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Brayton Cycle Economic Tool

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ABSTRACT

The Brayton Cycle Economic Tool estimates the levelized cost of energy (LCOE) for recompression closed Brayton Cycle (RCBC) systems. This techno-economic tool integrates an LCOE methodology (Drennen and Andruski, 2012) with an existing Brayton Cycle evaluation tool developed at Sandia (Pasch, 2016) – the RCBC Evaluation and Trade Studies Tool (RETS). The estimated LCOE for a 100 MWe Brayton system operating with an inlet turbine temperature of 700 degrees C with dry cooling are 0.832 $/kWh and 0.754 $/kWh for a first-of-a-kind and n^{th}-of-a-kind plant, respectively. Of these total costs, the various heat exchangers account for 17% of the total costs for the first-of-a-kind plant and 15% for the n^{th}-of-a-kind plant. Detailed sensitivity analysis illustrate the tradeoffs associated with higher inlet turbine temperatures, recuperator effectiveness, and choice of cooling technologies.

INTRODUCTION

The Brayton Cycle Economic Tool estimates the levelized cost of energy (LCOE) for recompression closed Brayton Cycle (RCBC) systems. This techno-economic tool integrates an LCOE methodology (Drennen and Andruski, 2012) with an existing Brayton Cycle evaluation tool developed at Sandia (Pasch, 2016) – the RCBC Evaluation and Trade Studies Tool (RETS). RETS is a supercritical CO_2 (sCO_2) recompression closed cycle (RCBC) modeling tool that calculates key system performance characteristics based on user-defined input on key variables such as: system size, recuperator effectiveness, and turbine inlet temperatures. Costs are broken down into categories: heat exchangers (recuperators, primary, and heat rejection), turbomachinery (turbines, compressors, and related subcomponents), electrical and control, facilities, project indirect, contingency, and owner's costs. Costing information for various components come from a variety of sources, including internal Sandia estimates (Carlson et al., 2017), vendor estimates, and other published estimates. Production costs are estimated using a levelized cost of energy

(LCOE) approach. LCOE calculations estimate the per unit ($/kWh) cost of production over the economic lifetime of the technology. Specifically, this calculation takes the capital costs, associated financing costs, O&M, fuel costs, and any externality costs (such as CO_2) and calculates a per unit production cost. LCOE is often used as an economic measure of energy costs as it allows for comparison of technologies with different capital and operating costs, construction times, and plant load factors. LCOE costs are estimated for both the both the first-of-a-kind (FOAK) and n^{th}-of-a-kind (NOAK) facility, using a methodology developed by NETL (2013).

RESULTS AND DISCUSSION

The estimated LCOE for a 100 MWe Brayton system operating with an inlet turbine temperature of 700 degrees C with dry cooling are 0.832 $/kWh and 0.754 $/kWh for a first-of-a-kind and n^{th}-of-a-kind plant, respectively, Figure 1. This figure also shows the relative importance of each major expense category to the total estimated cost. For the 100 MWe facility, the various heat exchangers and turbomachinery account for 15% and 17% of the total costs for the nth-of-a-kind plant, respectively. The non-component costs, ranging from fuel costs, project indirect, owner's costs, and contingency costs account for the majority of costs. Worth noting is that many of these costs are often overlooked in initial analysis of new technology costs.

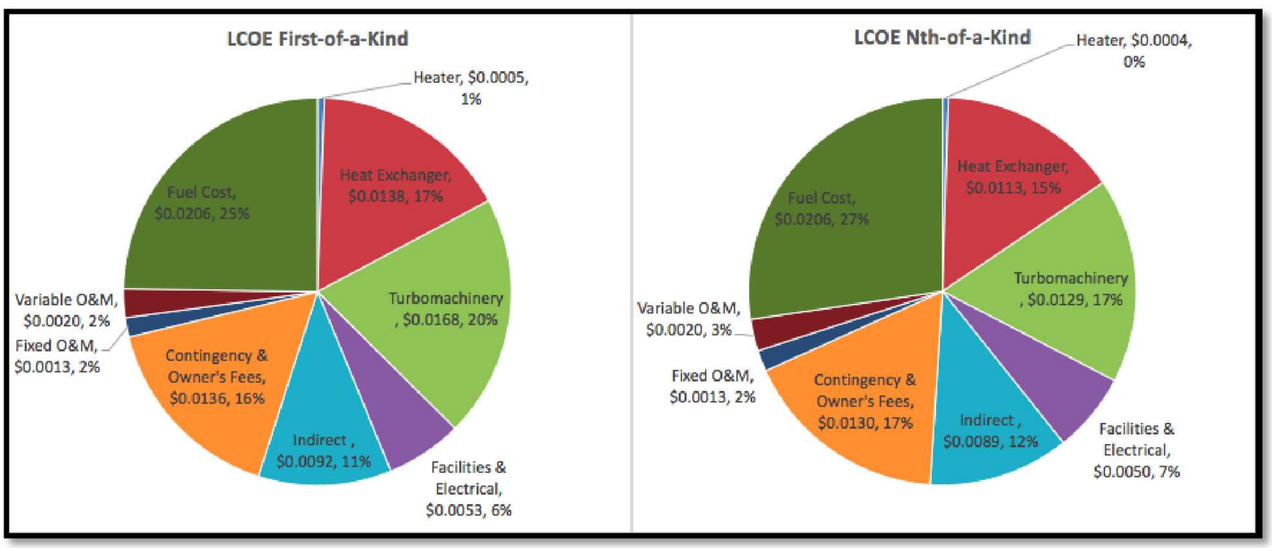

Figure 1. LCOE cost by category for the 100 MWe Brayton system.

This integrated tool allows for the testing of key sensitivities related to plant size, turbine inlet temperatures, and recuperator effectiveness. Each of the examples that follow required multiple runs of the RETS model. Future versions of this model will include an optimization routine.

Figure 2 shows the projected LCOE costs for systems from 10 to 300 MWe for several cases, varying turbine and minimum system temperatures. The results show that costs decline rapidly as size increases from 10 to 50 MWe, before slowly leveling off. They also show that costs are lower for higher turbine inlet temperatures (approximately 0.02 $/kWh when going from 550 to 650 degrees C). A similar cost reduction is realized when lowering the assumed minimum system temperature from 312 to 305 degrees C (0.018 $/kWh). These results show a comparable cost reduction associated with either reducing the minimum system temperature as noted above as increasing the turbine inlet temperature from 650 to

750 degrees C. This suggests that greater efforts should be made on control of the minimum cycle temperature than previously done because the benefits are similar and it is much more feasible than developing and testing high temperature materials.

Figure 3 is a more detailed analysis of the impact of varying turbine inlet temperatures on LCOE for a 20 MWe system with dry cooling. As turbine inlet temperature increases, certain individual system components (primary heat exchanger and high temperature recuperator) will require higher-quality alloys. The results show that the higher costs are offset by the increase in overall system efficiency. This figure also demonstrates the importance of fuel costs on the LCOE. For a system operating at 650 degrees C, a $4 difference in natural gas costs translates into a 0.03 $/kWh difference in LCOE. This difference is higher at lower temps and lower at higher temperatures.

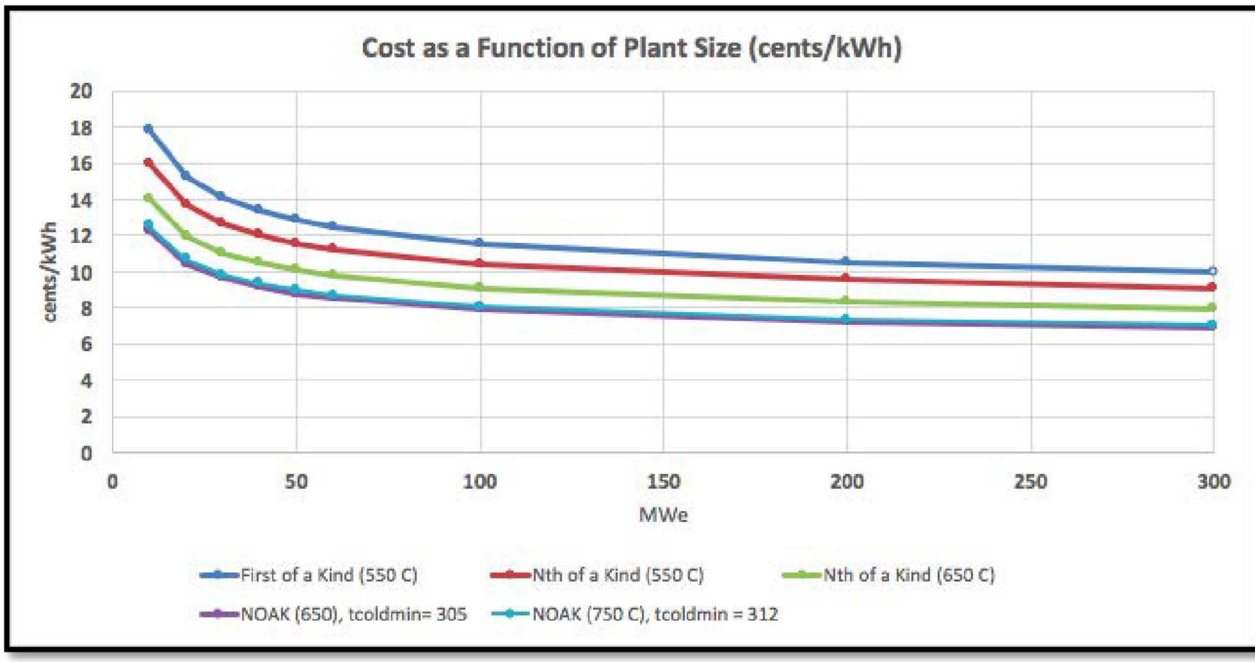

Figure 2. LCOE as a function of plant size, turbine inlet temperature, and minimum system temperature.

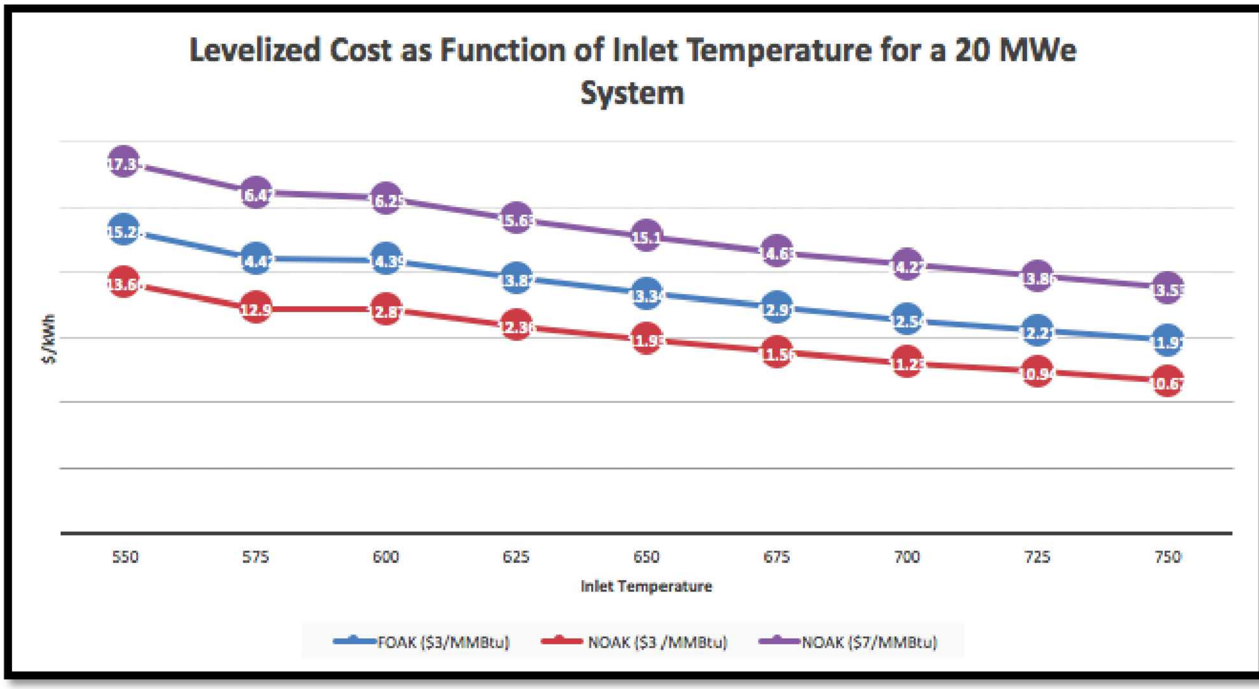

Figure 3. LCOE as a function of turbine inlet temperature and fuel costs.

Figure 4 demonstrates the tradeoffs of increased recuperator effectiveness, system efficiency, and resulting LCOE. As recuperator effectiveness increases, system efficiency increases. However, increasing recuperator effectiveness increases system costs and, beyond a certain point, the increased costs begin to outweigh the benefit of increased system efficiency. This analysis shows that the optimal recuperator effective, regardless of fuel price, is 92%.

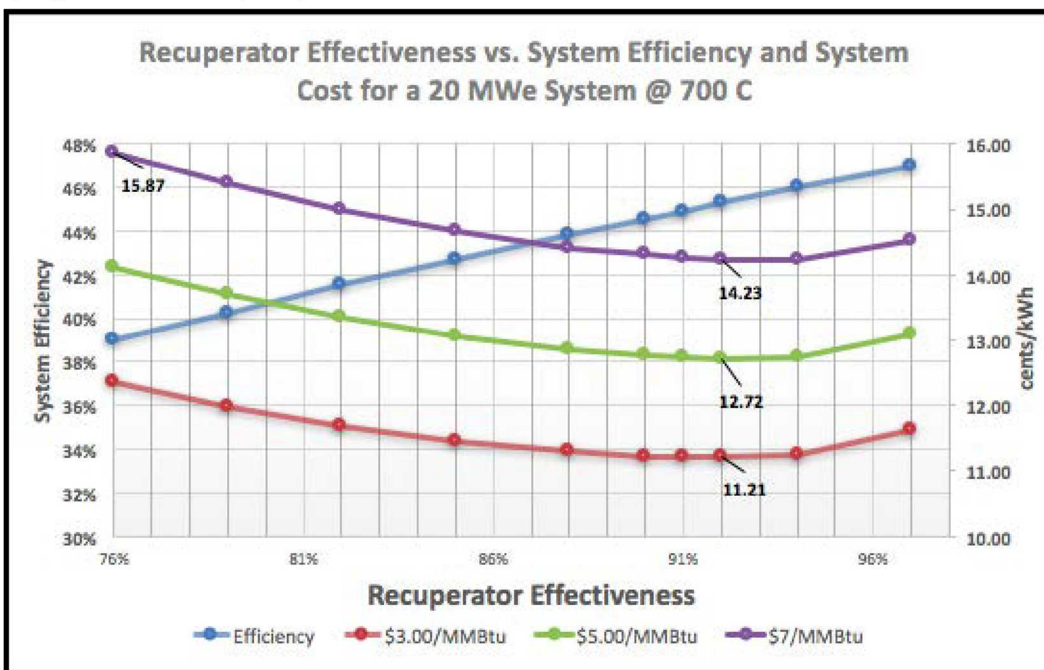

Figure 4. System efficiency and LCOE as a function of recuperator effectiveness.

Figure 5 and Figure 6 illustrate the sensitivity of the results to the technical assumptions regarding the approach temperatures for dry cooling in a hot dry climate (Yuma, AZ) and a cooler, northern location (Bismarck, ND). These results show the overall system efficiency drops sharply as the temperature differential increases (defined as log mean temperature difference (LMTD)), decreasing approximately 10% as the assumed differential increases from 3 to 15 degrees C in Yuma. This effect is due to the increased compressor work for warmer, less dense sCO_2. Obviously there is a tradeoff of increased costs for the air cooling heat exchanger with lower LMTD and system efficiency. But for Yuma, in the summer, the increased system costs translate into lower LCOE due to the increased system efficiencies. This same relationship holds for Bismarck, ND, although the overall LCOE are lower as the ambient air temperatures are not as extreme. Note that the minimum LMTD is approaching the critical temperature of CO_2 and was not decreased further into condensation.

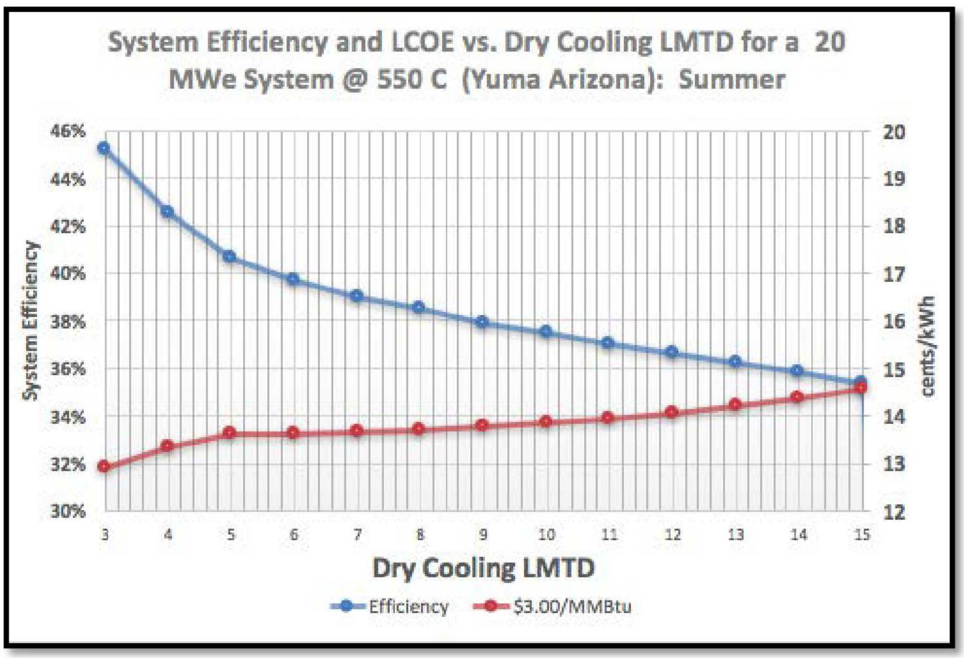

Figure 5. System efficiency and LCOE as function of approach temperatures in air cooled system in Yuma, AZ in the summer.

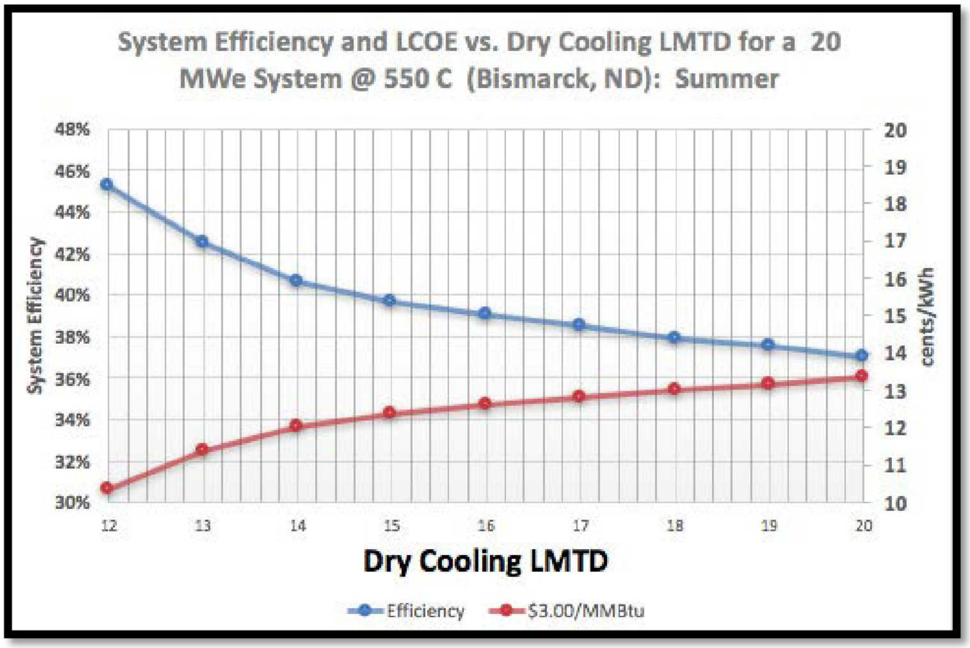

Figure 6. System efficiency and LCOE as function of approach temperatures in air cooled system in Bismarck, ND in the summer.

NEXT STEPS

Next steps include the translation of this economic tool from its current form in Excel to a code-based language for greater flexibility in parameter studies and optimization. Presently, the tool uses output from RETS to calculate the LCOE using Excel. Parameter studies require manually running RETS and the economics tool and recording results one at a time.

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