# Mechanical System Redesign Component Analysis

This section of the report will describe the process from beginning to end of the mechanical system redesign in order to power, heat, and cool the Xanadu Sports Complex. While this section will address the theory behind the redesign's process, more technical calculations used to size the various components can be found in Appendix D of this report.

## Fuel Source

The heart of a combined heat and power system is the source of electricity production, the prime mover. In order for the prime mover to create electricity on site, fuel is needed to maintain a combustion process. One of the most commonly used source of fuel for a CHP system is natural gas, however, recently there has been a steady increase in projects that utilize landfill gas to power their building. Currently there are approximately 424 operational landfill gas projects in 42 states that supply 10 billion kilowatt hours of electricity annually, and this number has been steadily rising each year.

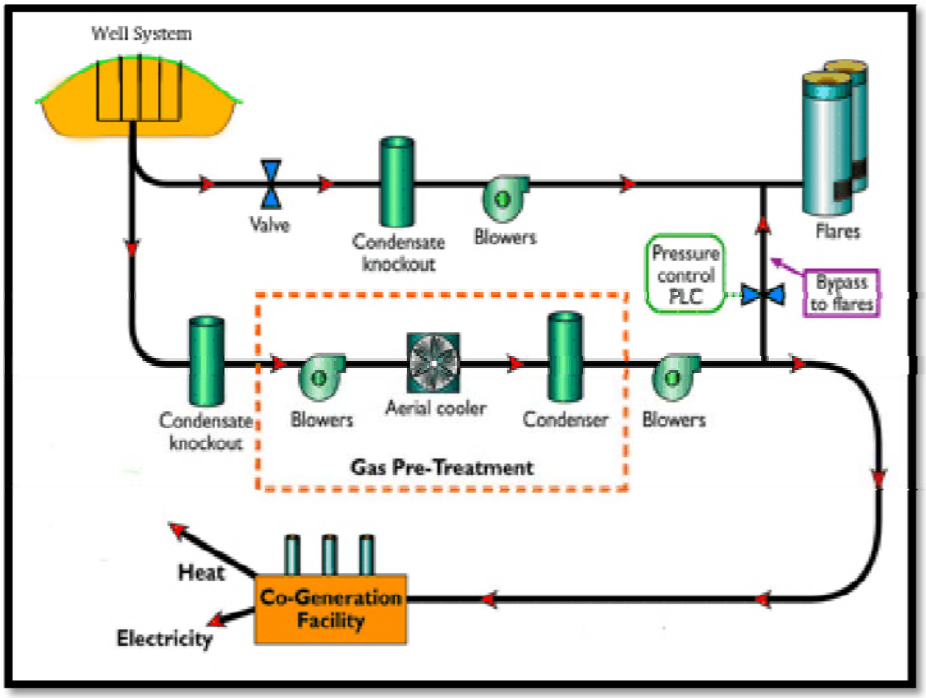

*Figure 20: Landfill Gas Collection Schematic*

Landfills are the largest human-made source of methane in the United States, accounting for nearly 24% of all methane created. The methane created by landfills is a by-product of the decomposition of solid waste that is collected at the site. The landfill gas (LFG) is composed of approximately 50% methane, 49% carbon dioxide, and 1% of non-methane organic compounds. Under normal conditions the LFG is generated by the decomposition process and is released to the atmosphere contributing to smog, global warming, and health concerns. However, it is possible to collect the LFG, treat the gas on site, and then pipe the treated gas to a building site to drive a CHP system. The collection of LFG is utilized by drilling into the landfill and then placing large vertical wells deep into the waste. The LFG flows into the wells and is either piped to the treatment center or to flares to burn off any excess gas. In lieu of flaring the excess gas it can be sold to other nearby facilities in need of a clean-burning fuel. During the treatment process moisture, particulates, and a large portion of contaminants are removed. The process begins by passing the gas through a filter and then a condenser that reduces the dewpoint of the gas to approximately 37 °F. After the dewpoint is reached, the gas is passed through one more filter and then reheated. The treated methane gas is now ready for use in the CHP system. Figure 20 provides a schematic of the landfill gas collection system.

GROWS Inc. landfill will be the landfill used for the Xanadu Sports Complex. The landfill is located approximately 3.5 miles from the building site. Through the use of the aerial imaging software Google Earth it was found that the GROWS landfill is roughly 4,053,804 square feet in active landfill area. Through multiple sources of research it has been determined that the average gas production for landfills is 0.344 standard cubic feet (scf) per square foot (sf) of landfill daily. This data yields a value of 58,104 scf/hr or 1,645 normal cubic meters (Nm$^3$) per hour produced from this particular landfill.

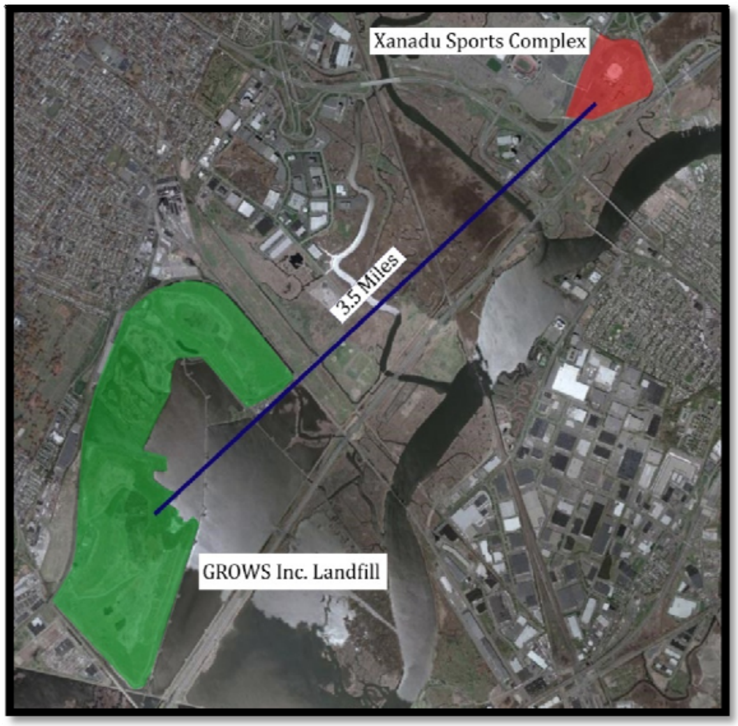

*Figure 21: Landfill Gas Service Aerial Image*

Finally, the quality of gas supplied to the building needs to be examined. The typical lower heating value for natural gas is 9.5 kWh/Nm$^3$. While the treatment of the landfill gas creates a high quality fuel, the lower heating value of methane is roughly half that of natural gas. The resulting lower heating value of 5.0 kWh/Nm$^3$ will need to be taken into consideration when selecting the prime mover.

**Prime Mover**

When selecting a prime mover, multiple options can be considered. The three most popular solutions are through the use of a turbine, a microturbine, or an engine. Each system has advantages and different ranges of the amount of electricity production capacity. As discussed in the building load analysis section of this report, the demand for the redesigned mechanical system ranges from 1,480 kilowatts in February to 2,200 kilowatts in July. This range of electrical capacity eliminates the possibility of a microturbine system due to the fact that a single microturbine can produce anywhere from 20 kilowatts to 500 kilowatts. This range is considerably lower than that needed for the Xanadu Sports complex; therefore, either a turbine system or an engine system are the logical choices. Besides the capacity the source of fuel must also be taken into consideration. In this case a treated methane gas with a lower heating value (LHV) of 5.0 kWh/Nm$^3$ will be the available fuel. Upon extensive research it was determined that General Electric (GE) had the most experience in the use of treated natural gas to fire their engines. GE has more than 25 years of experience in the combustion of landfill gas and currently, more than 1,100 landfill gas systems with a total electrical output of 1,050 megawatts use GE engines, specifically Jenbacher line of gas engines. Multiple case studies on the use of landfill gas for cogeneration have used GE Jenbacher engines, and they have proven to be very reliable throughout many years of service. For these reasons a GE Jenbacher engine was chosen to be the prime mover for the Xanadu Sports Complex.

Due to GE's specialty in the use of biogas produced from landfills, a special model of Jenbacher engines is available for the use of landfill gas with an approximate LHV of 5 kWh/Nm$^3$. In order to properly size the engine a decision must be made for the design to meet the building's thermal loads based on the engine's steam production or to meet the electrical load. Based on the results from the building load analysis section, it has been determined that the electrical load will always be much higher than the thermal loads; therefore, the system is designed to meet the electrical loads. Based on the electrical demand, a GE Jenbacer Engine model JMS 620 GS-BL was selected. Based on the technical calculations in Appendix D, this model engine can provide a maximum of 2,433 kilowatts. This will allow the engine to meet the electrical demand all year round with a 233 kilowatt leeway.

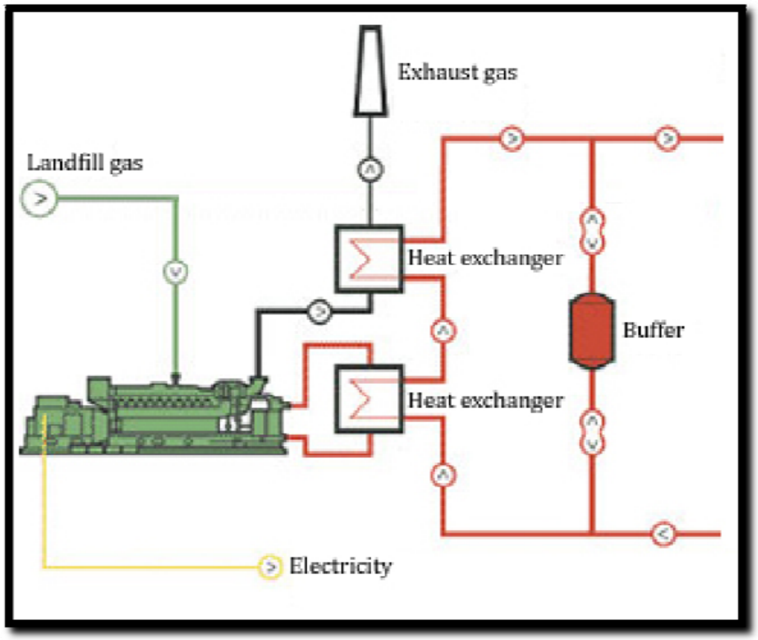

*Figure 22: Engine Heat Exchanger Schematic*

Through the continuous supply of landfill gas, the Jenbacher engine will run 24 hours a day, 365 days a year. The engine will throttle up or down to meet the current electrical demand. Through the combustion process a significant amount of energy cannot be converted to mechanical energy which would be used to produce electricity. This extra energy comes in the form of thermal energy which can be used with heat exchangers to produce medium pressure steam. Overall, a heat exchanger for the exhaust gas and a hot water loop heat exchanger are use to create steam. Figure 22 illustrates this process in a schematic.

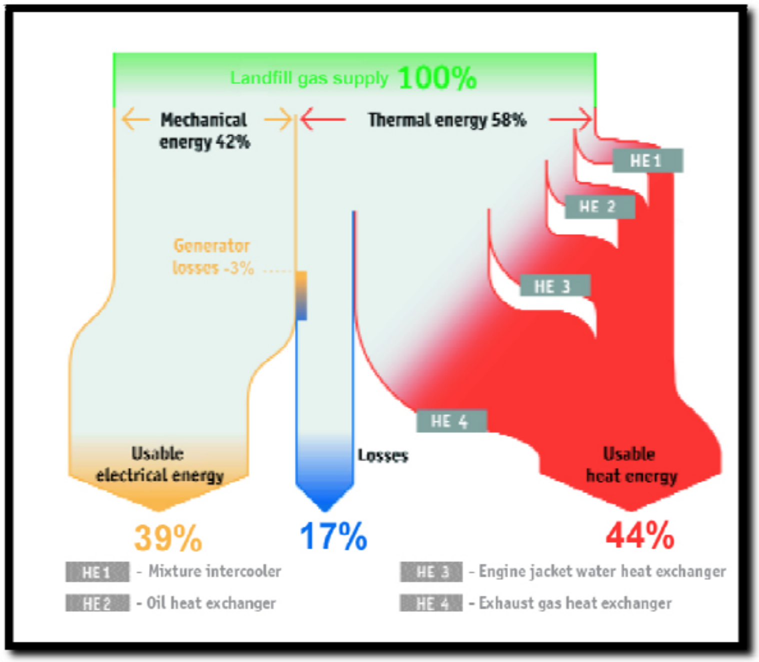

*Figure 23: Engine Efficiency Breakdown*

The efficiency for the engine process is illustrated in Figure 23. When the fuel enters the engine, 42% of the energy is converted to mechanical energy and the remaining 58% is attempted to be recovered for steam production. However, the generator used to convert mechanical energy to electrical energy produces losses of 3%, and through the heat exchangers another 17% of thermal energy is lost. This produces an electrical efficiency of 39% and a thermal efficiency of 44% for a total efficiency around 83%.

### Absorption Chiller/Heater

An absorption chiller/heater will replace the four existing direct expansion rooftop units in order to maintain thermal comfort inside the retail section of the building. This will replace the use of electricity for heating and cooling with the use of steam. The steam produced from the Jenbacher engine will be used to fire the absorption chiller. An absorption chiller replaces the mechanical compressing of a refrigerant found in the direct expansion units. The absorption chiller can achieve this process by using a thermochemical compressor. Essentially, two different fluids are used. One fluid is used as an absorber and another is used as a refrigerant. Typically, water is used as the refrigerant while lithium bromide, a nontoxic salt, is used as the absorber.

An absorption chiller is comprised of four main components: the generator, the condenser, the evaporator, and the absorber. The process begins in the generator where the steam produced from the engine is introduced. The steam flows into the generator's heat exchanger where the chiller will pump the water and lithium bromide solution over the heat exchanger coils. The solution begins to boil allowing the lithium bromide and water to separate. The water now separated from the lithium bromide turns to vapor and is carried over to the condenser. In the condenser the water vapor is condensed on the surface of a heat exchanger. The condenser's heat exchanger removes the vapor's latent heat by rejecting the energy to a cooling tower. The liquid water collects in the condenser and is sent to the evaporator. In the evaporator the liquid water flows over the surface of an evaporator coil. The water begins to boil and removes heat from the chilled water loop. This chilled water will then run to the four new rooftop units with chilled water coils. At the same time the lithium bromide collected in the generator is precooled through the use of a heat exchanger before it is used in the absorber. Once it reaches the absorber the water vapor from the evaporator process is absorbed by the lithium bromide flowing across the surface of the absorber coil. The heat of condensation and dilution is rejected to the cooling tower through the cooling water loop. The resulting water and lithium bromide solution is collected and pumped back to the generator to start the process once again. In order to provide heating the absorption chiller's change-over valve must be opened. This valve bypasses the absorber process. The generated hot water vapor is used to exchange heat between the evaporator coil and the hot water loop which services the hot water coils in the rooftop units. Figure 24 on the next page illustrates the process described in this paragraph.

In order to select the proper size of absorption chiller both the cooling and heating peak loads for the retail section need to be considered. Based on the TRACE 700 load calculations the peak cooling load is 267 tons and the peak heating load is 1,241 MBtu/hr. Based on the peak loads, it was determined that in order to meet the full capacity with a single chiller a double-effect absorption chiller was needed. The largest difference between a single-effect and a double-effect absorption chiller is that the double-effect captures some internal heat and uses it in the generator. This extra process reduces the steam requirements and boosts system efficiency. To meet the thermal loads a Carrier Double-Effect Absorption Chiller Model 16NK was selected. This model's cooling capacity is listed at 294 tons providing adequate cooling to the retail section year round. The maximum amount of steam consumption is 2,601 lbs/hr providing more than enough heating capacity for the few months it is needed. Based on the calculations in the building loads section and in Appendix D of this report, there will be anywhere from 630 lbs/hr to 2,100 lbs/hr of excess steam produced. Based on the final selection of the absorption chiller/heater the proper form of heat rejection must be selected. For this redesign heat ejection will be accomplished through the use of a cooling tower. Using the values of the cooling water flow rate and chiller cooling capacity a SPX Model JT49290 Cooling tower was selected through the use of use of the SPX web-based tower sizing and selection program.

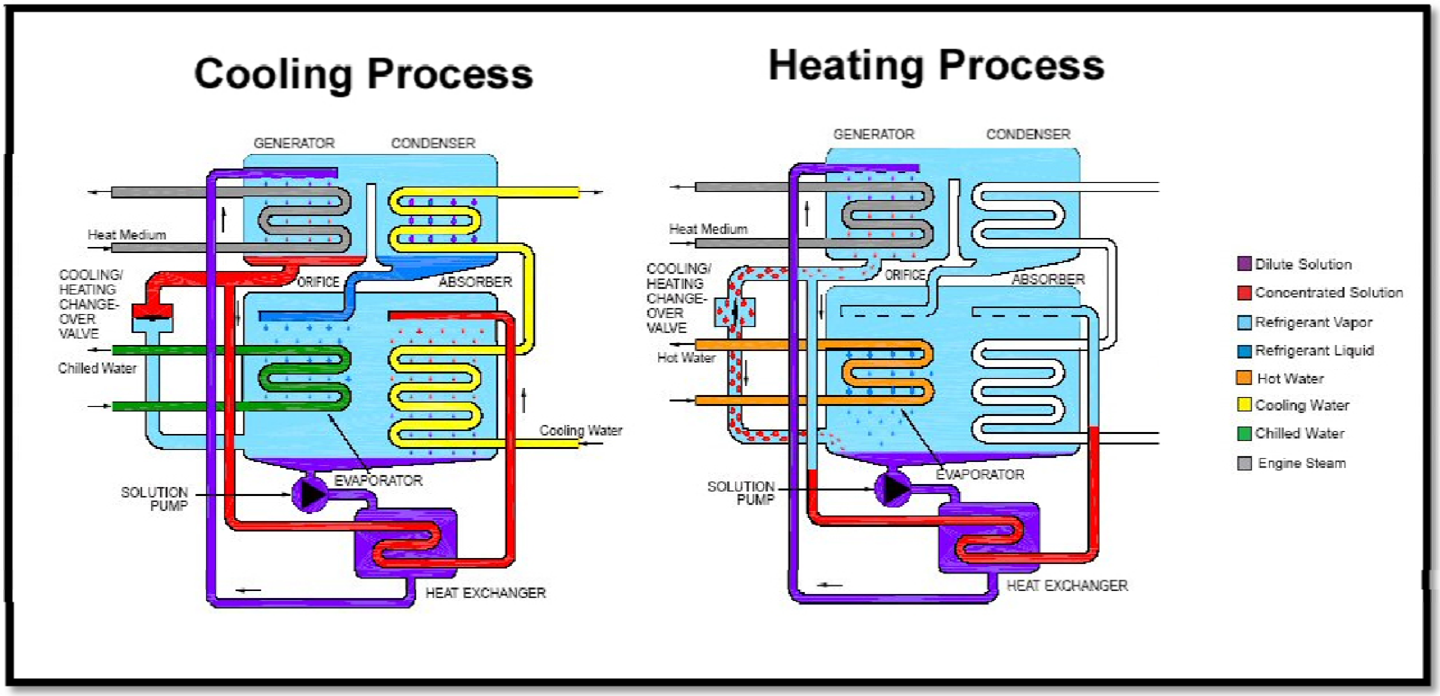

*Figure 24: Absorption Chiller/Heater Process*

The amount of excess steam produced is a considerable amount and can be used elsewhere in the complex to increase the overall efficiency of the project. The most practical application for this steam is for the use of heating the domestic water in the complex. While Building A itself does not have a high demand for domestic hot water, other sections of the complex do have a high demand. The excess steam can be piped to other parts of the complex to heat the domestic hot water and save more energy and utilities. While the savings from this extra process in the overall system can produce a large amount of savings due to the sheer size of the whole complex, the domestic hot water demand is beyond the scope of this report. It is recognized that extra savings and efficiency are possible but will not be analyzed and are considered an extra perk of this system.

### Rooftop Air Handling Units

For the four new rooftop units TRANE customizable rooftop units were selected. Based on the calculations and TRACE 700 energy model discussed in the ventilation system redesign section of this report, the four new rooftop units were sized. The total amount of air flow through the rooftop unit was found using the TRACE building model. The amount of supply air was calculated by selecting the higher required air flow based on either the ASHRAE 62.1 ventilation standard or the required air flow to maintain thermal comfort. To determine the required heating and cooling coil capacities the TRACE 700 peak loads were used based on the spaces each rooftop unit is supplying. With the data calculated in the ventilation redesign, the building load calculations, and the TRANE rooftop unit literature the units were designed. Table 3 below summarizes the four rooftop units selected.

***Table 3: Rooftop Unit Summary***

| Rooftop Unit | Casing Size | Supply Fan | | Exhaust Fan | | Heating Coil | Cooling Coil |
|---|---|---|---|---|---|---|---|
| | | BHP | RPM | BHP | RPM | Mbtu/hr | Mbtu/hr |
| A1 | 2 | 25 | 1043 | 10 | 750 | 317 | 924 |
| A2 | 4 | 30 | 1150 | 15 | 1000 | 563 | 1,296 |
| A3 | 2 | 11 | 800 | 6 | 700 | 109 | 504 |
| A4 | 2 | 11 | 800 | 6 | 700 | 86 | 480 |

All the mechanical system components discussed in this section work together to provide an efficient system to power, heat, and cool the Xanadu Sports Complex year round. Figure 25 on the next page illustrates in a schematic how all the mechanical system components come together.

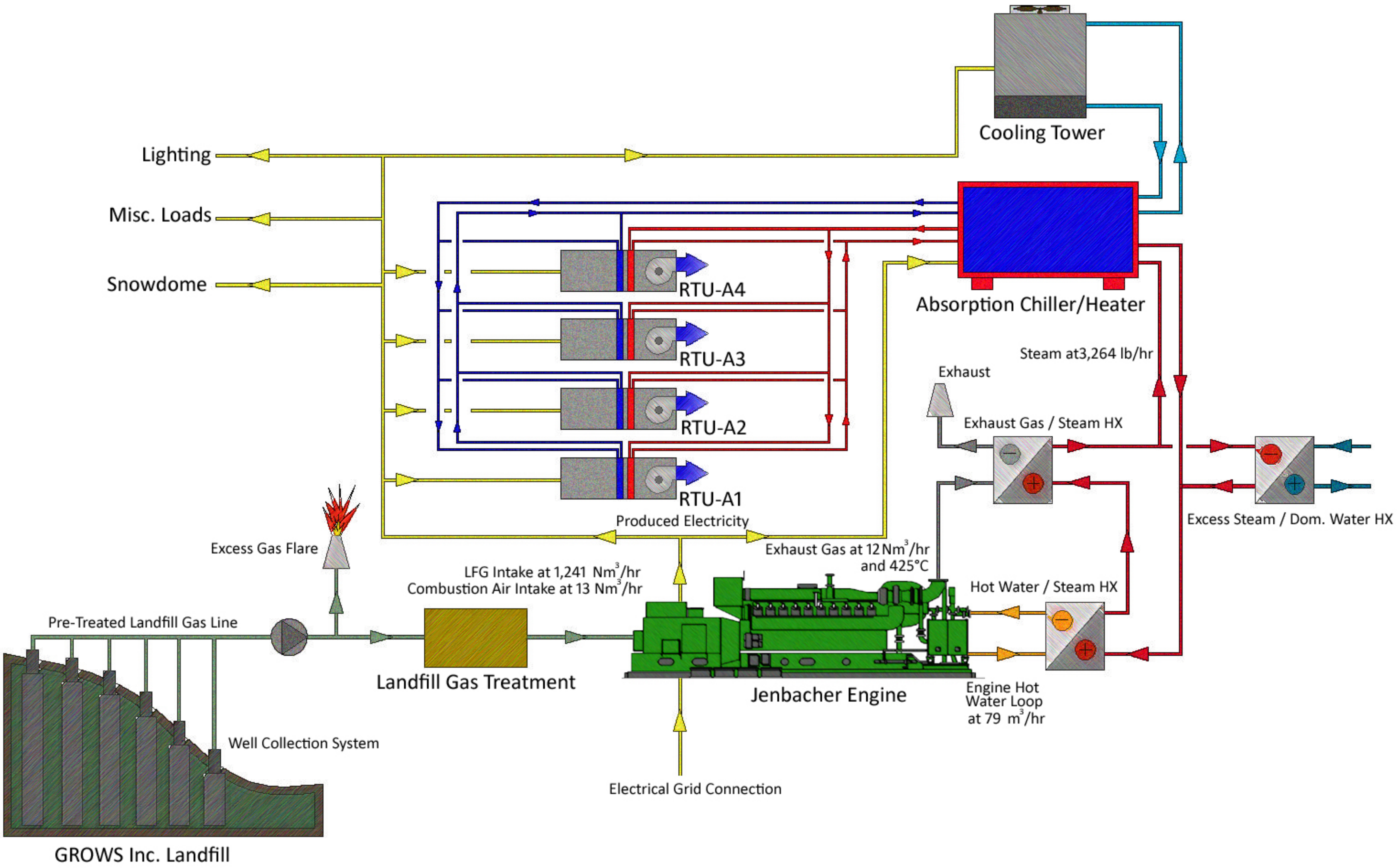

*Figure 25: Redesign Mechanical Schematic*