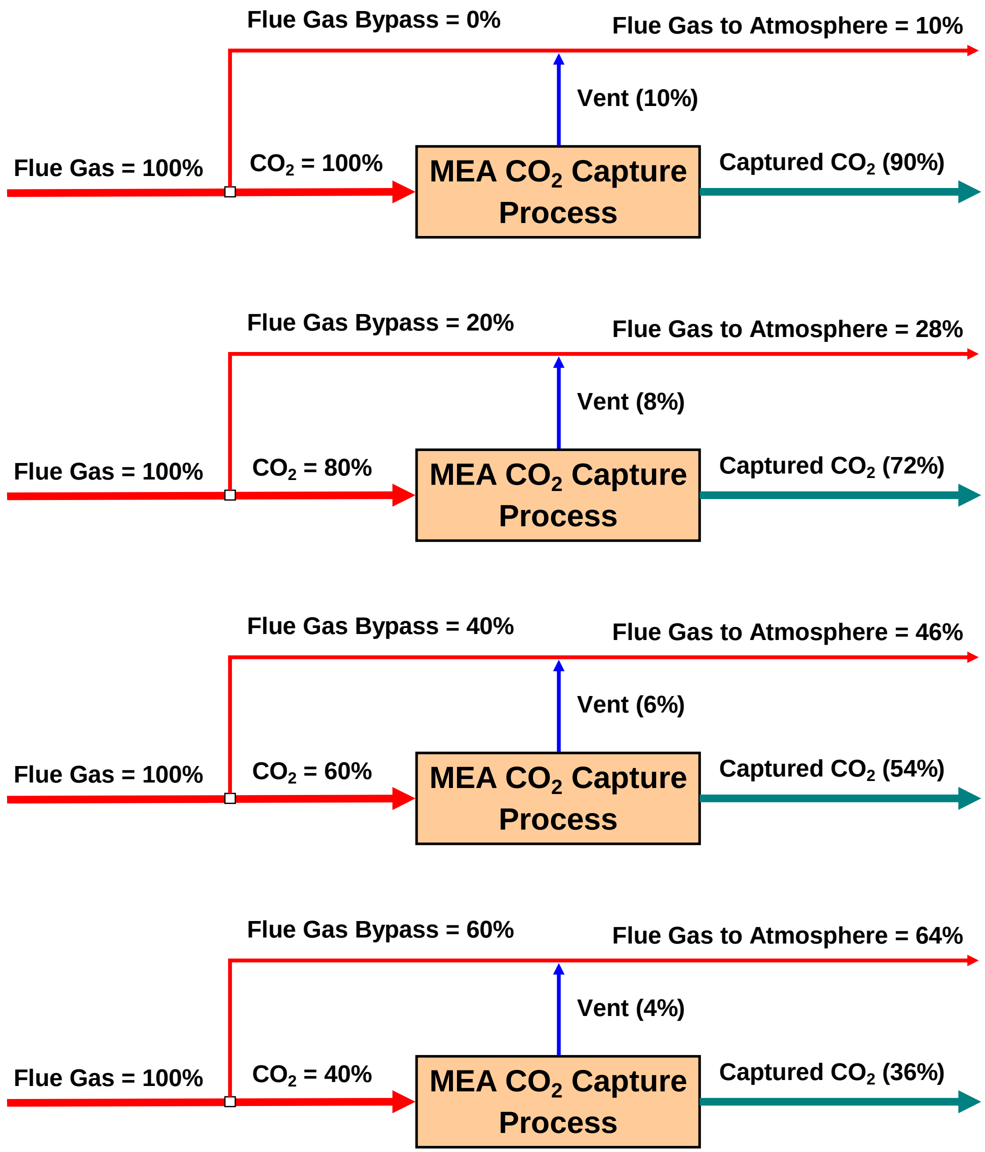
CO_2 Compression Layout	T_{in}	P_{in}	$P_{out,1st\ Compressor}$		CR_1	$T_{out,1st\ Compressor}$		$P_{out,2nd\ Compressor}$		CR_2	$T_{out,2nd\ Compressor}$		$P_{out,3rd\ Compressor}$		CR_3	$T_{out,3rd\ Compressor}$	
	°F	psia	psia	bar		°F	°C	psia	bar		°F	°C	psia	bar		°F	°C
Compression Train 1	105	14.7	**70**	4.8	4.76	355	179	**334**	23	4.77	355	179	**1,595**	110	4.78	355	179
Compression Train 2	105	14.7	**83**	5.7	5.65	383	195	**464**	32	5.59	383	195	**2,605**	180	5.61	383	195
Compression Train 3	105	19.0	**98**	6.8	5.16	368	187	**505**	35	5.15	368	187	**2,605**	180	5.16	368	187
Compression Train 4	105	19.0	**93**	6.4	4.89	357	181	**451**	31	4.85	357	181	**2,200**	152	4.88	357	181
Compression Train 5	105	19.0	**98**	6.8	5.16	367	186	**505**	35	5.15	367	186	**2,605**	180	5.16	367	186
Compression Train 6	105	19.0	**218**	15	11.47	516	269	**435**	30	2.00	211	100	**1,595**	110	3.67	373	189

Partial CO_2 Scrubbing

Partial CO_2 Scrubbing

- *Involves modular design of CO_2 absorption-desorption process, where each module handles certain percentage (20 to 25%) of flue gas flow.*
- *Envisioned as a first step toward reducing CO_2 emissions from existing power plants.*
- *The first CO_2 scrubbing module to be retrofitted to an existing power plant will be designed to use as much recovered heat as possible, to minimize efficiency and capacity losses.*
- *Subsequent modules will be deployed as CO_2 scrubbing technology improves.*

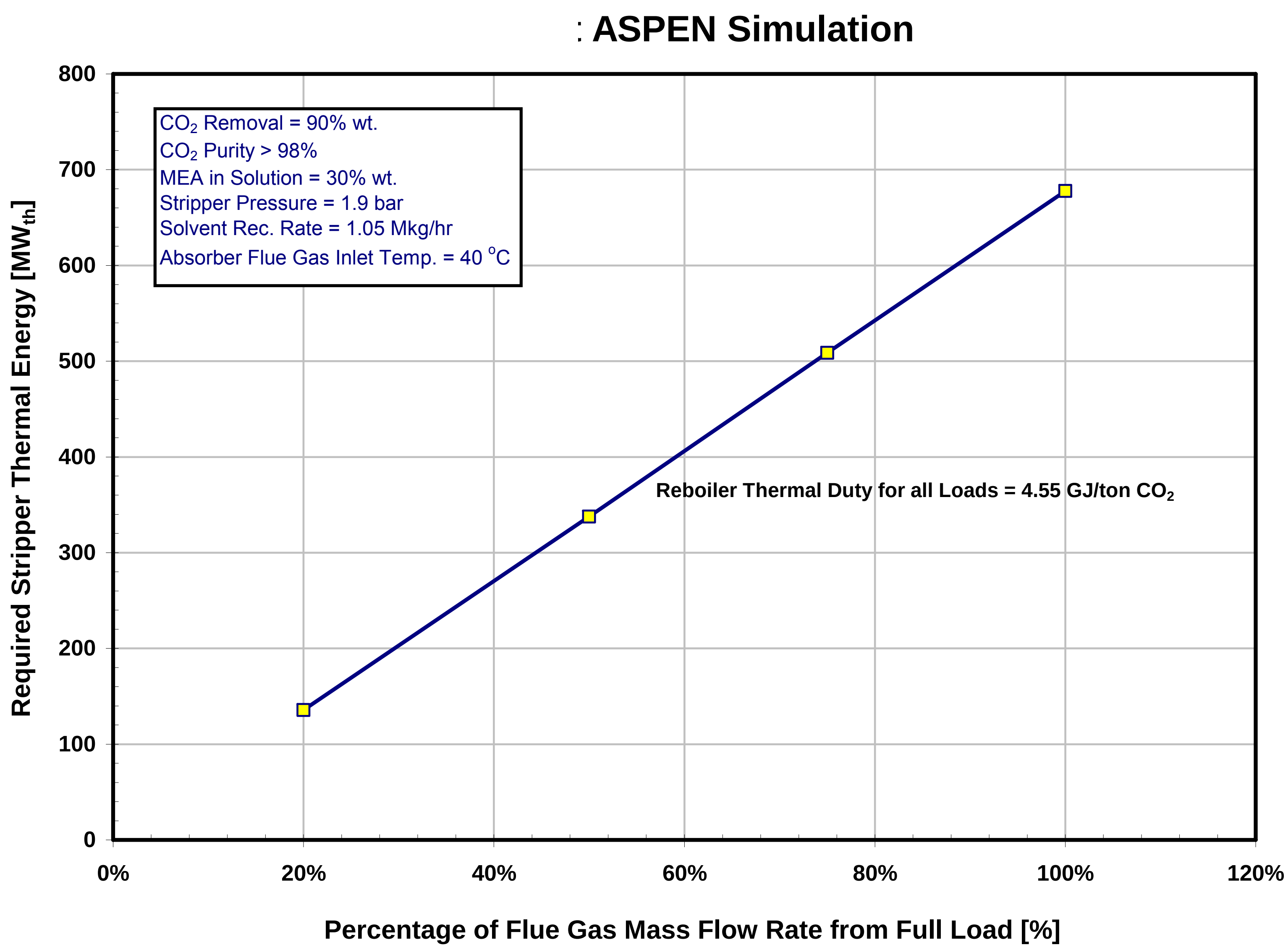
Partial CO_2 Scrubbing



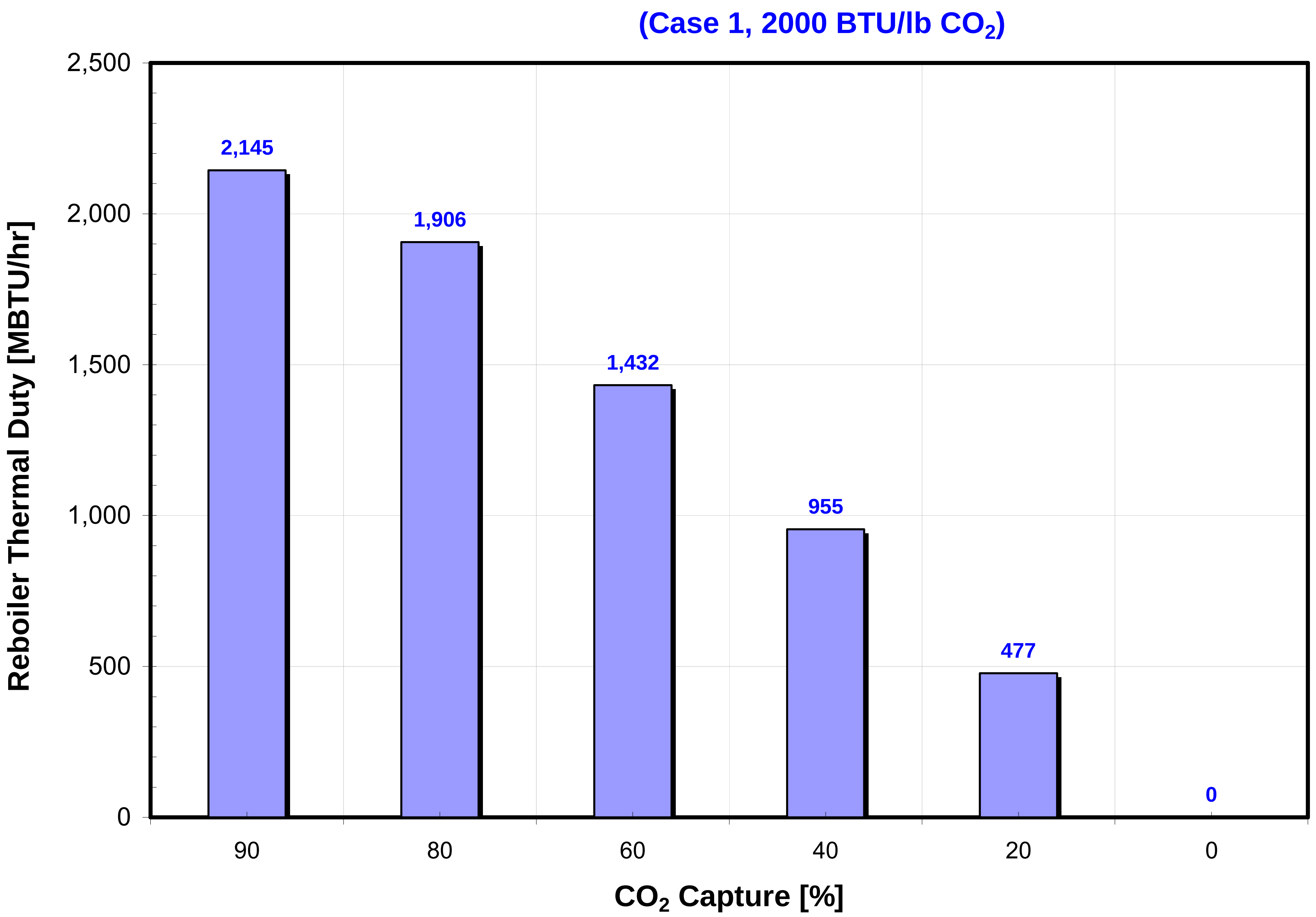
Partial CO_2 Scrubbing

- *Partial CO_2 scrubbing – path to faster deployment of post-combustion CO_2 capture.*
  - *35th International technical Conference on Clean Coal and Fuel Systems: Panel No. 7 "Speeding up of CCS Deployment: High Efficiency Power Plants with Partial Capture of CO_2", Prof. Janos Beer (MIT), Jeff Philips (EPRI), Tom Stringer (Alstom Power), Prof. Lars Stromberg (Vattenfall R&D), Ligang Zheng (CANMET)*
- ***NYSERDA Project**: Heat integration of partial CO_2 scrubbing concept is in progress for analyzed cases.*

Effect of Flue Gas Flow Rate on Stripper Energy



Results: Partial CO_2 Scrubbing



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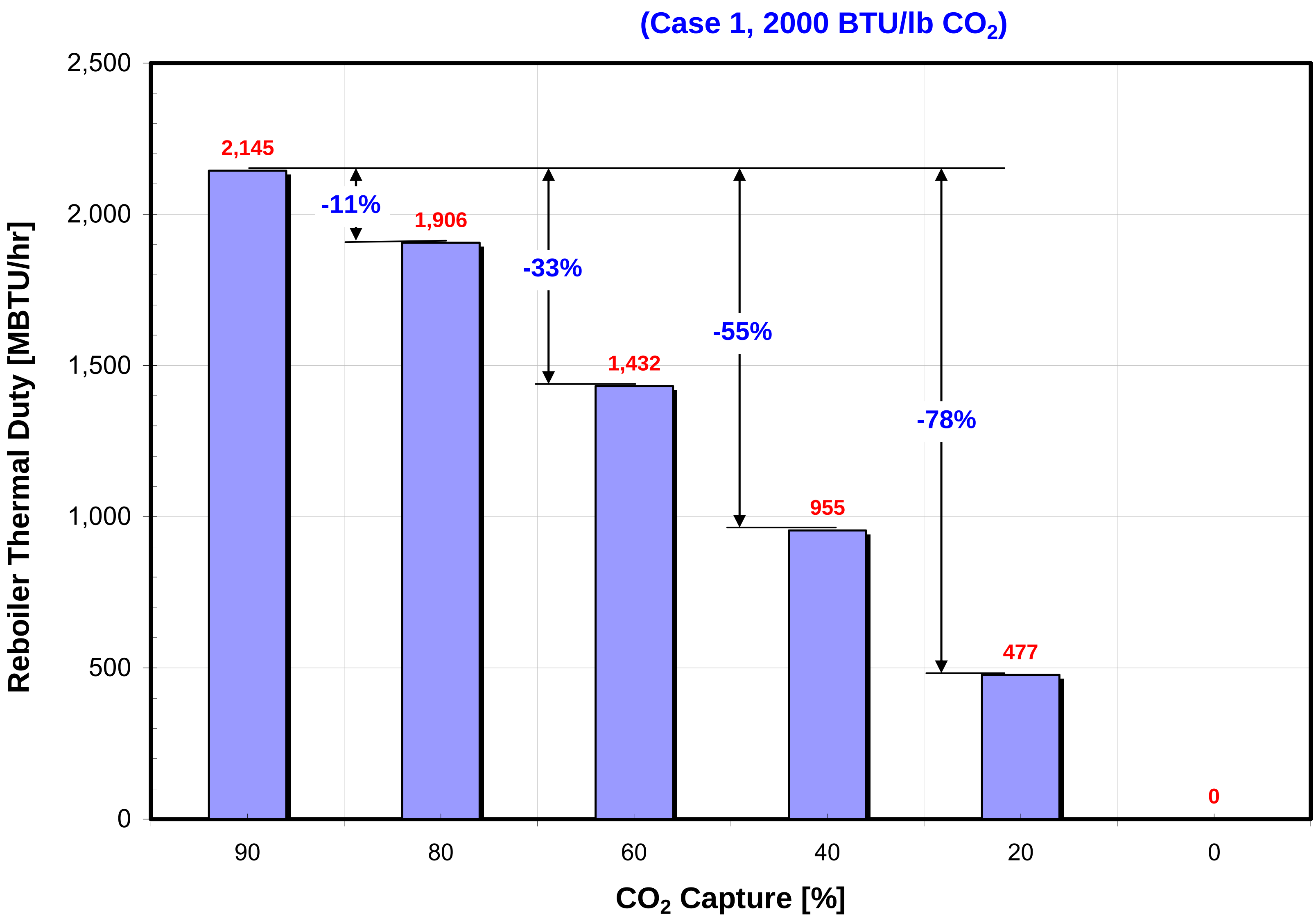
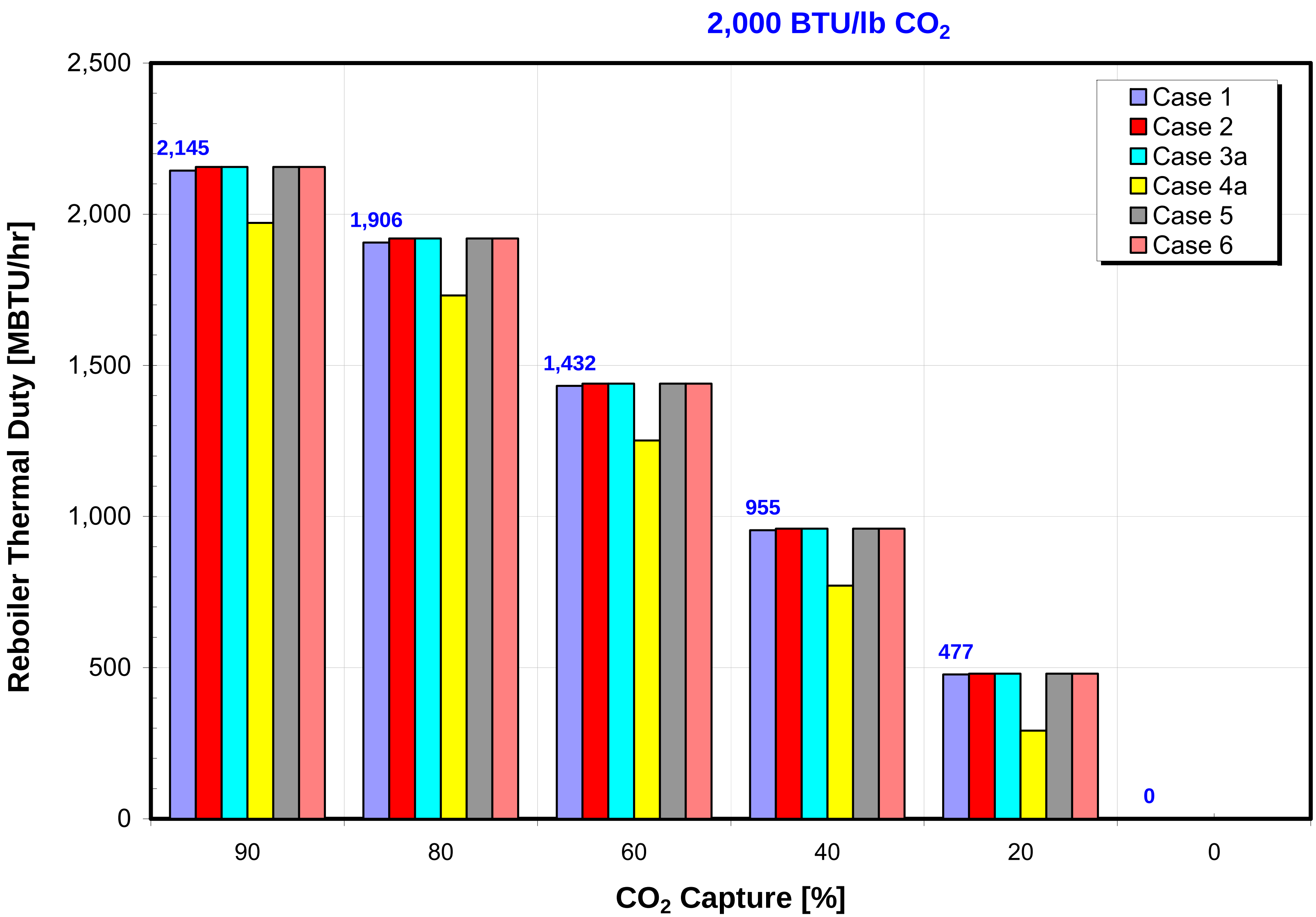
Results: Partial CO_2 Scrubbing

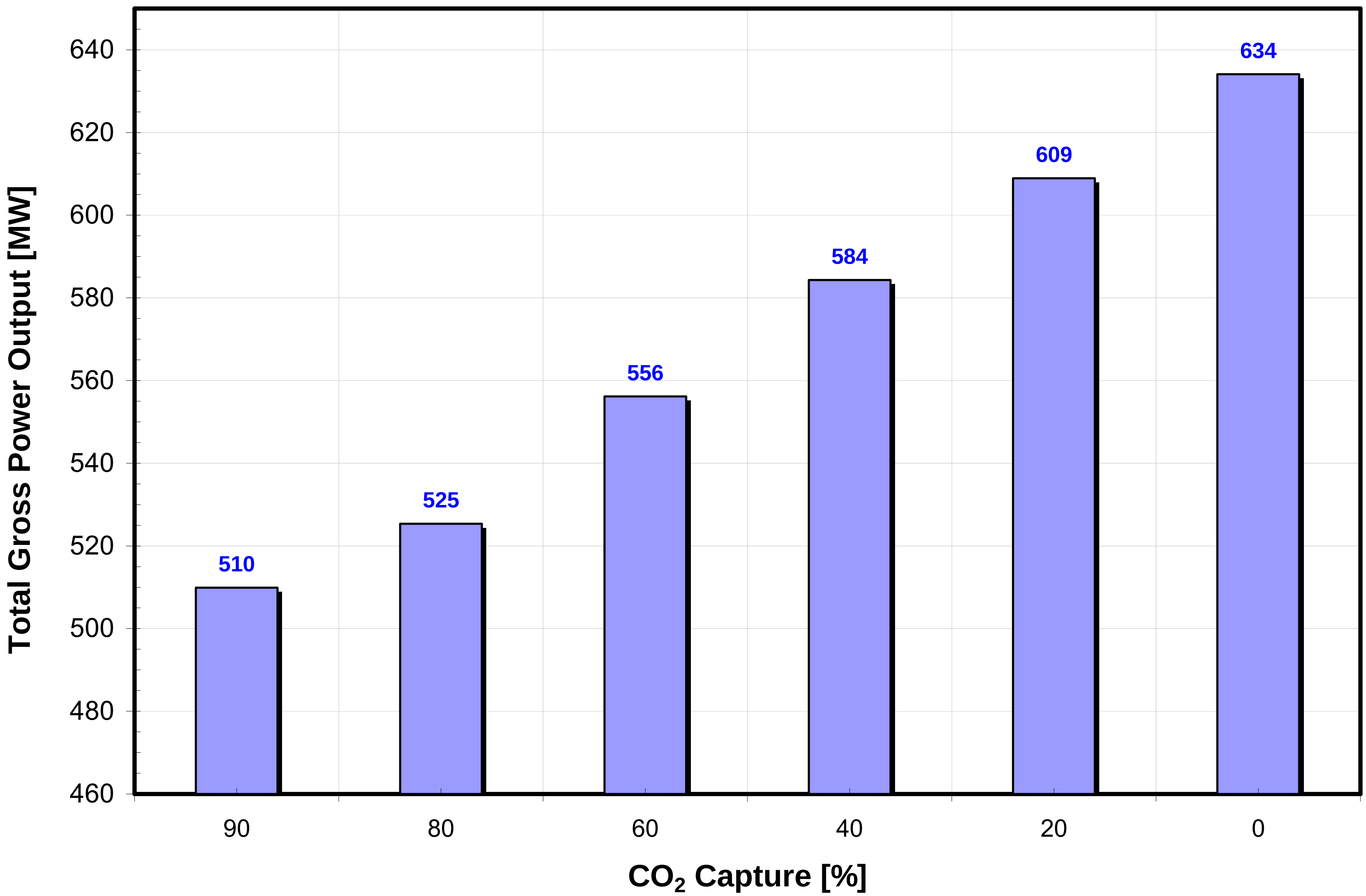


Results: Partial CO_2 Scrubbing

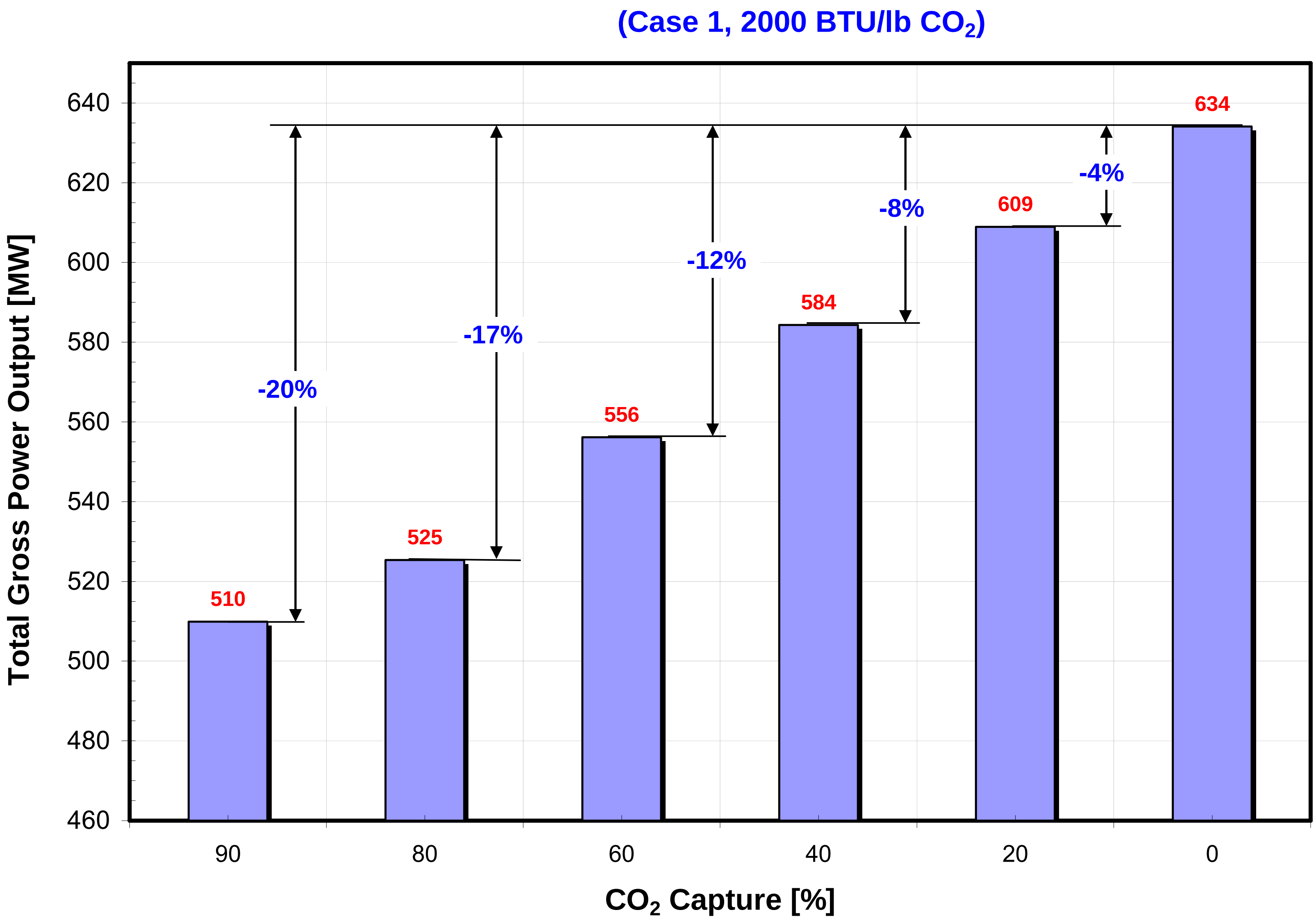


Results: Partial CO_2 Scrubbing

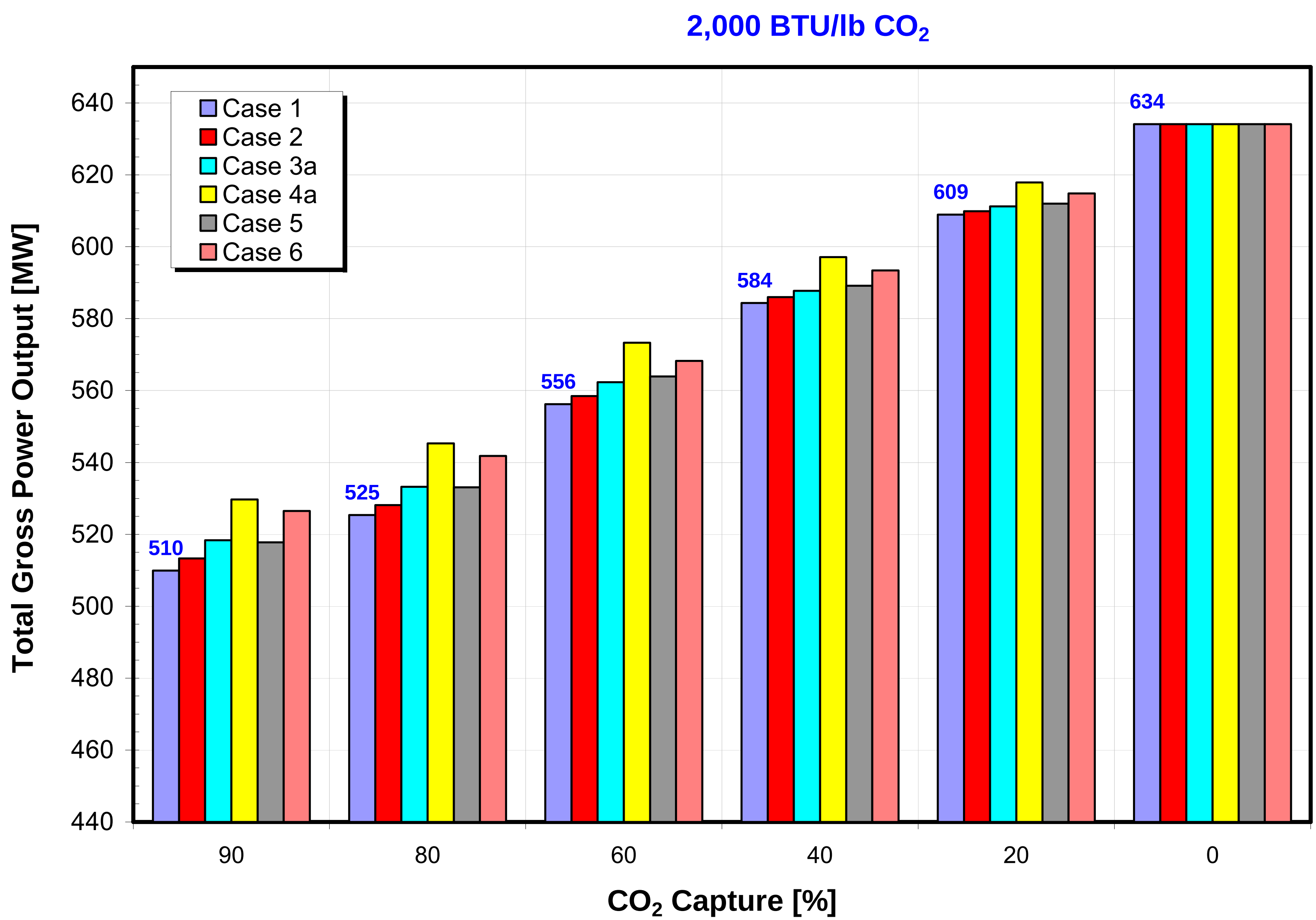
(Case 1, 2000 BTU/lb CO_2)



Results: Partial CO_2 Scrubbing



Results: Partial CO_2 Scrubbing



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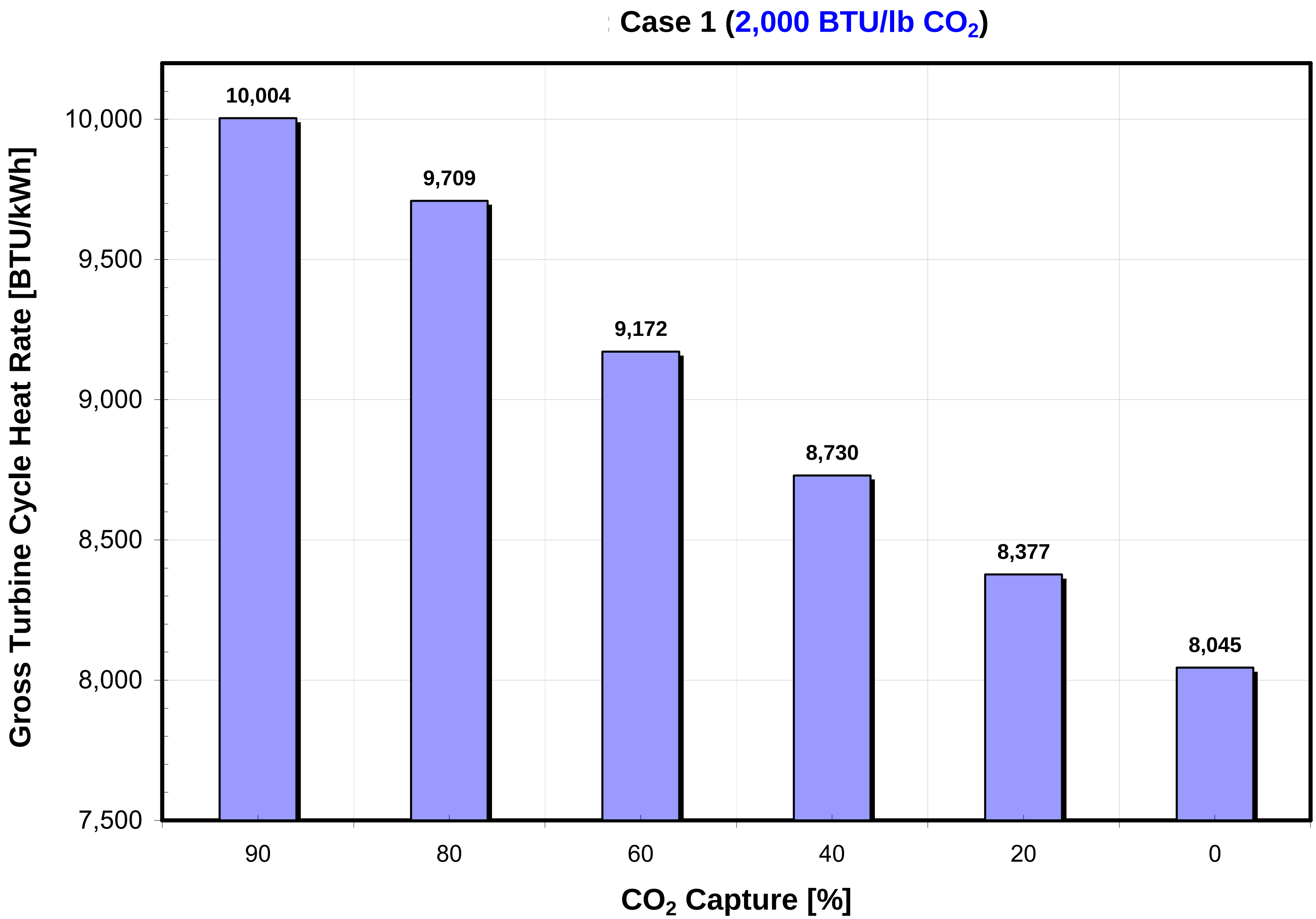
Results: Partial CO_2 Scrubbing



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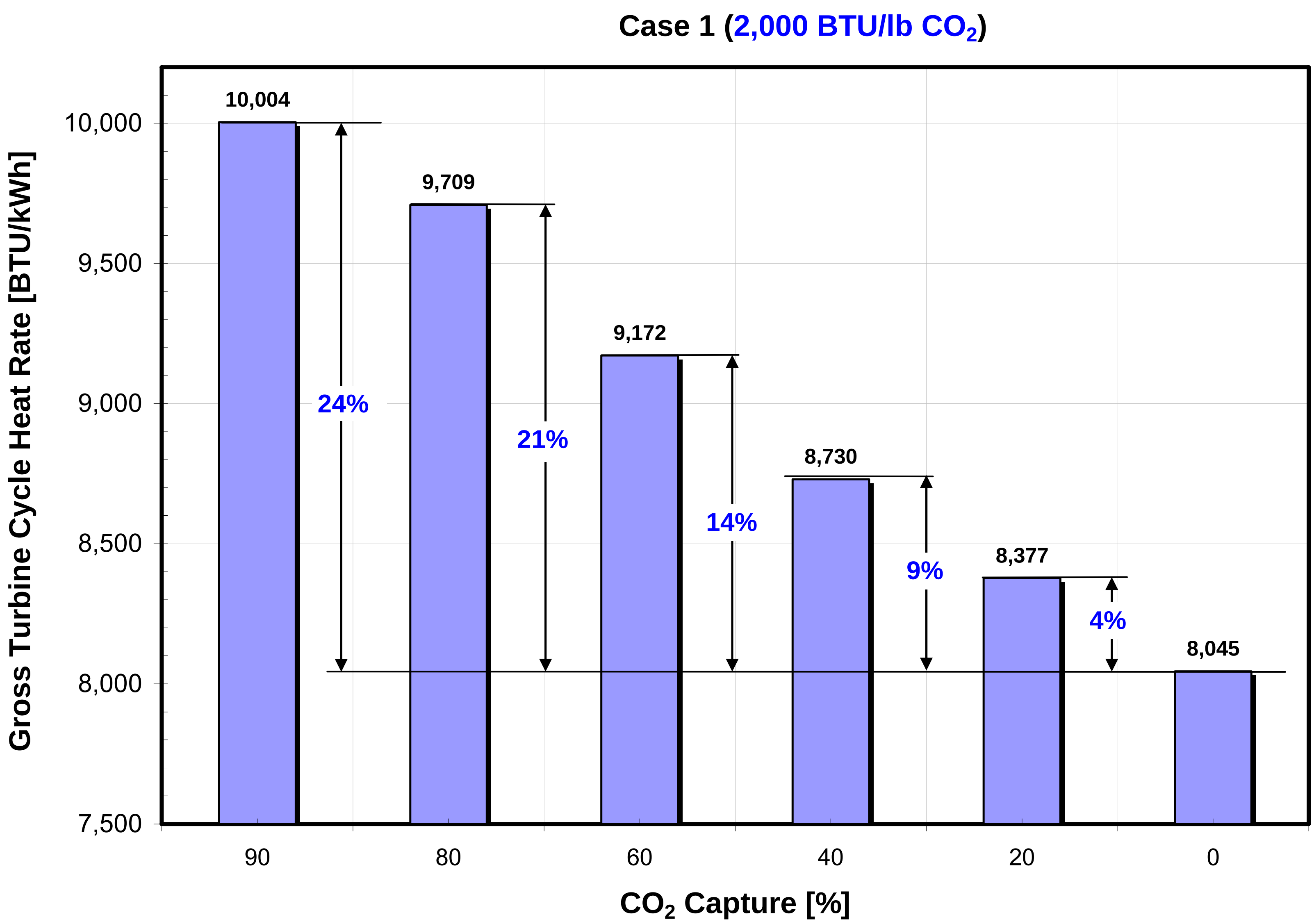
Results: Partial CO_2 Scrubbing



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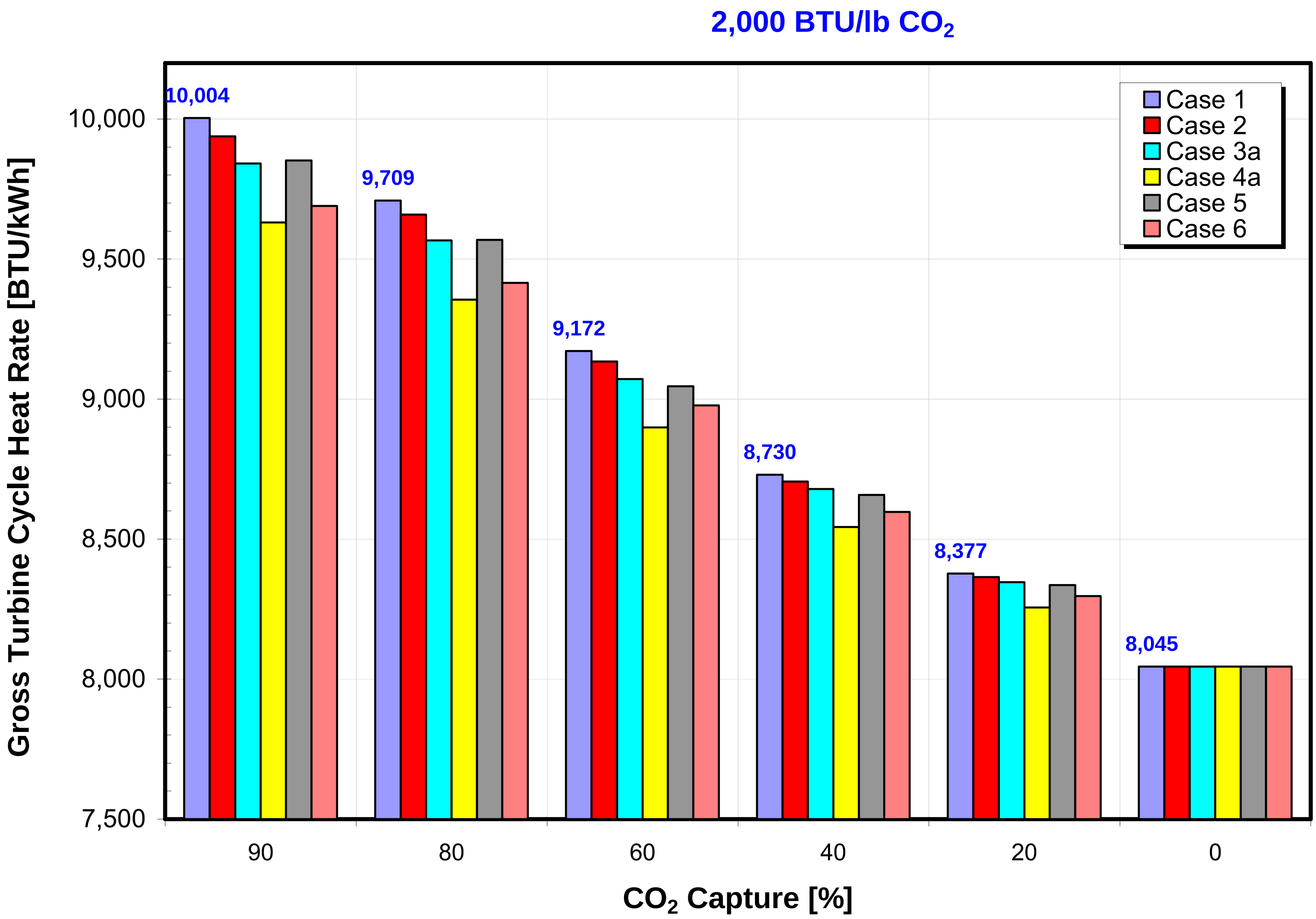
Results: Partial CO_2 Scrubbing



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Conclusions

- *Heat recovered from flue gas and CO_2 compression heat can be used to partially offset efficiency and capacity losses due to post-combustion CO_2 capture.*
  - *Optimization of MEA CO_2 capture process can reduce reboiler thermal duty by 26%.*
  - *Performance of steam turbine cycle can be improved by up to 1.5% by using heat recovered from flue gas for low-pressure feed water heating.*
    - *Improvement in turbine cycle heat rate is significantly higher (more than 6%) if high-pressure feedwater heater steam extractions are eliminated.*
  - *Thermal integration of CO_2 stripper with plant waste heat sources can:*
    - *Reduce reboiler thermal duty by more than 8%.*
    - *Improve gross turbine cycle heat rate by 4.6% and cycle efficiency by 1.32%-points relative to conventional CO_2 scrubbing process.*
    - *Improve net unit heat rate by 4.5% and net unit efficiency by 1.14 %-points relative to conventional CO_2 scrubbing process.*
  - *Effect of partial CO_2 scrubbing on unit efficiency and capacity is linear.*
  - *Development of advanced CO_2 sorbents is critical to reducing performance and capacity penalty due to CO_2 capture.*


Questions ?