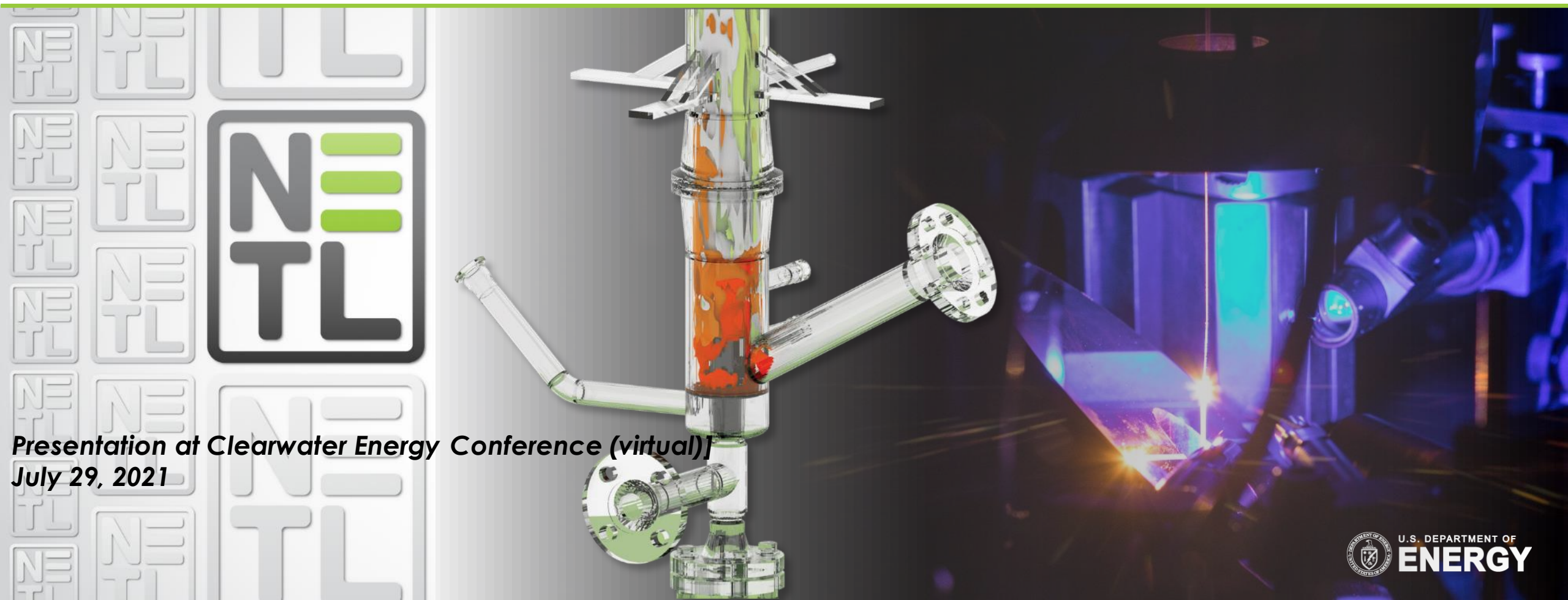


Techno-Economic Analysis of an Indirect sCO₂ Cycle for Natural Gas Combined Cycles (NGCCs)



Solutions for Today | Options for Tomorrow

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NETL Support Contractor*



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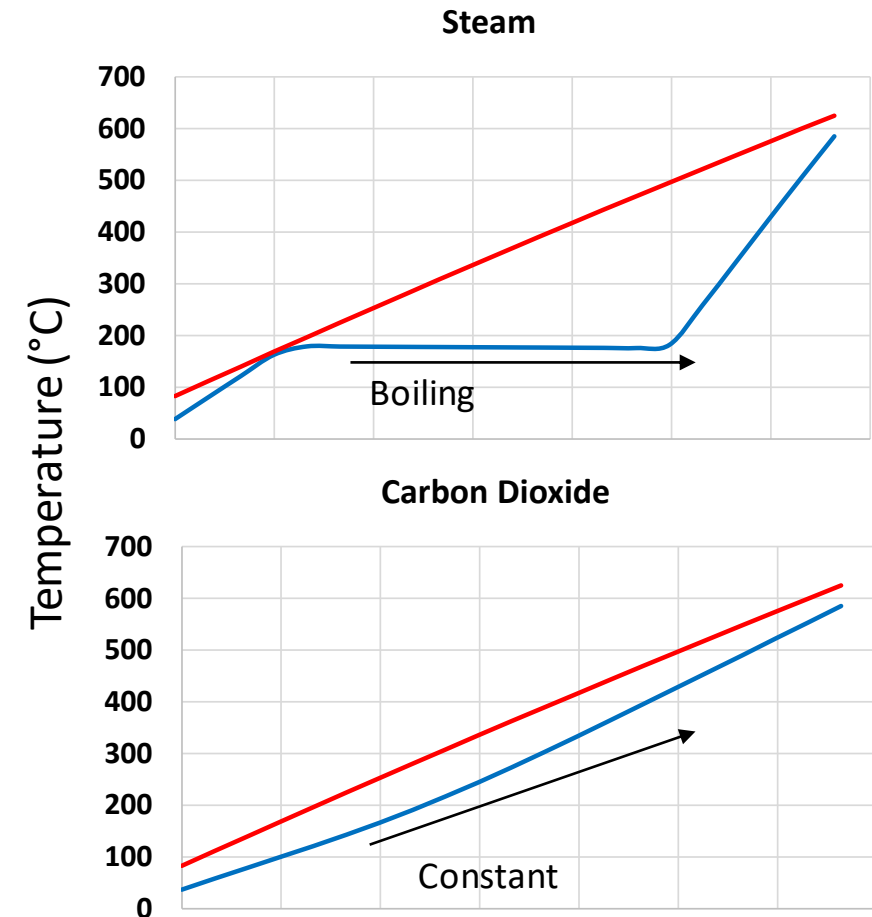
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- Overview
- Steam Rankine Bottoming Cycle
- Possible Supercritical Carbon Dioxide (sCO₂) Configurations
- Cost Analysis
- Summary of Cost and Performance
- Recommendations

Overview

- A natural gas combined cycle (NGCC) power plant employs a steam Rankine cycle as its bottoming cycle, in order to draw waste heat from the flue gas for additional power generation
- $s\text{CO}_2$ has a number of advantages over steam for this application, including smaller equipment footprint and a constant heat capacity for waste heat recovery [1]

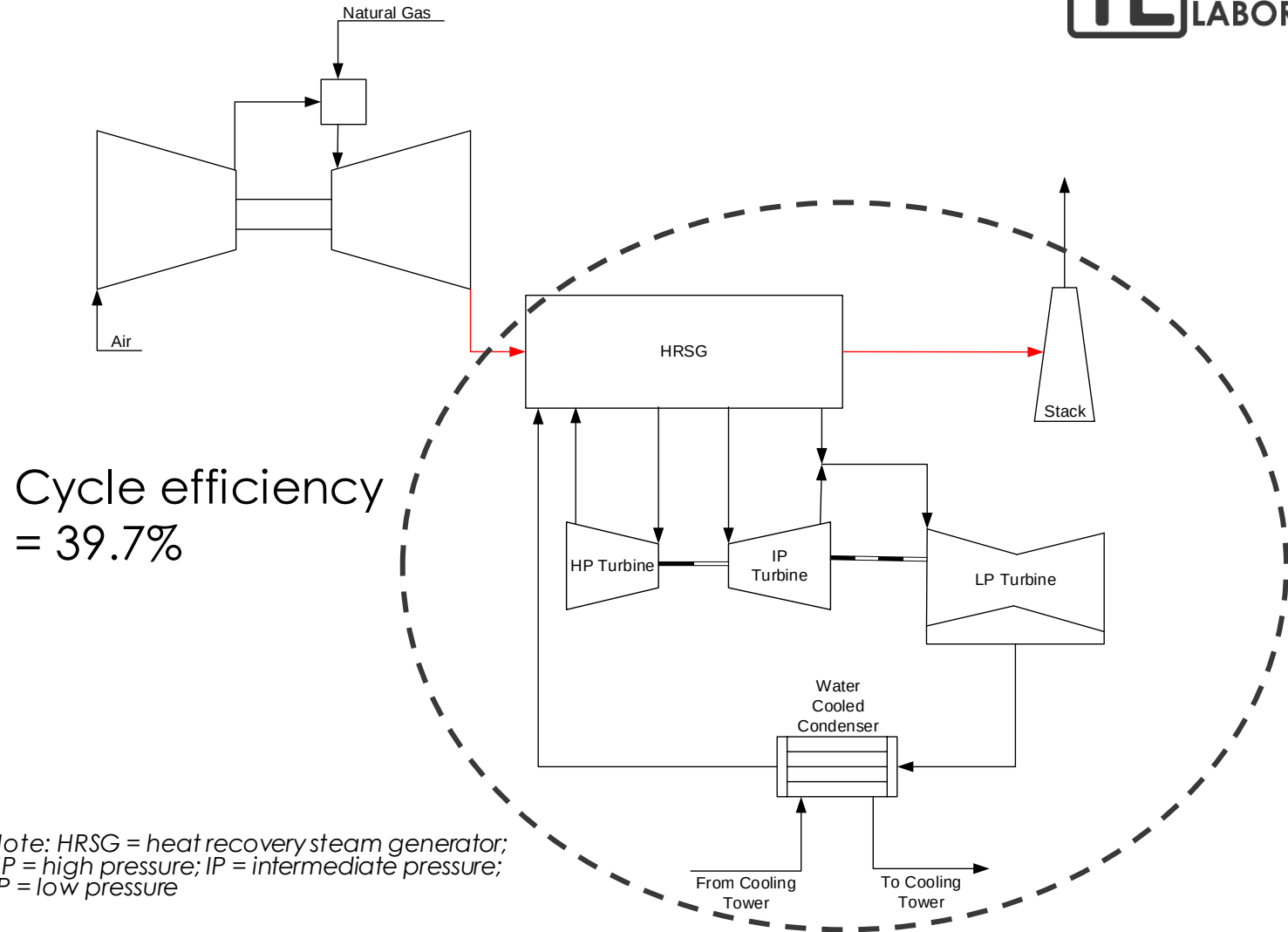


[1] M. Persichilli, et al., "Supercritical CO_2 Power Cycle Developments and Commercialization: Why CO_2 Can Displace Steam" Echogen, April 2012.

Source: NETL

Steam Rankine Bottoming Cycle

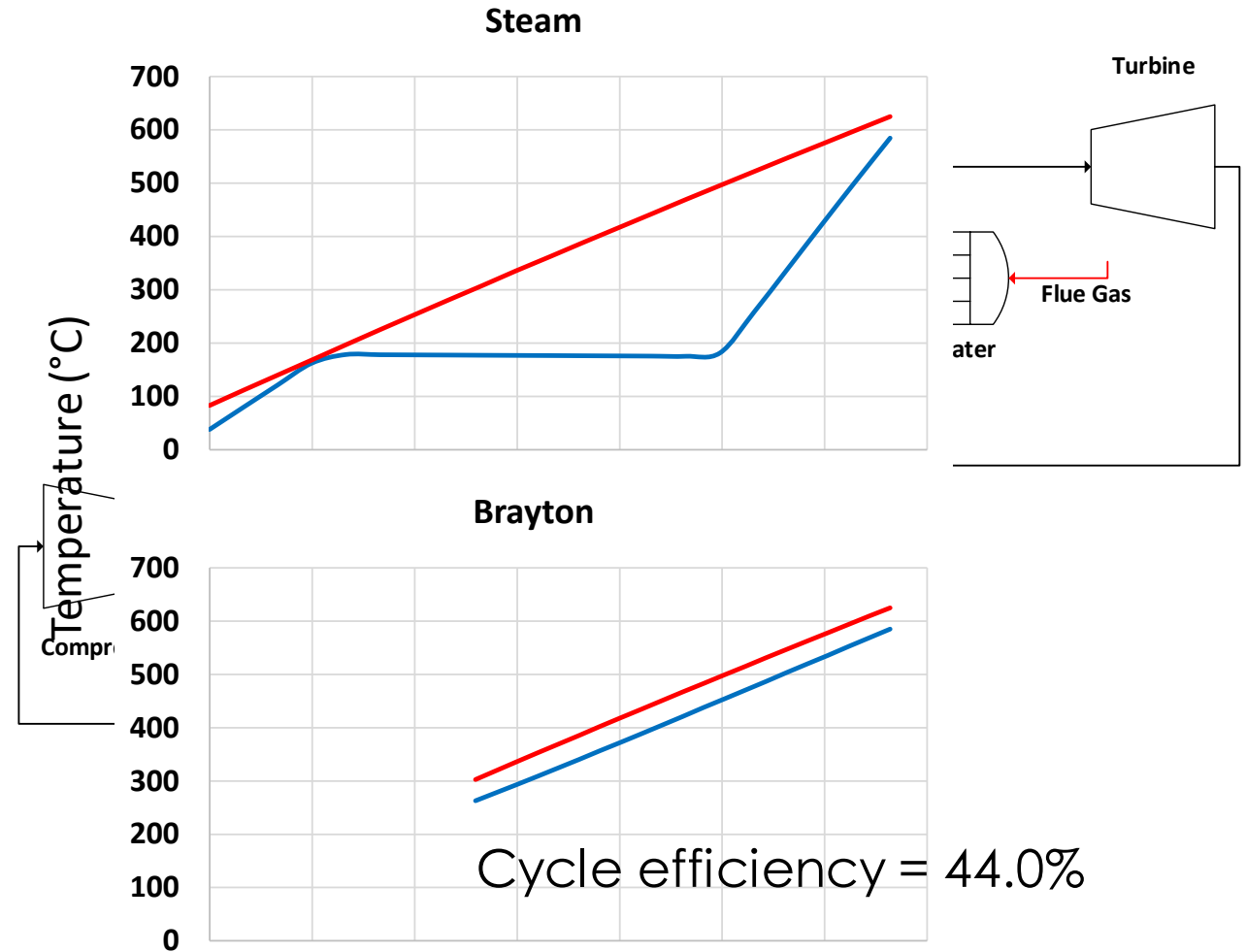
- Base case for NGCC bottoming cycle [1]
- Heat from combustion turbine is recuperated using steam Rankine cycle before being sent to stack, using turbines at three different pressures



[1] National Energy Technology Laboratory, "Bituminous Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 4," Department of Energy, June 2018.

Possible sCO₂ Configurations

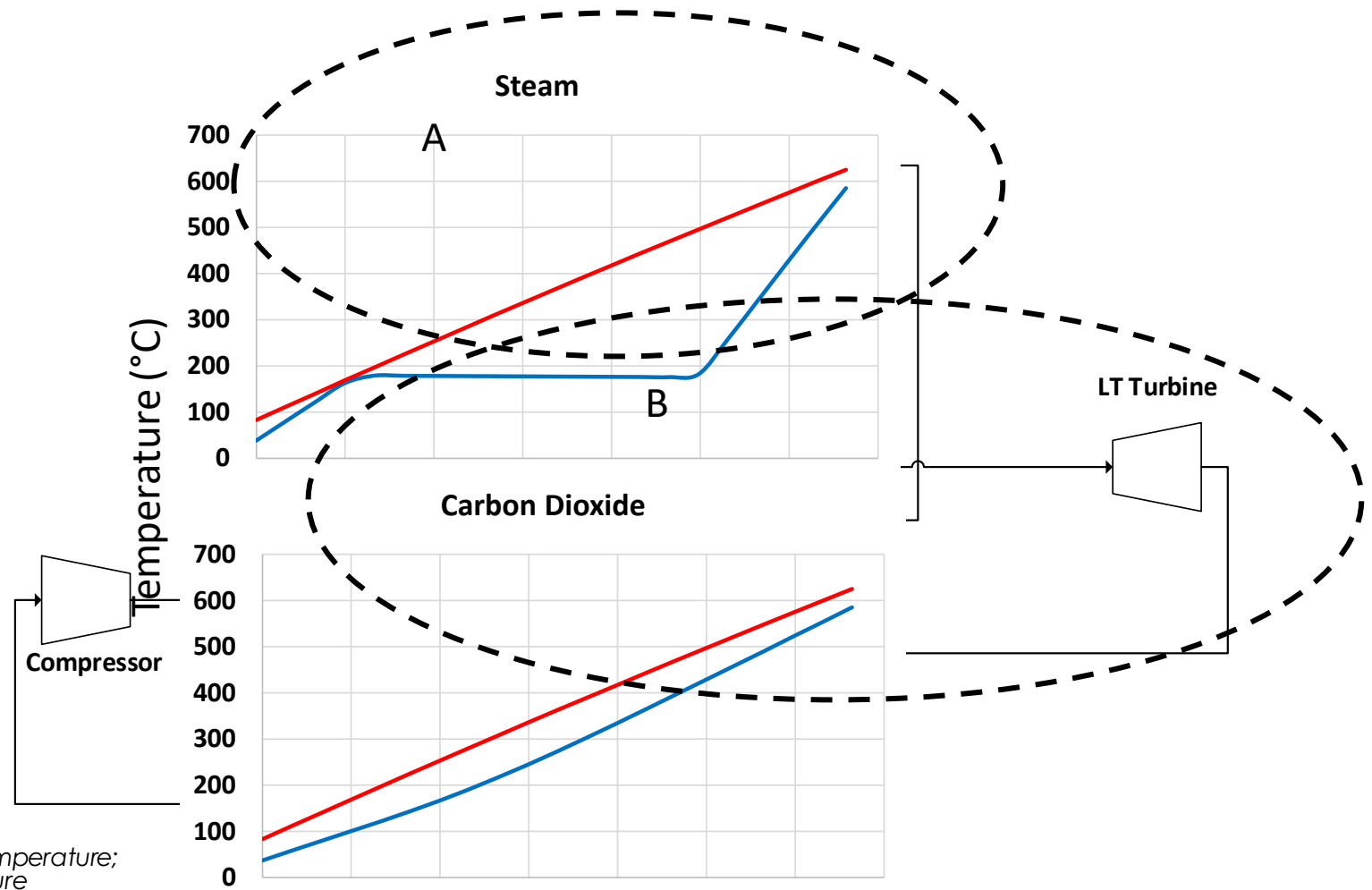
- A simple Brayton cycle features a heater to bring heat from the exhaust gas into the sCO₂ working fluid, and recuperators for recovering the turbine exhaust
 - Higher cycle efficiencies than the steam cycle, but is unable to recover all of the waste heat, resulting in lower efficiencies for the plant



Source: NETL

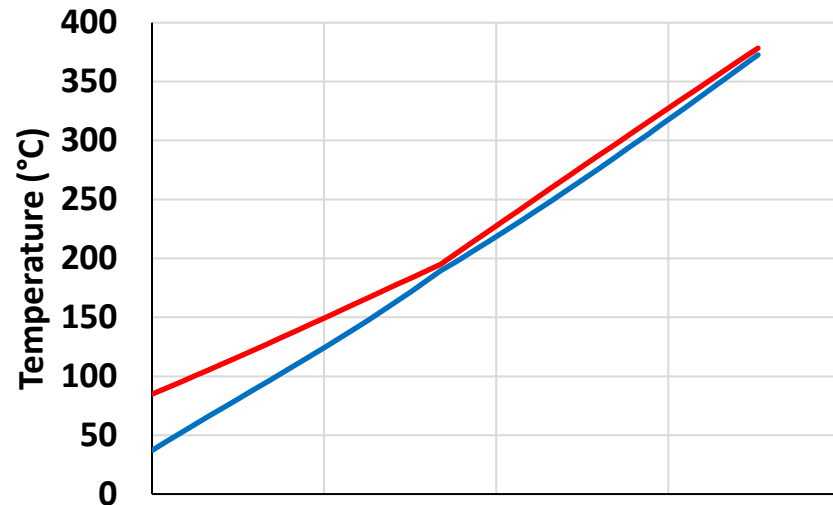
Possible sCO₂ Configurations (continued)

- The “Cascade” cycle in literature balances the efficiency of the cycle with the maximized recuperation of thermal energy
 - The cycle can be reimagined as two separate “cascaded” cycles, which make use of the waste heat twice

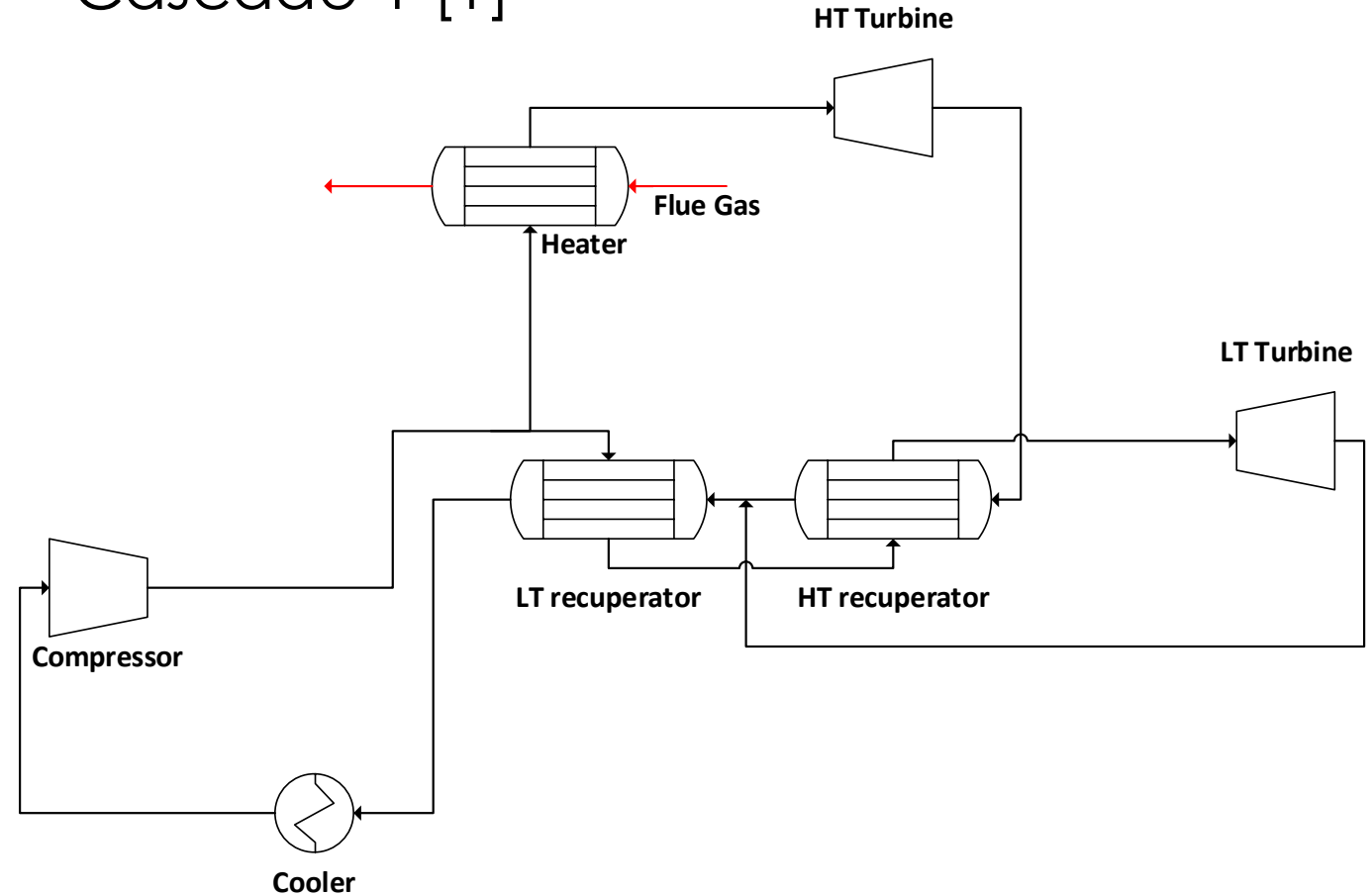


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Possible sCO₂ Configurations (continued)



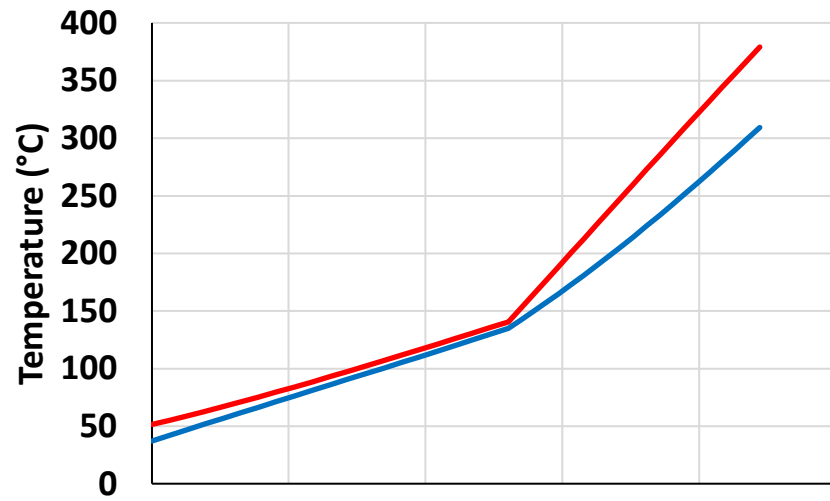
Cascade 1 [1]



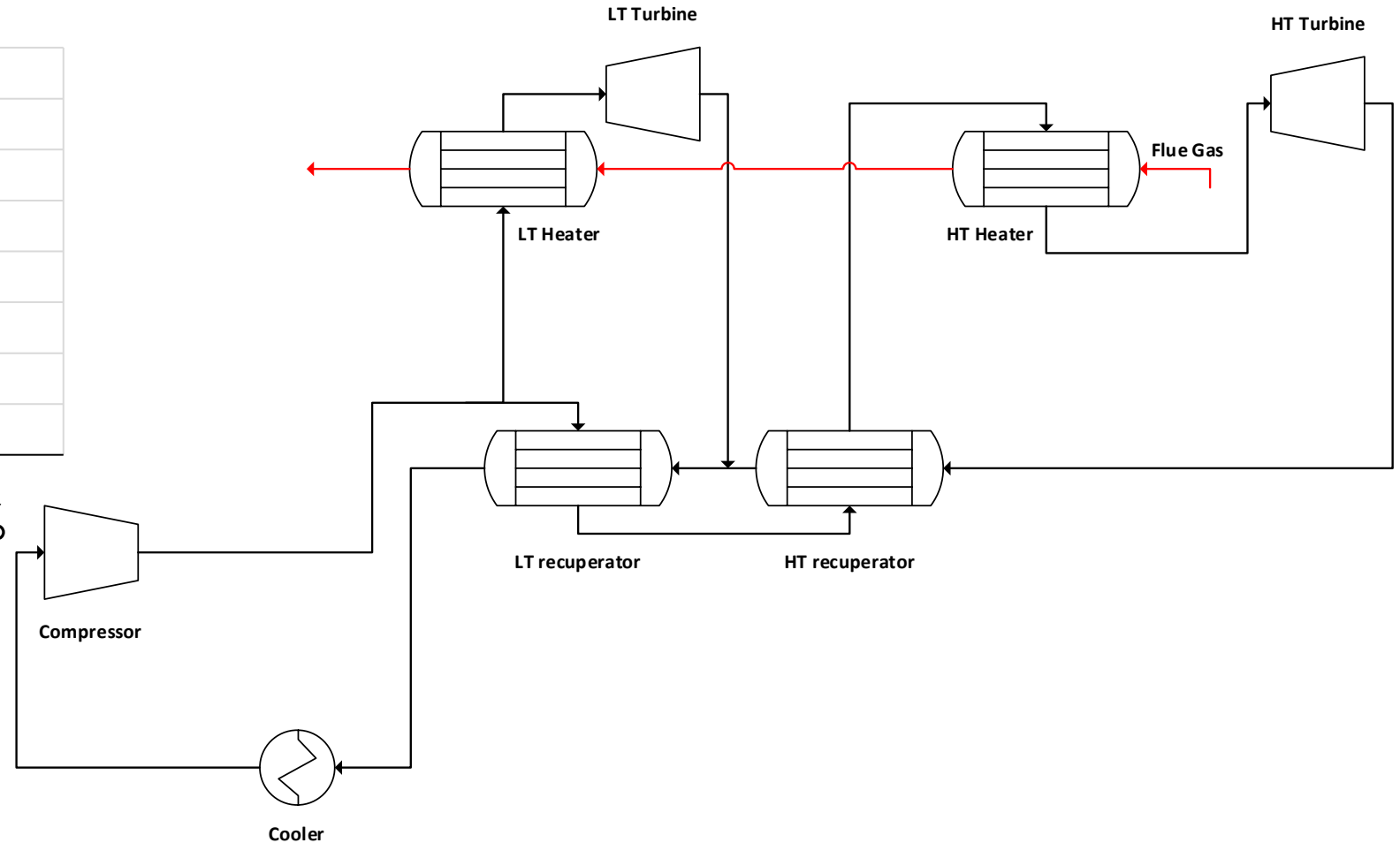
[1] Kimzey, Grant, "Development of a Brayton Bottoming Cycle using Supercritical Carbon Dioxide as the Working Fluid," EPRI, 2012.

Possible sCO₂ Configurations (continued)

Cascade 2 [1]



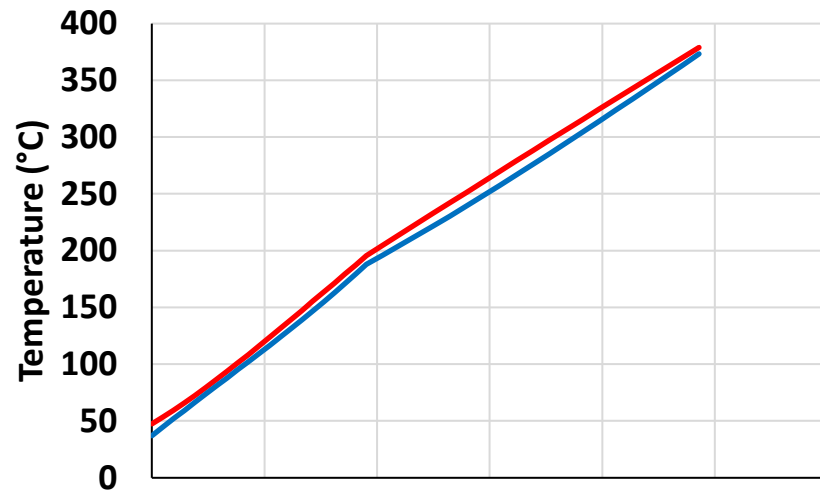
Cycle efficiency = 37.3%



[1] Kimzey, Grant, "Development of a Brayton Bottoming Cycle using Supercritical Carbon Dioxide as the Working Fluid," EPRI, 2012.

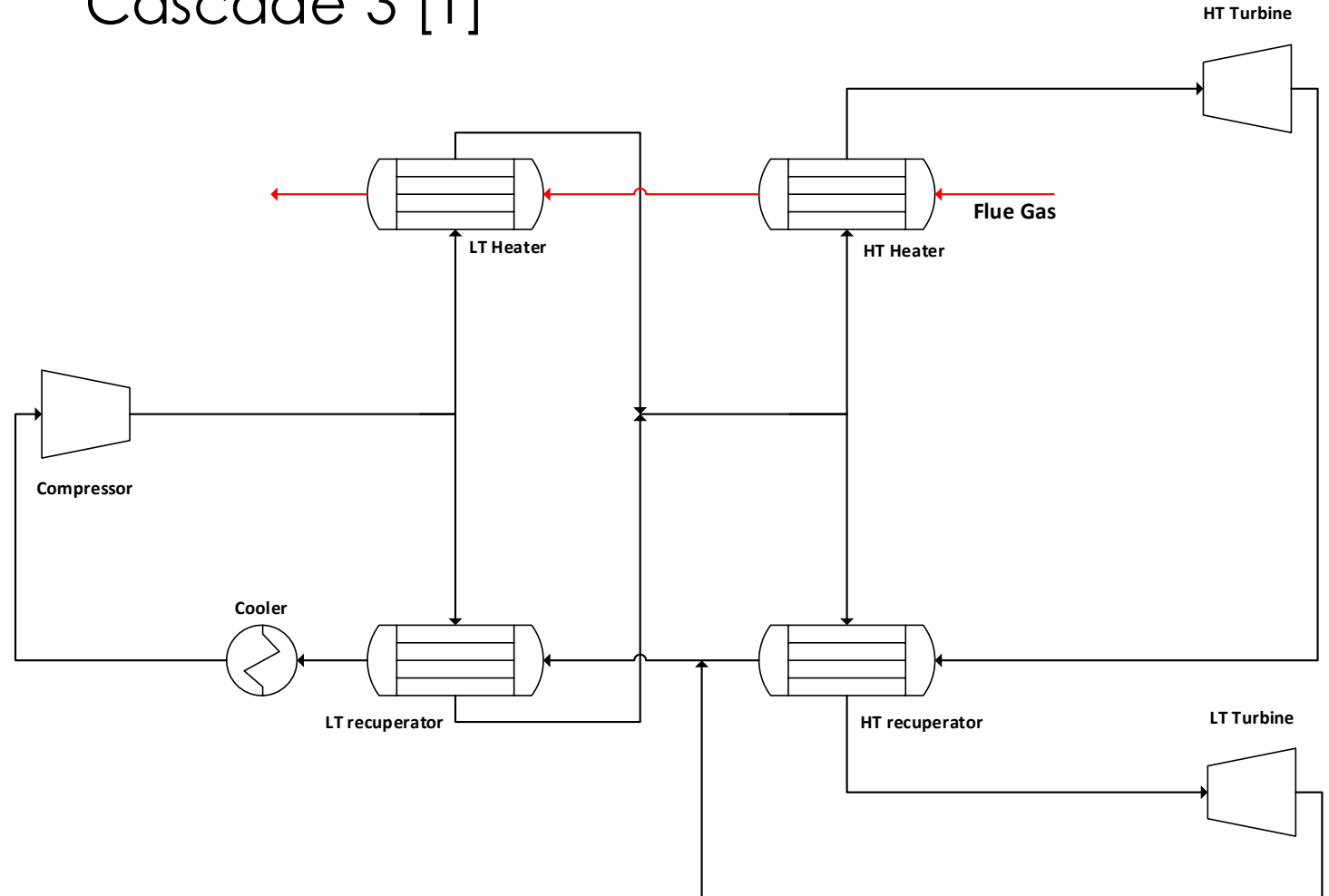
Source: NETL

Possible sCO₂ Configurations (continued)



Cycle efficiency = 39.2%

Cascade 3 [1]



[1] Kimzey, Grant, "Development of a Brayton Bottoming Cycle using Supercritical Carbon Dioxide as the Working Fluid," EPRI, 2012.

Source: NETL

Base Case Parameters

Combustion Cycle Parameters [1]	
Combustion Turbine Power, MWe	477
CO ₂ Capture/Removal Auxiliaries, kWe	0
HHV Combustion Turbine Efficiency, %	35.2%
LHV Combustion Turbine Efficiency, %	39.0%
Natural Gas Feed Flow, kg/hr (lb/hr)	93,300 (206,000)
HHV Thermal Input, kWt	1,355,000
LHV Thermal Input, kWt	1,223,000

Bottoming Cycle Parameters	
Inlet Temperature (To Main Compressor), °C [3]	20
Low Pressure, Mpa [3]	5.86
High Pressure, Mpa [3]	28
Gas-to-gas Heat Exchanger Temperature Approach, °C [1]	40
Compressor Efficiency, % [2]	85
Intercooler Pressure Drop, Mpa [3]	0.03
Turbine Isentropic Efficiency, % [2]	92.7
Recuperator/Heater Pressure Drop, Mpa*	0.74
Generator Efficiency, % [2]	98.5
Flue Gas Inlet Temperature, °C [1]	625
Flue Gas Outlet Temperature, °C [1]	83
NG Thermal Input, MW [1]	1355
Combustion Turbine Power, MW [1]	477
Recuperator Temperature Approach, °C [3]	5.6
Flue Gas Mass Flow Rate, Kg/S [1]	1093
Heater (Hot Side) Pressure Drop, Psi [1]	0.75

*Vendor recommendation.

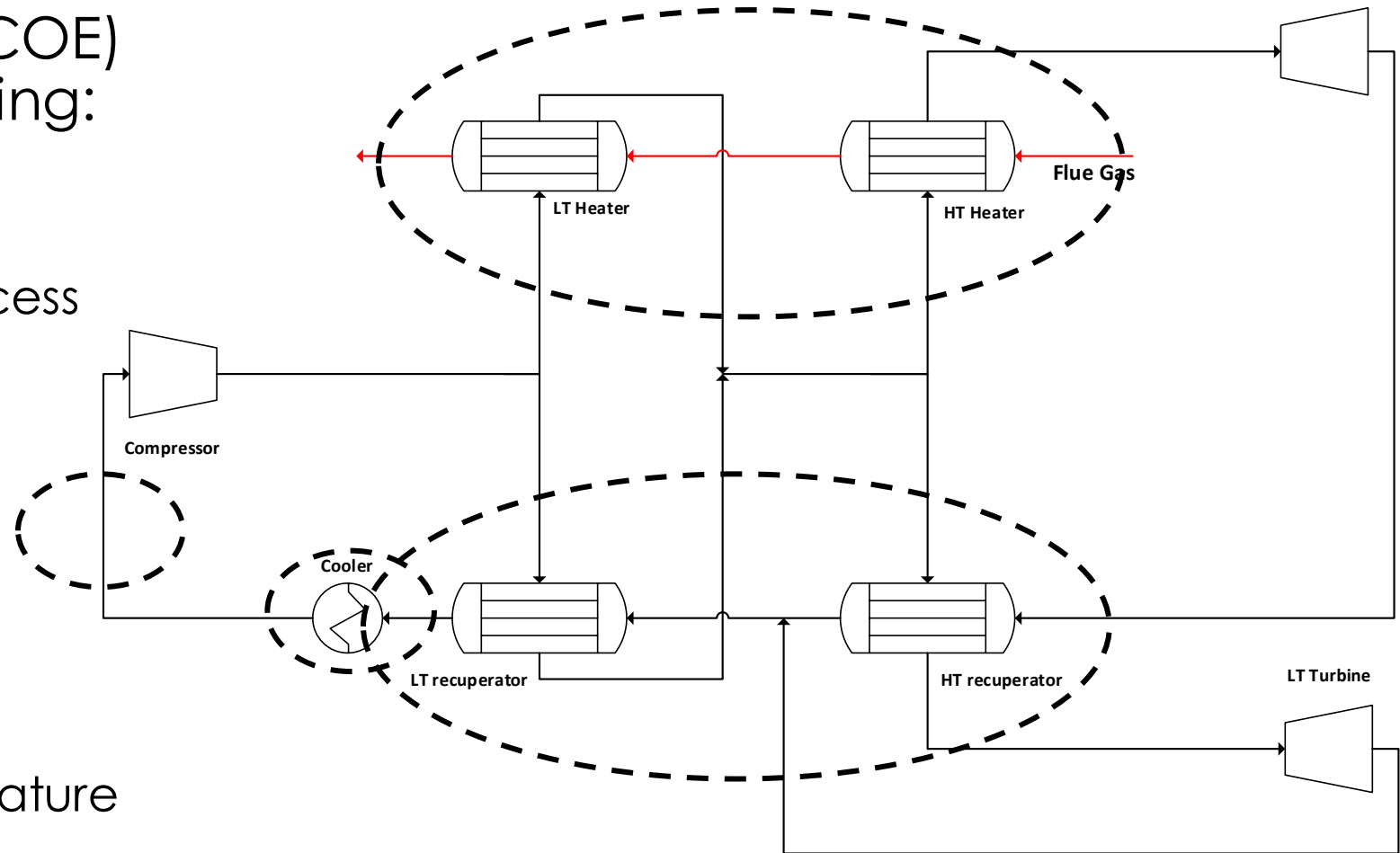
[1] National Energy Technology Laboratory, "Bituminous Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 4," Department of Energy, June 2018.

[2] National Energy Technology Laboratory, "Quality Guidelines for Energy Systems Studies: Process Modeling Design Parameters", Department of Energy, June 2019.

[3] National Energy Technology Laboratory, "Cooling System Cost and Performance Models for Economic CO₂ Plant Optimization of Cooling Technology and Cold CO₂ Temperature", Department of Energy, October 2020.

Cost Analysis

- Full cost of electricity (COE) estimate generated using:
 - Aspen Plus v.10
 - NIST REFPROP
 - Cost correlations for process equipment [1]
 - Vendor data
- Sensitivities include:
 - Recuperator pinch temperature
 - Heater pinch temperature
 - Compressor inlet temperature
 - Cooling technology [2]

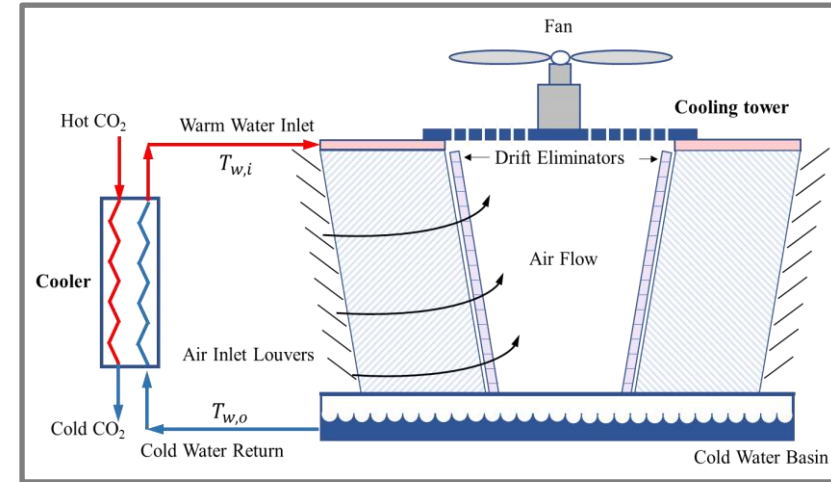


[1] National Energy Technology Laboratory, "sCO₂ Power Cycle Component Cost Correlations from DOE Data at a Spanning Multiple Scales and Applications", Department of Energy, June 2019.

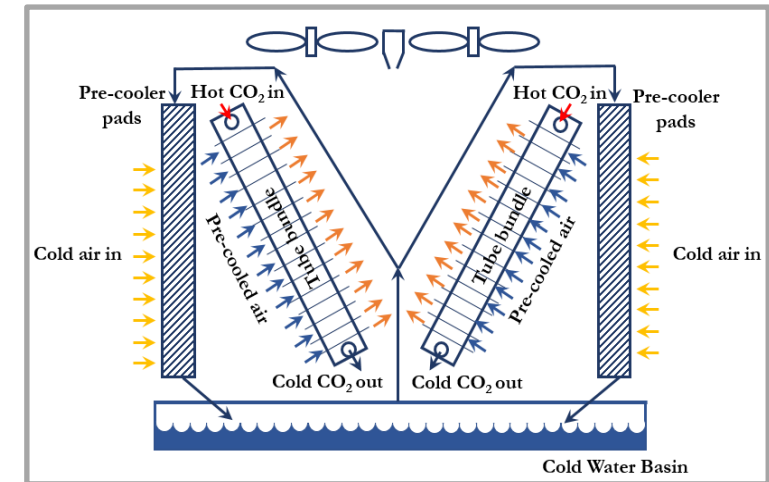
[2] National Energy Technology Laboratory, "Cooling System Cost and Performance Models for Economic sCO₂ Plant Optimization of Cooling Technology and Cold sCO₂ Temperature", Department of Energy, September 2019. Source: NETL

Cost Analysis (continued)

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Source: NETL [2]



[1] National Energy Technology Laboratory, "sCO₂ Power Cycle Component Cost Correlations from DOE Data Spanning Multiple Scales and Applications", Department of Energy, June 2019.

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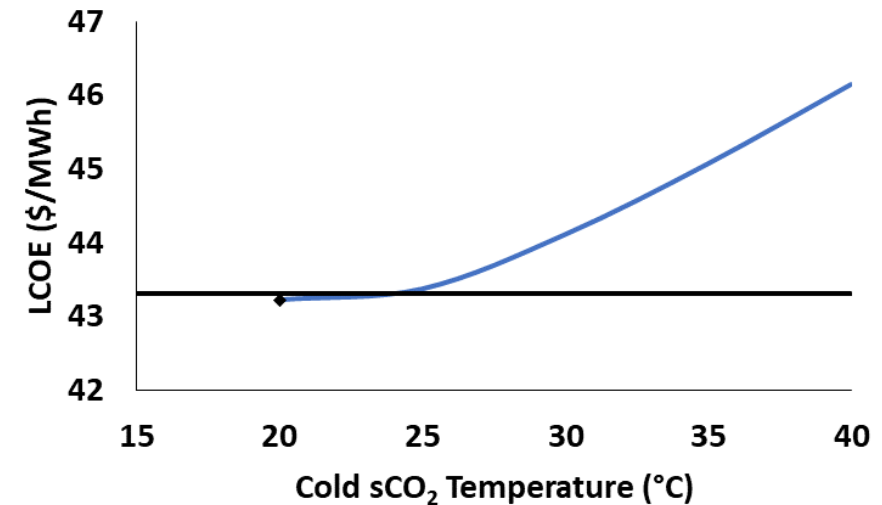
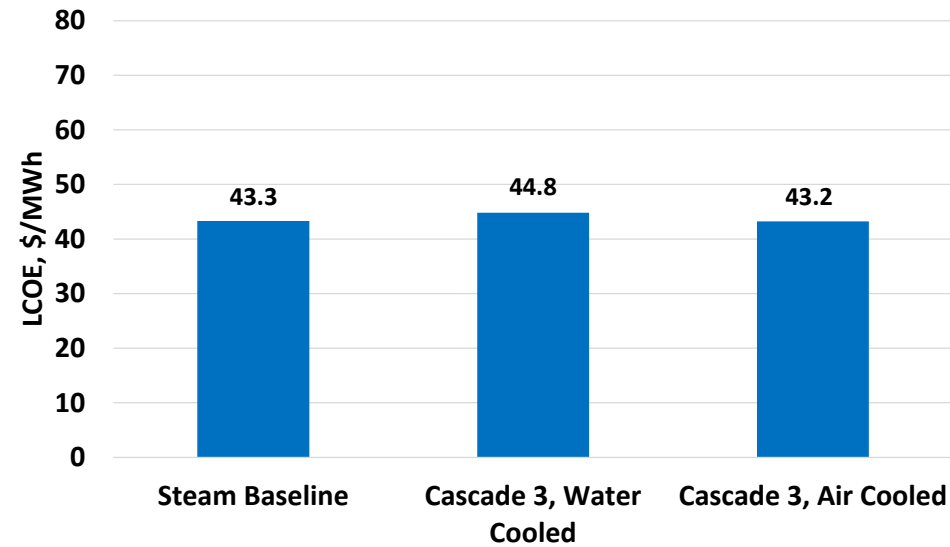
Summary of Cost and Performance

- Results suggest a cycle that is on par with steam Rankine cycle on both an efficiency and cost basis
- Range of values is result of all sensitivity analyses
- In terms of levelized COE (LCOE), impacts on heater and recuperator approach favored lower cost options, whereas cooler technology and cold temperatures favored higher efficiency options

	Steam	Cascade 3
HHV Plant Efficiency	53.6%	49.2–54.4%
Power Output (MW_{sh})	727	667–737
<i>Bottoming Cycle</i>		
Power Output (Minus auxiliaries)	263	195–269
TPC ($\$/\text{kW}_{\text{net}}$)	780	730–901
TPC (\$MM)	567	518–658
LCOE (\$/MWh)	43.3	43.0–46.4
<i>Capital</i>	9.9	9.2–11.4
<i>Fixed O&M</i>	3.6	3.4–4.1
<i>Variable O&M</i>	1.7	1.6–2.1
<i>Fuel</i>	28.1	27.7–30.6

Summary of Cost and Performance (continued)

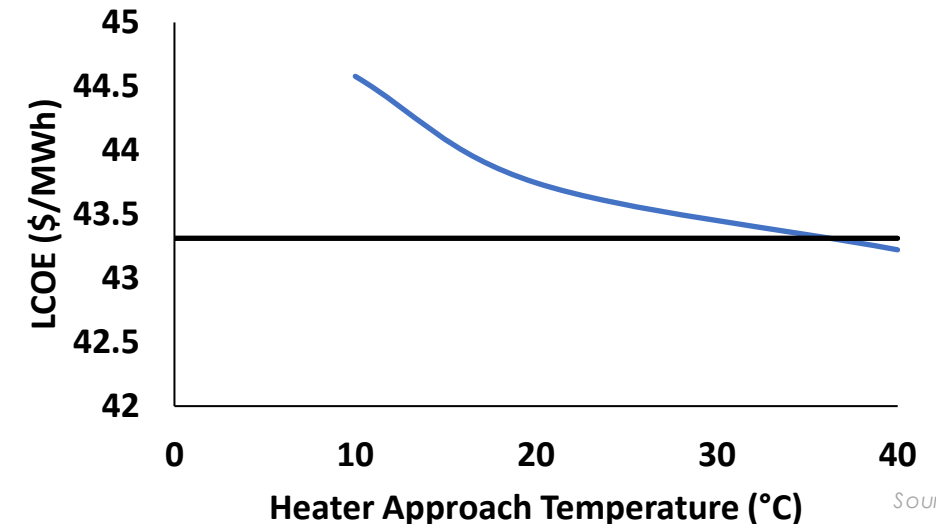
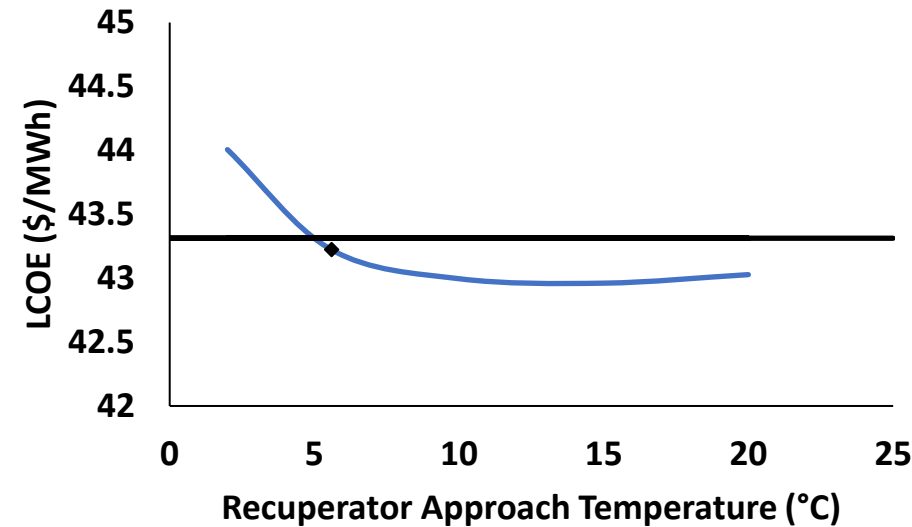
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Source: NETL

- Research indirect sCO₂ bottoming cycles for NGCCs equipped with carbon capture systems
- Investigate higher performing combustion turbines which have higher exhaust temperatures and produce higher quality waste heat for the bottoming cycle
- Optimize the primary heater and cooling systems, as these remain the largest cost drivers for the cycle

Acknowledgements



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