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This is a model of a gas turbine combined cycle with an unconventional bottoming cycle - one that generates power by expanding hot high pressure air in a turbine. It represents a discharge mode for a Liquid Air Energy Storage (LAES) system and is based on the patented VPS Cycle described in {1}.

This model is one of several samples used to model the Liquid Air Energy Storage (LAES) system described in {1}. The proposed LAES system operates in two modes:
(1) Energy Storage (S5-30a), and
(2) Energy Recovery (this model for the LAES system in {1}), and an alternative recovery system shown in (S5-30c).

Energy Discharge Model Details:
Cold liquid air enters the system from the storage tank and is pumped to supercritical pressure of 1925 psia (132.7 bar). Supercritical air is heated in three steps: (1) GT Inlet Cooler [3], (2) Air Preheater [9], and finally (3) Topping Heater [6]. Precooling GT inlet air increases the GT output power as a direct benefit. The Air Preheater cools the air expander exhaust and condenses water vapor that's recycled back to the primary air stream upstream of the Topping Heater. Preheated moist air enters the Topping Heater where it is heated to its final temperature by cooling the GT exhaust. Air enters the expander at about 985 F (529 C) and expands to almost atmospheric pressure before entering the Air Preheater before being exhausted to the environment.

The model presents an assessment of the overall plant and an assessment for the bottoming cycle alone. The bottoming cycle characteristics assume:
(1) GT inlet air cooling is credited to the bottoming cycle (as avoided power) with an assumed COP of 3.5 (available for editing as a custom script input).
(2) GT exhaust heat is considered as exergy input to the bottoming cycle.
These assumptions are built into the script which calculates the 'Equivalent net power recovery (ENPR)'. The script also computes the bottoming cycle exergy efficiency as the ratio of this power to the exergy input to the bottoming cycle from the GT exhaust and the liquid air.

Because this energy recovery cycle involves heat input from the GT exhaust, it is not a simple matter to define a round-trip efficiency for the combined Energy Storage (S5-30a) and Energy Discharge system. A very simplistic assessment computes the ratio of specific power in the bottoming cycle to that needed to produce the liquid air. On that basis the round-trip efficiency is about 69%. However, that ignores the fact that the heat input from GT exhaust could have been used to make power in a conventional bottoming cycle interacting with the environment.

THERMOFLEX Specifics:
The 'Air' stream in this cycle is modeled using THERMOFLEX's LNG Fuel (orange) stream. Thermo-physical properties for LNG Fuel are handled in the same way as the "User-defined general fluid" feature for Refrigerant streams. In both cases, the properties are pre-computed using the widely used, but very slow, NIST (REFPROP) formulations and stored in a lookup table. The time-consuming process needed to populate the table is only done once, as a pre-processing step. Thereafter, cycle calculations use a speedy lookup method to evaluate properties needed to model the cycle. The rationale for using LNG here, instead of refrigerant, is LNG supports phase change and can be mixed with water, both requirements for this cycle. The LNG is actually not a fuel, the composition entering the model is (78.12% N_2 + 20.96% O_2 + 0.92% Ar). Properties of the LNG fuel entering this model are exactly the same as those of the Refrigerant stream delivered to the storage tank in the companion model (S5-30a).

Related Models:
The LAES charge cycle and an alternative discharge cycle are modeled in the following files:
(1) (S5-30a) Liquid Air Energy Storage - Storage Mode (Air Liquefaction).TFX
(2) (S5-30c) Liquid Air Energy Storage - Recovery Mode with Direct Expansion + District Cooling.TFX

References:
{1} Case Studies of Advanced Liquid Air Energy Storage + Next-Generation Combined Cycle Plants Based on the Patented "VPS Cycle" Technology, ELECTRIC POWER Conference 2020 (April 16, 2020).
{2} VPS Cycle with Steam Feasibility Study for Bulk Power Storage in New York City, New York State Energy Research and Development Authority report number 13-12 (May 2013).

Liquefied Air Energy Recovery with Combined Cycle

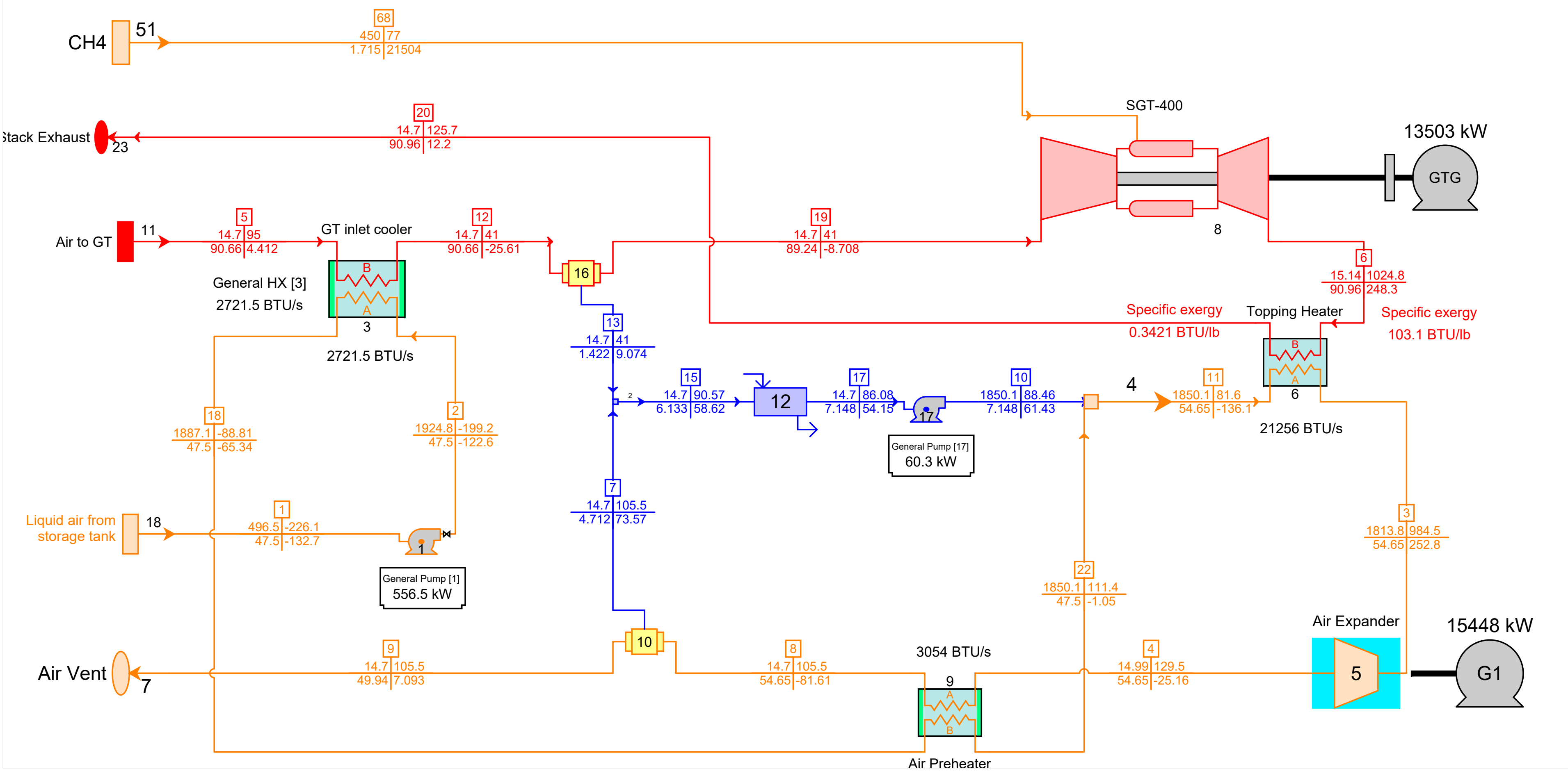
Overall Plant Summary

Gross power	28951 kW
Plant auxiliary	642.6 kW
Net power	28308 kW
Net gaseous fuel LHV input (FuelLHV)	132877 kBTU/hr
Liquid air exergy input (ELA)	11416 BTU/s
Total exergy input (TEI, =ELA+FuelLHV)	48326 BTU/s
Exergy efficiency (Net power / TEI)	55.52 %

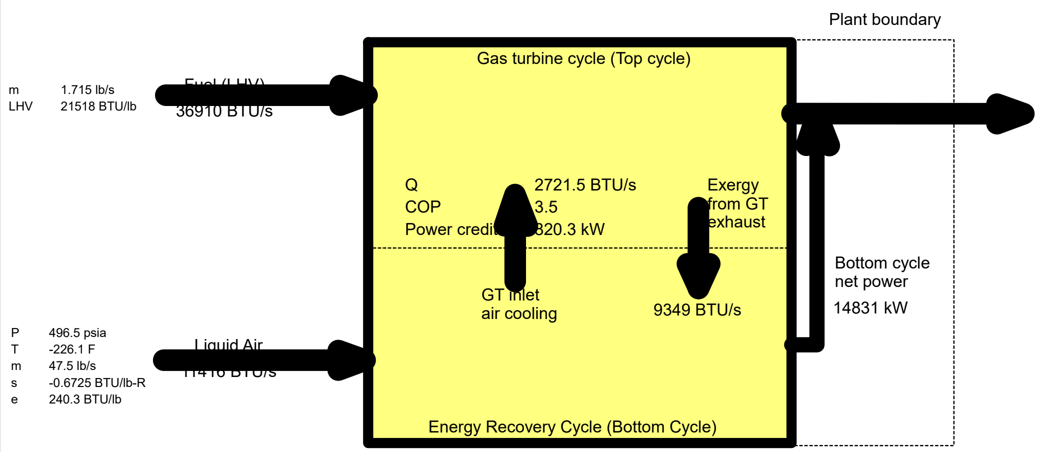
Energy Recovery Cycle (Bottoming Cycle) Summary

Gross power generation	15448 kW
Avoided electric chiller power for GT inlet air cooling (+)	820.3 kW
Bottoming cycle auxiliary load	616.8 kW
Equivalent net power recovery (ENPR)	15651 kW
Liquid air exergy input (ELA)	11416 BTU/s
Exergy from GT exhaust (EGTX)	9349 BTU/s
Total exergy input (TEI, =ELA+EGTX)	20764 BTU/s
Exergy efficiency (ENPR/TEI)	71.45 %

(Refer to sheet "Exergy Flow Diagram" for more info)



Plant Exergy Flow Schematic



Plant

Total Exergy In (fuel + liquid air)	48326 BTU/s
Exergy efficiency (total net power / total exergy in)	55.52 %

Bottom Cycle (Energy Recovery)

Equivalent net power recovery (net power + avoided chiller power)	15651 kW
Total exergy input (liquid air exergy + exergy from GT exhaust)	20764 BTU/s
Exergy efficiency (equivalent net power / total exergy input)	71.45 %

Note: Reference Condition (Ambient):

Pressure	*14.7 psia*
Temperature	*95 F*

Reference Basis for Exergy Analysis