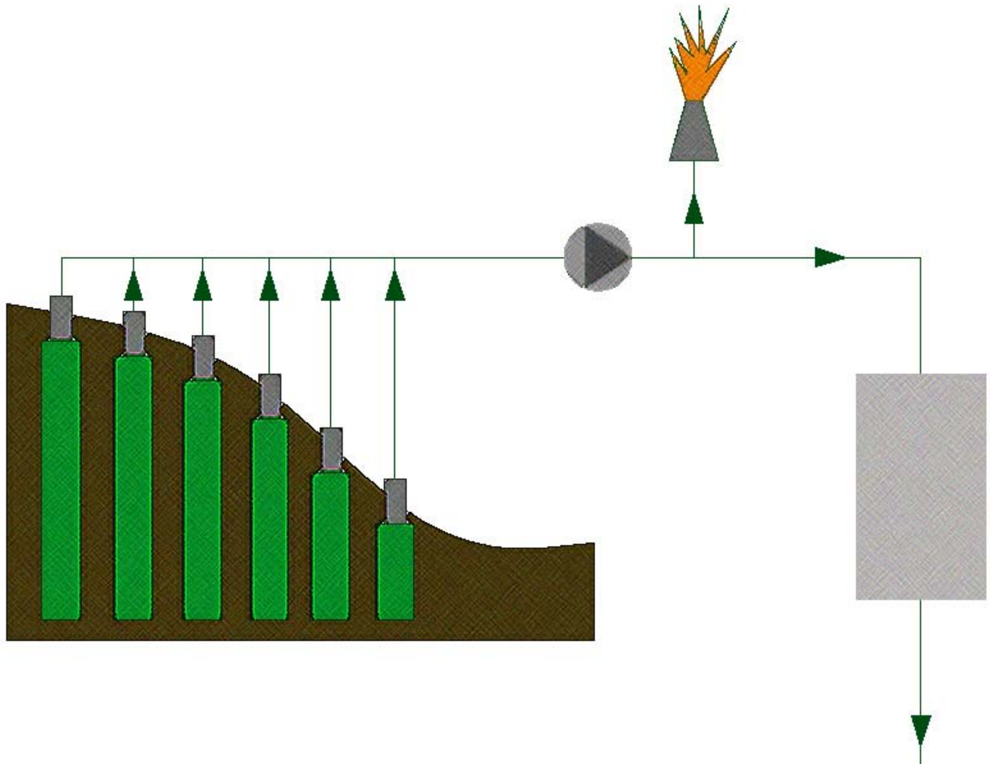
Appendix D: Sample Redesign Calculations

GROWS Inc. Landfill



Landfill Gas Flowrate = 1,645 Nm^3/h

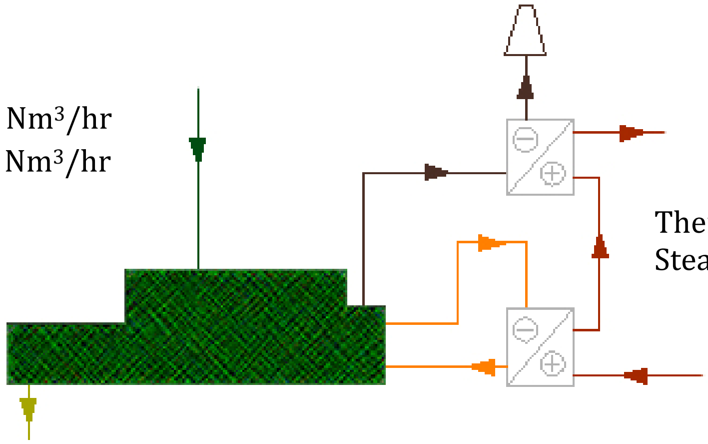
Approximate Size: 4,053,804 ft^2
Average Gas Production*= 0.344 scf/ ft^2/day

Landfill Gas = (4,053,804 ft^2) x (0.344 scf/ ft^2/day) / (24 hours) = 58,104 scf/hr
Landfill Gas Produced = (58,104 scf/hr) = **1,645 Nm^3/h**

*Sources: Waste Management http://www.americanlandfill.com/facility/gas_to_energy.asp
http://www.mrwmd.org/landfill-gas-power.htm

Engine: Jenbacher JMS 620 GS- NL

Gas Flowrate = 745 Nm^3/hr
Air Flowrate = 13.01 Nm^3/hr



Thermal Output = 3,022 kW
Steam Generation = 3572 lb/hr

Electrical Output = 3,043 kW

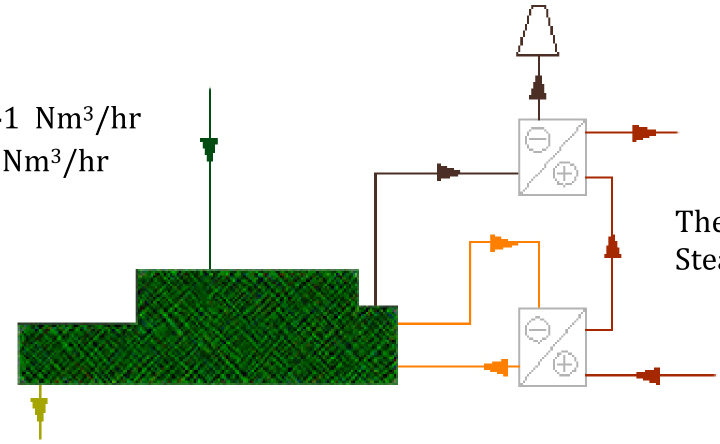
Natural Gas:

Natural Gas Volume Flowrate = 745 Nm^3/hr
Fuel Lower Heating Value = 9.5 kWh/Nm^3
Electrical Efficiency = 43.0%
Thermal Efficiency = 42.7%
Total Efficiency = 85.7%
Exhaust Gas to HX = 41.6%
Exhaust Gas Volume Flowrate = 13.66 Nm^3/hr
Full Load Exhaust Gas Temperature = 425°C
Steam Generated Pressure = 125 psig
Steam Total Heat = 1,193 (Btu/lb)
Combustion Air Volume Flowrate = 13.01 Nm^3/hr
Hot Water Volume Flowrate = 129.7 m^3/hr

Max Electrical Output = (745 Nm^3/hr) x (9.5 kWh/Nm^3) x (0.43) = **3,043 kW**
Max Thermal Output = (745 Nm^3/hr) x (9.5 kWh/Nm^3) x (0.427) = **3,022 kW**
Steam Generation = (3,002 kW) x (3,412 Btu/hr/kW) / (1193 Btu/lb) x (0.416)
= **3572 lb/hr**

Engine: Jenbacher JMS 620 GS- BL

Gas Flowrate = 1,241 Nm³/hr
Air Flowrate = 10.85 Nm³/hr



Thermal Output = 2,743 kW
Steam Generation = 3264 lb/hr

Electrical Output = 2,433 kW

<u>Landfill Gas:</u>

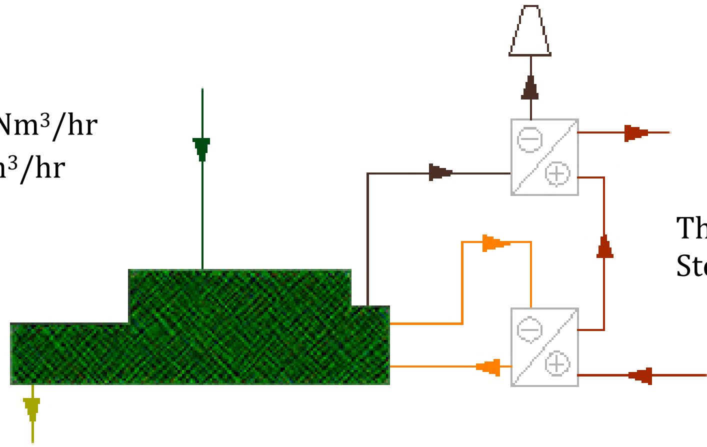
Landfill Gas Volume Flowrate = 1,241 Nm³/hr
Fuel Lower Heating Value = 5 kWh/Nm³
Electrical Efficiency = 39.2%
Thermal Efficiency = 44.2%
Total Efficiency = 83.4%
Exhaust Gas to HX = 41.6%
Exhaust Gas Volume Flowrate = 11.78 Nm³/hr
Maximum Demand Exhaust Gas Temperature = 467°C
Steam Generated Pressure = 125 psig
Steam Total Heat = 1,193 Btu/lb
Combustion Air Volume Flowrate = 10.85 Nm³/hr
Hot Water Volume Flowrate = 78.5 m³/hr

Summer

Max Electrical Output = (1,241 Nm³/h) x (5 kWh/Nm³) x (0.392) = **2,433 kW**
Max Thermal Output = (1,241 Nm³/h) x (5 kWh/Nm³) x (0.442) = **2,743 kW**
Amount of Flared Gas = (1,645 Nm³/h) – (1,241 Nm³/h) = **404 Nm³/hr**
Max Steam Generation = (2,743 kW) x (3,412 Btu/h/kW) / (1193 Btu/lb) x (0.416)
= **3264 lb/hr**
Min Fuel Input = (2,407 kW) / (5 kWh/Nm³) / (0.392) = **1,228 Nm³/hr**
Min Thermal Output = (1,228 Nm³/h) x (5 kWh/Nm³) x (0.442) = **2,714 kW**
Min Steam Generation = (2,714 kW) x (3,412 Btu/h/kW) / (1193 Btu/lb) x (0.416)
= **3,229 lb/hr**

Engine: Jenbacher JMS 620 GS- BL (cont.)

Gas Flowrate = 1,241 Nm³/hr
Air Flowrate = 10.85 Nm³/hr



Thermal Output = 2,743 kW
Steam Generation = 3264 lb/hr

Electrical Output = 2,433 kW

Winter

Max Fuel Input = (1,855 kW) / (5 kWh/Nm³) / (0.392) = **946 Nm³/hr**

Max Thermal Output = (946 Nm³/h) x (5 kWh/Nm³) x (0.442) = **2,092kW**

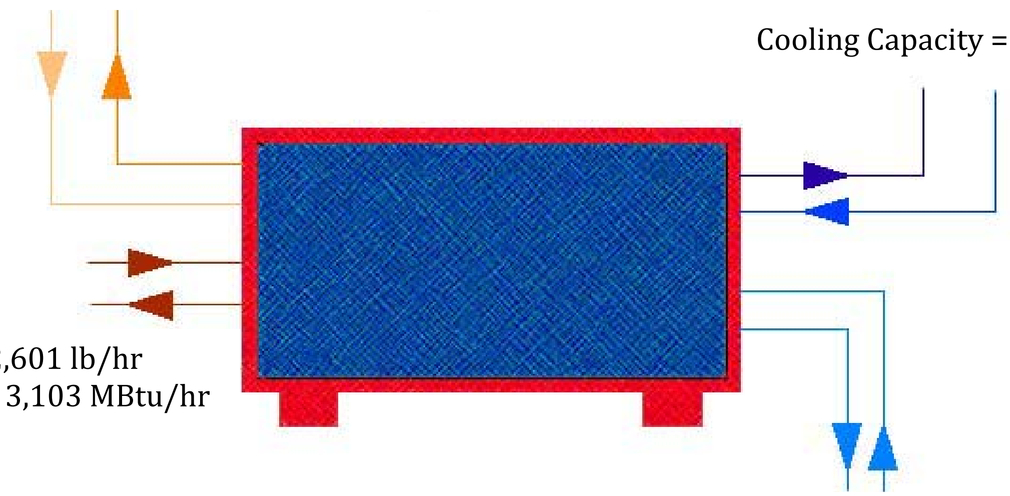
Max Steam Generation = (2,092 kW) x (3,412 Btu/h/kW) / (1193 Btu/lb) x (0.416)
= **2489 lb/hr**

Min Fuel Input = (1,832 kW) / (5 kWh/Nm³) / (0.392) = **935 Nm³/hr**

Min Thermal Output = (935 Nm³/h) x (5 kWh/Nm³) x (0.442) = **2,066 kW**

Min Steam Generation = (2,066 kW) x (3,412 Btu/h/kW) / (1193 Btu/lb) x (0.416)
= **2458 lb/hr**

Absorption Chiller/Heater: Carrier 16NK



Double-Effect and Steam Fired
Cooling Capacity = 1034 kW = 294 Tons = 3,528,000 Btu/hr
Chilled Water Volume Flowrate = 44.4 L/s = 11.7 gal/s
Cooled Water Temperature = 45°F
Cooled Water Volume Flowrate = 74.2 L/s = 1,176 gpm
Steam Consumption = 1180 kg/h = 2601 lb/hr

Energy Input = (2,601 lb/hr) x (1,193 Btu/lb) = **3,103 MBtu/hr**
Energy Output = **3,528 MBtu/hr**
COP = (3,528 MBtu/hr) / (3,103 MBtu/hr) = **1.14**

Cooling
Full Load Demand
Engine Steam Produced = **3,264 lb/hr**
Chiller Steam Consumption = **2,601 lb/hr**
Excess Steam = (3264 lb/hr) – (2601 lb/hr) = **663 lb/hr**
Partial Load Demand
Engine Steam Produced = **3,229 lb/hr**
Chiller Steam Consumption = **2601 lb/hr**
Peak Steam Consumption= **2,601 lb/hr**
Excess Steam = (3264 lb/hr) – (2601 lb/hr) = **628 lb/hr**

(Even at the minimum demand there is still enough steam to meet the maximum cooling load, therefore a standby centrifugal chiller is not needed.)

Heating

Minimum Load Demand

Engine Steam Produced = **2458 lb/hr**

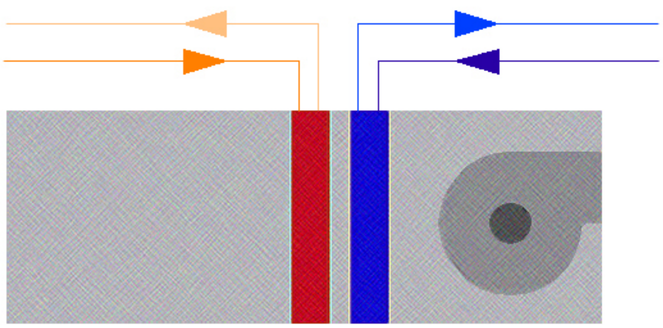
Steam Capacity = (2458 lb/hr) x (1,193 Btu/lb) = **2,932 MBtu/hr**

Peak Heating Demand = **1,239 MBtu/hr**

Excess Steam Capacity = (2,932 MBtu/hr) – (1,239 MBtu/hr) = **1693 MBtu/hr**

(Even at the minimum electrical demand there is still enough steam to meet the maximum heating load, therefore a standby gas-fired boiler is not needed.)

Rooftop Unit A1: TRANE Rooftop Unit



Peak Cooling = 77 tons
Peak Heating = 337 MBtu/hr
Peak Supply = 29,477 cfm
Peak Return = 24,761 cfm
Peak Outside Air = 16%
Total Static Pressure = 2.0 inches
Return Static Pressure = 0.8 inches

Step 1: Casing Size
Peak Heating = 337 MBtu/hr from Table GD-1 **Casing 2** is selected

Step 2: Supply and Exhaust Fan
Peak Supply = 29,477 cfm and External Static Pressure = 2.0 inches
a **supply fan at 25 bhp and 1043 rpm** is selected
Peak Return = 24,761 cfm and Return Static Pressure = 0.8 inches
an **exhaust fan at 10 bhp and 750 rpm** is selected

Step 3: Hot Water Heating System
Supply Fan Heat = (25 bhp x 2.8) = **70 Mbtu/hr**
Supply Fan Temperature Rise = 70,000 Btu / (1.085 x 29,477 cfm) = **2.19°F**
Mixed Air Temperature = 70°F + (0.16)(0°F - 70°F) = **58.8°F**
Total Winter Heating Load = 337 MBtu/hr - 20.3 Mbtu/hr = **316.7 Mbtu/hr**
Steam Needed = (316,700 Btu/hr) / (1,193 Btu/lb) = **265.5 lb/hr**
Steam Remaining = (2458 lb/hr) – (265.5 lb/hr) = **2192.5 lb/hr**

Step 4: Chilled Water Cooling System

Peak Cooling = 77 tons = **924,000 Btu/hr**

Water Leaving Temperature = [(924,000 Btu/hr) / (500) / (294 gpm)] + 45°F = **51°F**

ΔT_L = 90°F - 51°F = 39°F

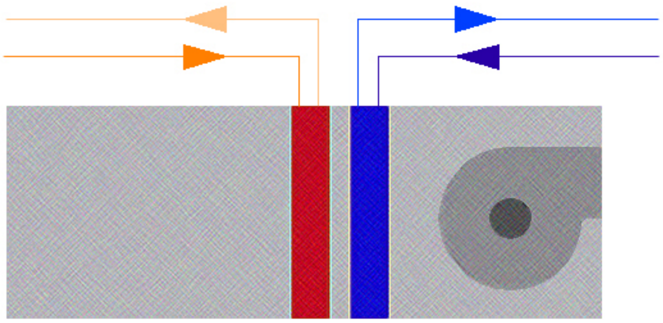
ΔT_S = 55°F - 45°F = 10°F

LMTD = **21.3°F** (From LMTD Table)

Capacity = 232,000 Btu/hr/row (Coil selection chart)

Rows = (924,000 Btu/hr) / (232,000 Btu/hr/row) = 3.98 rows = **4 Rows**

Rooftop Unit A2: TRANE Rooftop Unit



Peak Cooling = 108 tons
Peak Heating = 647 MBtu/hr
Peak Supply = 36,318 cfm
Peak Return = 27,239 cfm
Peak Outside Air = 25%
Total Static Pressure = 2.0 inches
Return Static Pressure = 0.8 inches

Step 1: Casing Size
Peak Heating = 647 MBtu/hr from Table GD-1 **Casing 4** is selected

Step 2: Supply and Exhaust Fan
Peak Supply = 36,318 cfm and External Static Pressure = 2.0 inches
a **supply fan at 30 bhp and 1150 rpm** is selected
Peak Return = 27,239 cfm and Return Static Pressure = 0.8 inches
an **exhaust fan at 15 bhp and 1000 rpm** is selected

Step 3: Hot Water Heating System
Supply Fan Heat = (30 bhp x 2.8) = **84 Mbtu/hr**
Supply Fan Temperature Rise = 84,000 Btu / (1.085 x 29,477 cfm) = **2.63°F**
Mixed Air Temperature = 70°F + (0.25)(0°F - 70°F) = **52.5°F**
Total Winter Heating Load = 647 MBtu/hr - 84 Mbtu/hr = **563 Mbtu/hr**
Steam Needed = (563,000 Btu/hr) / (1,193 Btu/lb) = **472 lb/hr**
Steam Remaining = (2192.5 lb/hr) – (472 lb/hr) = **1721 lb/hr**

Step 4: Chilled Water Cooling System

Peak Cooling = 108 tons = **1,296,000 Btu/hr**

Water Leaving Temperature = [(1,296,000 Btu/hr) / (500)/(294 gpm)] +45°F =**54°F**

ΔT_L = 90°F – 54°F = 36°F

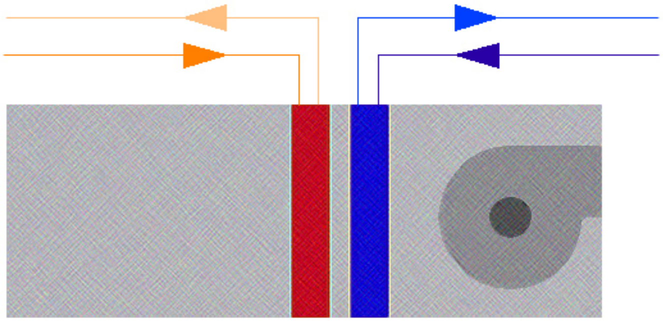
ΔT_S = 55°F - 45°F = 10°F

LMTD = **19.5°F** (From LMTD Table)

Capacity = 232,000 Btu/hr/row (Coil selection chart)

Rows = (1,296,000 Btu/hr) / (232,000 Btu/hr/row) = 5.58 rows = **6 Rows**

Rooftop Unit A3: TRANE Rooftop Unit



Peak Cooling = 42 tons
Peak Heating = 140 MBtu/h
Peak Supply = 17,615 cfm
Peak Return = 15,854 cfm
Peak Outside Air = 10%
Total Static Pressure = 1.5 inches
Return Static Pressure = 0.6 inches

Step 1: Casing Size
Peak Heating = 140 MBtu/hr from Table GD-1 **Casing 2** is selected

Step 2: Supply and Exhaust Fan
Peak Supply = 17,615 cfm and External Static Pressure = 1.5 inches
a **supply fan at 11 bhp and 800 rpm** is selected
Peak Return = 15,854 cfm and Return Static Pressure = 0.6 inches
an **exhaust fan at 6 bhp and 700 rpm** is selected

Step 3: Hot Water Heating System
Supply Fan Heat = (11 bhp x 2.8) = **31 Mbtu/hr**
Supply Fan Temperature Rise = 31,000 Btu / (1.085 x 17,615 cfm) = **1.62°F**
Mixed Air Temperature = 70°F + (0.10)(0°F - 70°F) = **63°F**
Total Winter Heating Load = 140 MBtu/hr - 31 Mbtu/hr = **109 Mbtu/hr**
Steam Needed = (109,000 Btu/hr) / (1,193 Btu/lb) = **91 lb/hr**
Steam Remaining = (1721 lb/hr) – (91 lb/hr) = **1630 lb/hr**

Step 4: Chilled Water Cooling System

Peak Cooling = 42 tons = **504,000 Btu/hr**

Water Leaving Temperature = [(504,000 Btu/hr) / (500) / (294 gpm)] + 45°F = **48°F**

ΔT_L = 90°F – 48°F = 42°F

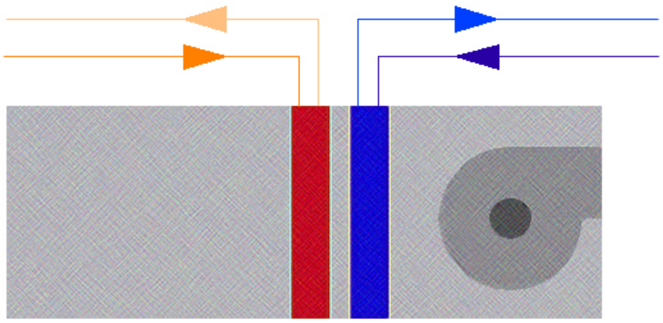
ΔT_S = 55°F - 45°F = 10°F

LMTD = **22.25°F** (From LMTD Table)

Capacity = 232,000 Btu/hr/row (Coil selection chart)

Rows = (504,000 Btu/hr) / (232,000 Btu/hr/row) = **2 Rows**

Rooftop Unit A4: TRANE Rooftop Unit



Peak Cooling = 40 tons
Peak Heating = 117 MBtu/h
Peak Supply = 16,553 cfm
Peak Return = 14,898 cfm
Peak Outside Air = 10%
Total Static Pressure = 1.5 inches
Return Static Pressure = 0.6 inches

Step 1: Casing Size
Peak Heating = 117 MBtu/hr from Table GD-1 **Casing 2** is selected

Step 2: Supply and Exhaust Fan
Peak Supply = 16,553 cfm and External Static Pressure = 1.5 inches
a **supply fan at 11 bhp and 800 rpm** is selected
Peak Return = 14,898 cfm and Return Static Pressure = 0.6 inches
an **exhaust fan at 6 bhp and 700 rpm** is selected

Step 3: Hot Water Heating System
Supply Fan Heat = (11 bhp x 2.8) = **31 Mbtu/hr**
Supply Fan Temperature Rise = 31,000 Btu / (1.085 x 16,553 cfm) = **1.73°F**
Mixed Air Temperature = 70°F + (0.10)(0°F - 70°F) = **63°F**
Total Winter Heating Load = 117 MBtu/hr - 31 Mbtu/hr = **86 Mbtu/hr**
Steam Needed = (86,000 Btu/hr) / (1,193 Btu/lb) = **72 lb/hr**
Steam Remaining = (1630 lb/hr) – (72 lb/hr) = **1558 lb/hr**

Step 4: Chilled Water Cooling System

Peak Cooling = 40 tons = **480,000 Btu/hr**

Water Leaving Temperature = [(480,000 Btu/hr) / (500) / (294 gpm)] + 45°F = **48°F**

ΔT_L = 90°F – 48°F = 42°F

ΔT_S = 55°F - 45°F = 10°F

LMTD = **22.25°F** (From LMTD Table)

Capacity = 232,000 Btu/hr/row (Coil selection chart)

Rows = (480,000 Btu/hr) / (232,000 Btu/hr/row) = **2 Rows**