12 Plant Design

The plant design is a executed to a level of detail in which the main specifications of the individual components of the biogas installation are determined. Moreover, a ground plan is constructed. The process of designing the plant is implemented in the Excel tool in which the energy potential is generated, based in the given biomass quality and quantity. As aforementioned two scenarios are considered. The plant design is based on the scenario excluding the abattoir waste. The main reason is that the legislative landscape for biogas plants that handle abattoir waste is relatively non-transparent and ever changing. In turn, this leads to uncertainty in terms of finances and time. Nevertheless, future developments in the aforementioned landscape might lead to a stronger position for biogas plants including abattoir waste.

12.1 Components

This chapter highlights the team's proposed main specifications of the individual components this power plant will feature: the biogas digester , its gasholder dome, the scrubbing system (although this was not explored in detail) and the generator.

12.1.1 Biogas Digester

The team recommends the construction of a concreate and heated continuously stirred tank reactor (CSTR) under mesophilic conditions, as a proven technology for commercial biogas applications worldwide. Moreover, this is the only technology available in South Africa that has been proven on a commercial scale so-far. The tables below demonstrate the conditions the digester will be operating at, the proposed geometry, and the input and output (mass balance).

Tank Conditions

A specific temperature needs to be maintained in order to keep the microbiological process at an optimum. Mesophilic microbial organisms perform best at temperatures ranging from 32 to 42 degrees Celsius. The required heat (recuperated from the engine) can be estimated, by assuming one-dimensional heat transfer through the digester walls (conduction). With a heat transfer coefficient $k = 0{,}8\,\mathrm{W/(m \cdot K)}$, a minimum temperature inside the digester of $T_{i,min} = 32\,°\mathrm{C}$, a minimum temperatures outside the digester of $T_{o,min} = 15{,}9\,°\mathrm{C}$, and a thickness of $t = 15\,\mathrm{mm}$, the the heat losses of the digester $\dot{Q}_{digester}$ can be estimated as:

$$\dot{Q}_{digester} = 2 \cdot \pi \cdot k \cdot h_{slurry} \cdot \frac{T_{i,min} - T_{o,min}}{\ln\left(\frac{r_i + t}{r_i}\right)} = 0{,}28\,\mathrm{kW}.$$

The maximum pressure inside will occur at the digester floor. The pressure can be estimated using Bernoulli's equations, assuming that the gas in the gasholder is kept at atmospheric conditions and that the forces occurring during stirring are negligible. The value is important for structural dimensioning later in time:

$$p_{i,max} = p_{atm} + \rho_{slurry} \cdot g \cdot h_{slurry}.$$

The most important specifications of the reactor can be found in Table 24.

TABLE 24: KEY SPECIFICATIONS OF THE DIGESTER CONDITIONS.

Description	Value	Unit
Temperature (mesophilic)	32	°C
Heat Transfer Coefficient Concrete	0,8	W/mK
Maximum static pressure	135,11	kPa
Required Heat to maintain Temperature	0,28	kW

Geometry

The chosen digester type will be cylindrical in shape. By defining a height to radius ratio, the calculated slurry volume can be broken down into the two variable dimensions of the chosen geometric figure. In this work a slurry level to radius ratio of $\frac{h_{slurry}}{R} = 1$ was chosen. To prevent overflow a safety factor of $S_{tank} = 1{,}26$ as a factor for additional height of the digester was chosen. Thus determining the ultimate height and volume of the digester.

TABLE 25: KEY GEOMETRICAL DATA OF THE PROPOSED DIGESTER DESIGN.

Description	Value	Unit
Digester Volume	163,85	m^3
Slurry Volume	129,83	m^3
Buffer Volume	33,98	m^3
Radius	3,46	m
Thickness	0,15	m
Digester Height	4,36	m
Slurry Level	3,46	m

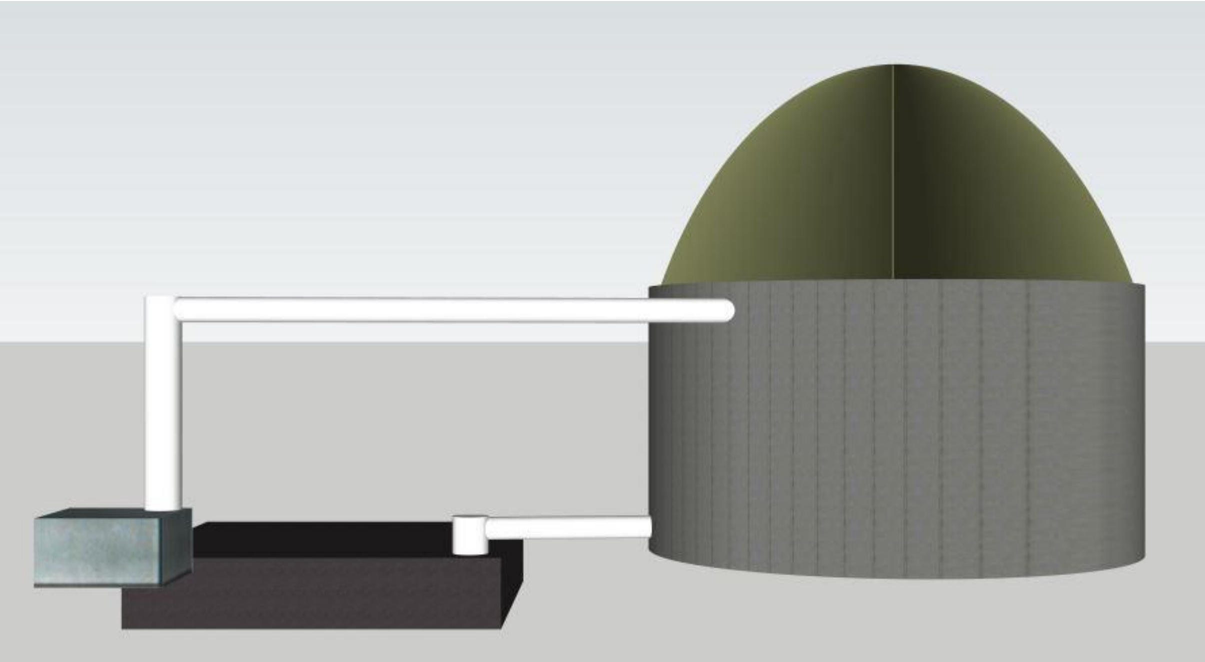

FIGURE 4: SIDE VIEW OF THE BIOGAS INSTALLATION.

Input and Output
The input and output of the biogas digester is based on a mass balance as visualized in Figure 5.

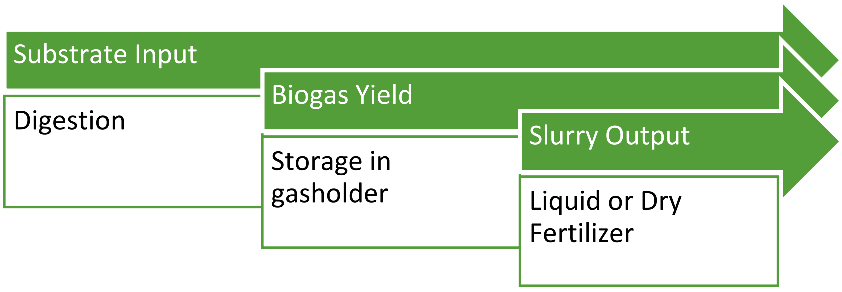

FIGURE 5: FLOW-CHART DEMONSTRATING THE SUBSTRATE CONVERSION INTO 2 PRODUCTS.

Table 26 shows the most important input and output values. The calculations of these values can be found in Energy Potential.

TABLE 26: INFLOW AND OUTFLOW VALUES OF THE DIGESTER.

Description	Value	Unit
Substrate input	4,33	m^3/day
Liquid fertilizer output	4,12	m^3/day
Dry fertilizer output	206,07	kg/day
Hourly biogas yield	171,87	m^3/day

12.1.2 Gas Storage

Functional Requirements

The gas will be stored with a membrane fixed on top of the digester. The membrane is designed to hold approximately 4 hours, $t_{storage}$, of gas produced per day to compensate for the load duration of 20 hours per day. Due to the material strain the pressure inside cannot exceed a certain threshold. In this case the maximum pressure difference cannot exceed 5 mbar (Steinhauser, 2008). If the pressure exceeds this threshold the gas must be flared off, which will be the case during maintenance.. The relevant design parameters of the gasholder can be found in Table 27.

TABLE 27: PARAMETERS THE GAS STORAGE IS DESIGNED FOR.

Description	Value	Unit
Biogas Storage Capacity in Hours	4	h
Maximum pressure difference	0,5	kPa

Material of the Membrane

The membrane's volume is a called a thermal plastic foil, which is a plastic, resistant to UV, weather, fungus, microbes, and biogas, as well as tear proof. It is crucial that the membrane fulfills all of these requirements in order for the gasholder to fulfill its purpose and to ensure a long lifespan.

Geometry of the Membrane

The global geometrical design parameters of the gasholder can be found in Table 28. As the gas holder should store 4 hours' worth of biogas the required volume can be calculated using the equation shown below:

$$V_{gasholder} = S_{gasholder} \cdot V_{BG,daily} \cdot t_{storage},$$

where $S_{gasholder} = 1{,}2$ is a safety factor applied to the maximum required storage capacity. The geometry is estimated to be paraboloidal in shape and includes some of the buffer space above the slurry level (cylindrical). As the radius the gas bag has, is determined by the digester radius, the only parameter requiring calculation is the height of the bag above the digester. The maximum height of the gasbag depends also on the buffer space left at the top of the digester above the slurry level. The geometrical value can be calculated as a result of all other geometrical parameters:

$$V_{gasholder} = V_{paraboiloid} + V_{cylinder}.$$

TABLE 28: GEOMETRICAL DESIGN PARAMETERS OF THE GASHOLDER.

Description	Value	Unit
Volume	34,37	m^3
Radius	3,46	m
Height Gasholder	2,72	m

12.1.3 Slurry Basin

This basin, which will act as an overflow tank, in which the slurry can be stored in temporarily post-digestion. As the fertilizer will not necessarily be picked up daily, it can be stored for a certain amount of time. In this case the team chose seven days — weekly pick-ups — approximately one fourth of the retention time. The global geometrical design parameters, with exception to the thickness can be found in Table 29.

TABLE 29: : GEOMETRICAL DESIGN PARAMETERS OF THE SLURRY BASIN, INCLUDING.

Description	Value	Unit
Volume	28,85	m^3
Side A	5,37	m
Side B	5,37	m
Depth	1,0	m

12.1.4 Scrubber

The approximate content of 0,5 vol.% of H_2S in the gas will be reduced to a concentration of 0,05 vol.% of H_2O, to prevent corrosion downstream the installation (Steinhauser, 2008). The gas treatment system must handle a flow rate of approximately 8,59 $\frac{m^3}{h}$.

12.1.5 Generator

The team recommends installing a a generator of the power of 17,26 kW. This CHP engine, will also provide the digester with the heat required to maintain a digester temperature of 32°C to 42°C. The global generator design parameters, can be found in Table 30.

TABLE 30: GENERATOR DESIGN PARAMETERS.

Description	Value	Unit
Power Anually	98.016,87	kWh
Full-load Hours Annually	5680	h
Average Daily Duration	20	h
Average Load Factor	80	%

12.2 Ground Plan

The ground plan this report features, gives an impression as to how large the footprint of this installation will be. It can be used and adapted to meet conditions at the farm. It will be necessary to pour a concrete foundation, to lay piping, place the scrubbing system, and which can with stand the vibrations of the internal combustion engine. The ground plan's key values can be found in Table 31. The team recommends involving a civil engineer in this matter.

TABLE 31: KEY VALUES OF THE GROUND PLAN.

Description	Value	Unit
Accumulated Area	67,28	m^2

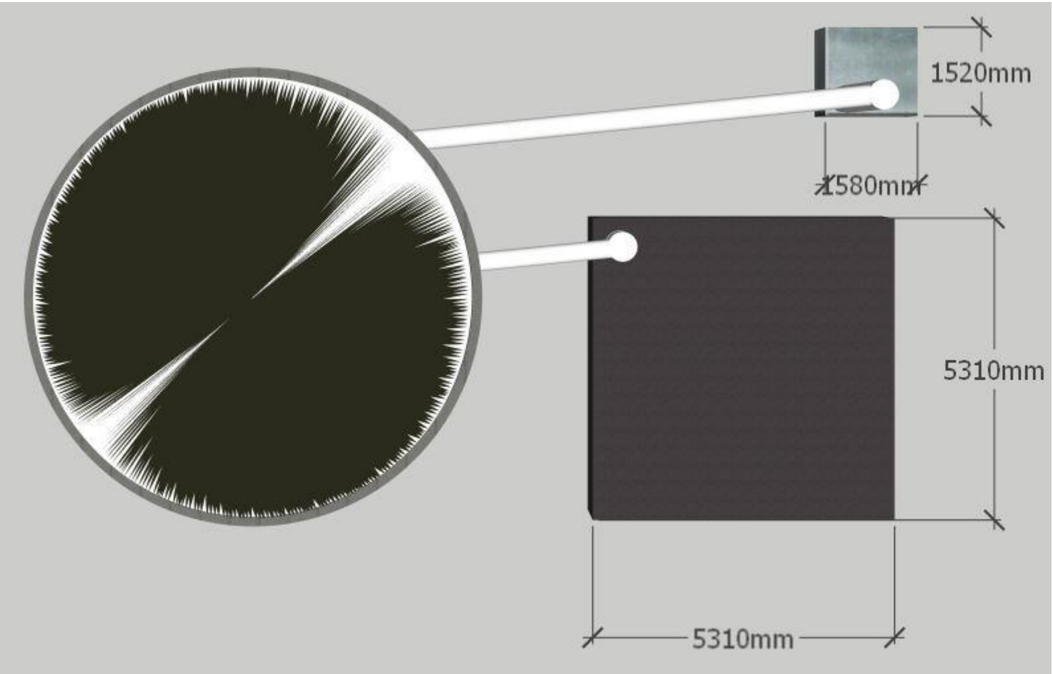

FIGURE 6: EXAMPLE TOP VIEW OF THE BIOGAS INSTALLATION.

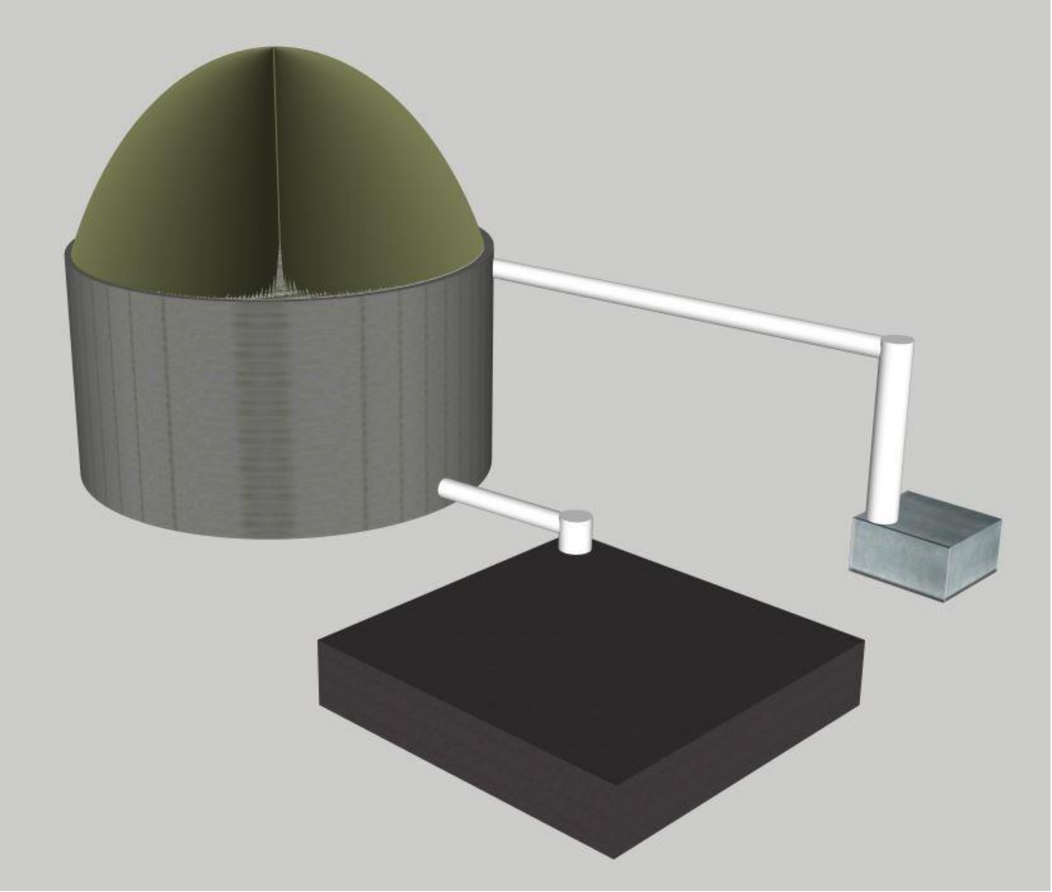

Figure 7: 3D-view of the Biogas Installation.