Georgia Tech College of Engineering
George W. Woodruff School of Mechanical Engineering

Project 1: Combined Cycle Analysis and Design

ME 4315: Fall 2025
Section A
Dr. Simmons

Presented by:
Parth Patel

Introduction

Objective: The primary objective of this project was to develop a comprehensive thermodynamic and economic model of a 2-on-1 combined cycle power plant based on the specifications for the Astoria Plant and Plant 2.

Methodology: Using EES, a detailed model was constructed to simulate the plant's performance. This model was then used to conduct a series of parametric studies to analyze the system's sensitivity to key design, operational, environmental, and economic parameters.

Scope: This report presents the key trends and sensitivities observed from the parametric analyses, covering the impact of choices like pressure ratio, environmental factors like ambient temperature, and economic factors like the cost of fuel.

Design: Sensitivity to Pressure Ratio (PR2)

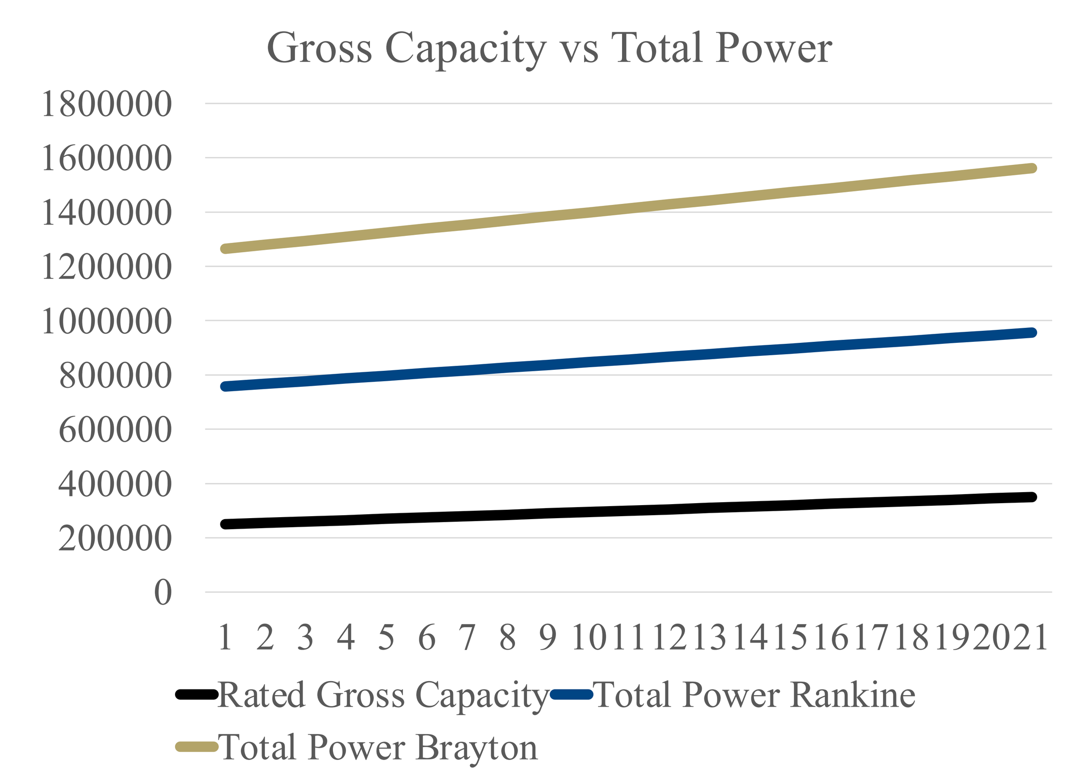
PR2	Q_in_gv	Work_g	n_cycle
5	346079	638	0.7659
6	350532	605.3	0.7561
7	355006	576.3	0.7466
8	359541	549.9	0.7372
9	364167	525.8	0.7278
10	368910	503.3	0.7185
11	373790	482.4	0.7091
12	378828	462.7	0.6997
13	384044	444.1	0.6902
14	389458	426.4	0.6806
15	395088	409.6	0.6709
16	400957	393.5	0.6611
17	407087	378	0.6511
18	413501	363.2	0.641
19	420226	348.9	0.6307
20	427291	335.1	0.6203
21	434727	321.7	0.6097
22	442568	308.8	0.5989
23	450853	296.3	0.5879
24	459625	284.1	0.5767
25	468934	272.2	0.5652

Analysis: A parametric study was conducted on the Brayton cycle pressure ratio (PR2), varying it from 5 to 25, to observe its effect on cycle performance.

Specific Data: The results show that as PR2 increases from 5 to 25, the specific work of the gas turbine decreases from 638 kJ/kg to 272.2 kJ/kg. Concurrently, the calculated overall cycle efficiency decreases from 76.6% to 0.5652.

Implication: The model indicates that for this system, a lower pressure ratio results in higher specific work and greater overall efficiency, showing a high sensitivity to this core design parameter.

Operational: Power Split Sensitivity



Analysis: A parametric study was performed by varying the Rated Gross Capacity input, and the resulting Total Power Rankine and Total Power Brayton outputs were plotted.

Observations : The chart clearly shows a direct, linear relationship between the input and the outputs. The calculated power for the Brayton cycle is higher than the power for the Rankine cycle.

Implication: This linear trend indicates that the Rated Gross Capacity acts as the primary driver for the power output of both cycles in this model. The model's logic appears to scale the power of each cycle directly based on this input, rather than showing a dynamic trade-off between them. This suggests the model is constrained to produce a power output that is directly proportional to the user-defined capacity inputs.

Model Soundness and Limitations

Air-Standard Assumption: The model is based on an air-standard assumption for the Brayton cycle, which simplifies the analysis by treating the working fluid as pure air. This does not account for the different thermodynamic properties of actual combustion products (e.g., CO_2, H_2O).

Simplified Constraints: The model operates with several simplified constraints. Key temperatures, such as the turbine outlet (T4I) and the HRSG stack gas outlet (T_34_b), are defined as fixed inputs. In a real system, these temperatures are resultant variables determined by the overall system performance and component interactions.

Absence of Pressure Drops: The model neglects pressure losses in the combustor and HRSG. In reality, friction causes pressure to drop, which would lower the work output of the turbines. As a result, the model overestimates the plant's actual net power and thermal efficiency.

Evnironmental Considerations

T1 [K]	n_cycle	M_dot_g	Work_g	Exergy
250	0.6975	482.7	565.6	61607
255	0.6994	488	559.5	66061
260	0.7014	493.4	553.3	70593
265	0.7035	499	547.1	75209
270	0.7055	504.7	541	79915
275	0.7076	510.5	534.7	84714
280	0.7097	516.5	528.5	89614
285	0.7119	522.7	522.3	94621
290	0.714	529.1	516	99739
295	0.7162	535.6	509.7	104975
300	0.7185	542.4	503.3	110337
305	0.7207	549.3	497	115836
310	0.7231	556.5	490.6	121473
315	0.7254	563.8	484.2	127256
320	0.7278	571.4	477.8	133193
325	0.7302	579.2	471.3	139292
330	0.7327	587.3	464.8	145562
335	0.7352	595.7	458.3	152012
340	0.7377	604.3	451.8	158653
345	0.7404	613.2	445.2	165494
350	0.743	622.4	438.6	172546

Purpose: To understand the impact of environment conditions on plant performance, the air temperature was analyzed over a range from 250 K to 350 K

Effects: As ambient temperature (T1) rises from 280 K to 310 K, the required compressor work increases (exergy rises from 89,614 kW to 121,473 kW). This directly reduces the net specific work of the gas turbine from 528.5 kJ/kg to 490.6 kJ/kg. The model also indicates that the gas mass flow rate increases from 516.5 kg/s to 556.5 kg/s over this range.

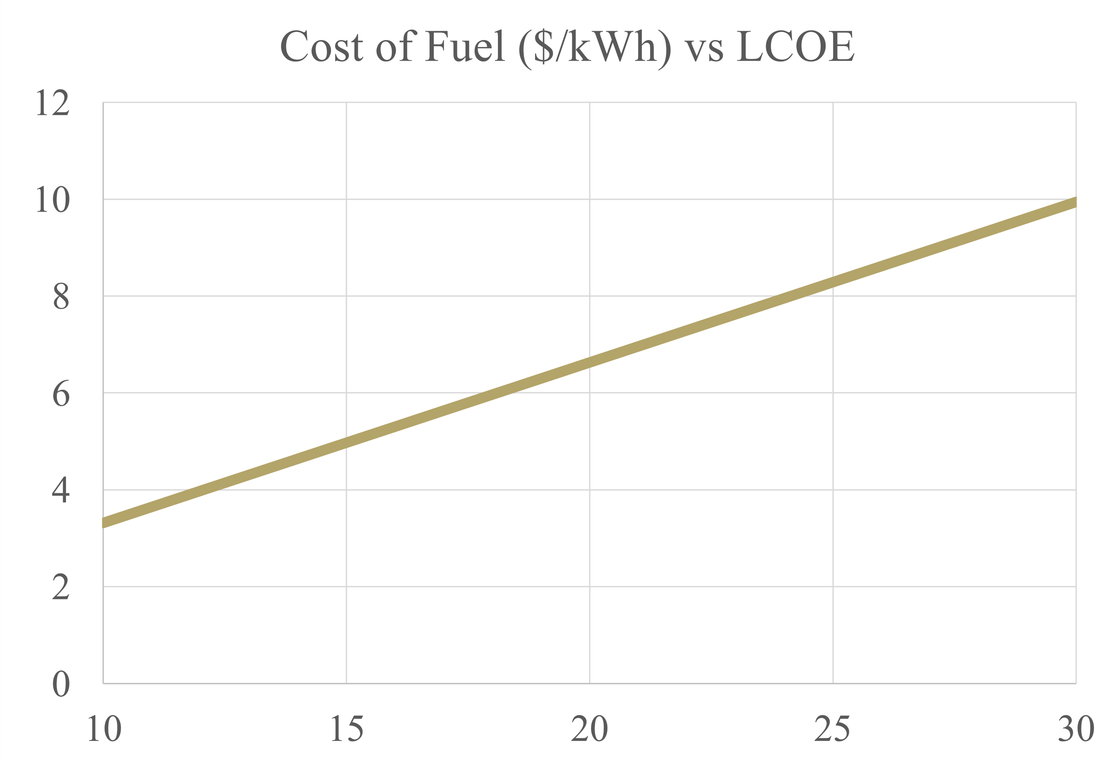
Overall Implication: The analysis shows that plant performance is affected by ambient conditions. The increased work of compression on hotter days reduces the specific work output of the gas turbine, which is a key factor influencing overall plant performance and efficiency.

Key Implications and Takeaways

System Interconnection: The parametric studies reveal that the combined cycle plant is a highly interconnected system where overall performance responds to a wide range of design, operational, and environmental factors.

Key Relationships: The analysis highlights key relationships, such as the negative impact of high ambient temperature on compressor work and the dominant role of fuel price in the plant's final LCOE. These relationships are critical considerations in the design and operation of a real-world power plant.

Economic Analysis



Analysis: The plant's economic performance was tested by varying the cost of fuel from 10 to 30. A plot of the results shows a clear trend.

Specific Data: The plot of LCOE_t versus fuel cost shows a direct, linear relationship. As the fuel cost doubles from 10 to 20, the calculated Levelized Cost of Energy (LCOE_t) also doubles from 3.316 to 6.63.

Implication: The model demonstrates that fuel cost is a primary driver of the final cost of electricity produced, suggesting that the plant's economic viability is highly dependent on the price of natural gas in Georgia.

Future Design Recommendations

Design Optimization: Based on the trends observed, future design efforts should focus on a careful optimization of the pressure ratio, as it showed a significant impact on both specific work and overall efficiency.

Environmental Considerations: The plant's response to ambient temperature suggests that designs for hotter climates could benefit from mitigation strategies, such as air cooling, to maintain power output during periods of high demand.

Model Refinement: A detailed HRSG model that calculates the stack temperature due to a defined pinch point would allow for a more robust analysis of the interaction between the Brayton and Rankine cycles and provide insights into system optimization.

Component Quality vs. Cost: The analysis shows that higher isentropic efficiencies directly improve plant performance. A future design recommendation is to perform a life cycle cost analysis. This would balance the higher initial capital cost of premium quality compressors and turbines against the long-term fuel savings from their increased efficiency to find the most economically optimal components.