13 Plant Design

The plant design is executed to a level of detail in which the main specifications of the individual components of the biogas installation are determined. The process of designing the plant is implemented in the Excel tool in which the energy potential is generated, based on the given biomass quality and quantity. As aforementioned two scenarios are considered.

13.1 Components

This chapter highlights the team's proposed main specifications of the individual components this power plant will feature: mixing tank, pasteurizer, shredder, anaerobic digester, post storage, gas treatment, gas storage, generator, heating system, electricity distribution.

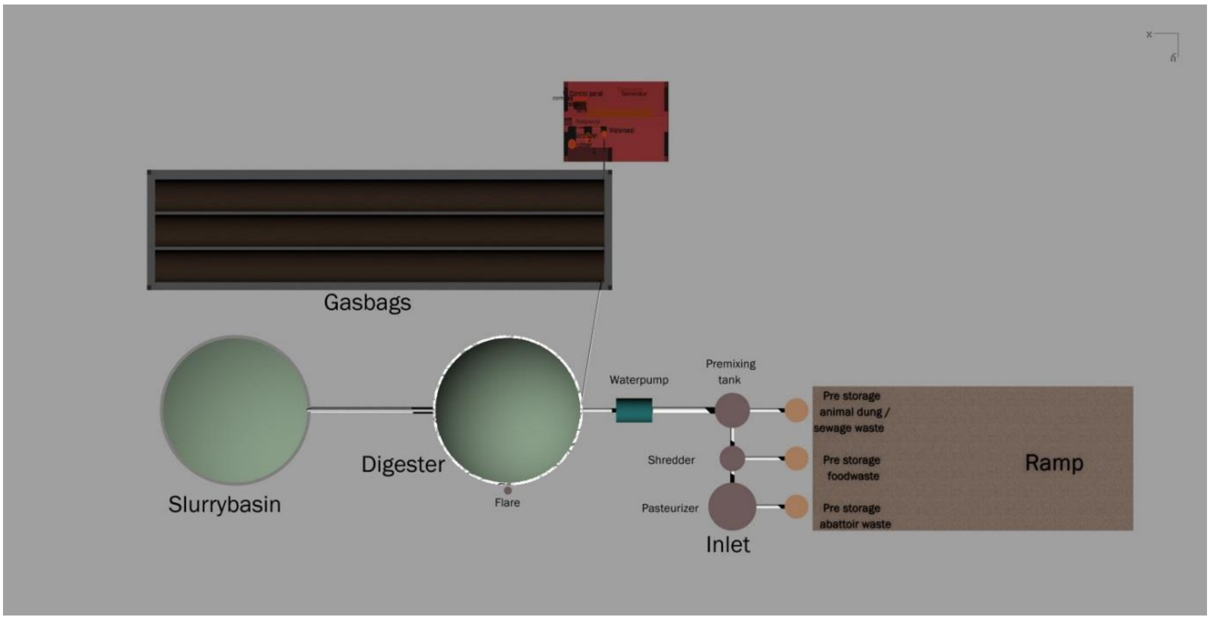

FIGURE 8 TOP VIEW BIOGAS PLANT

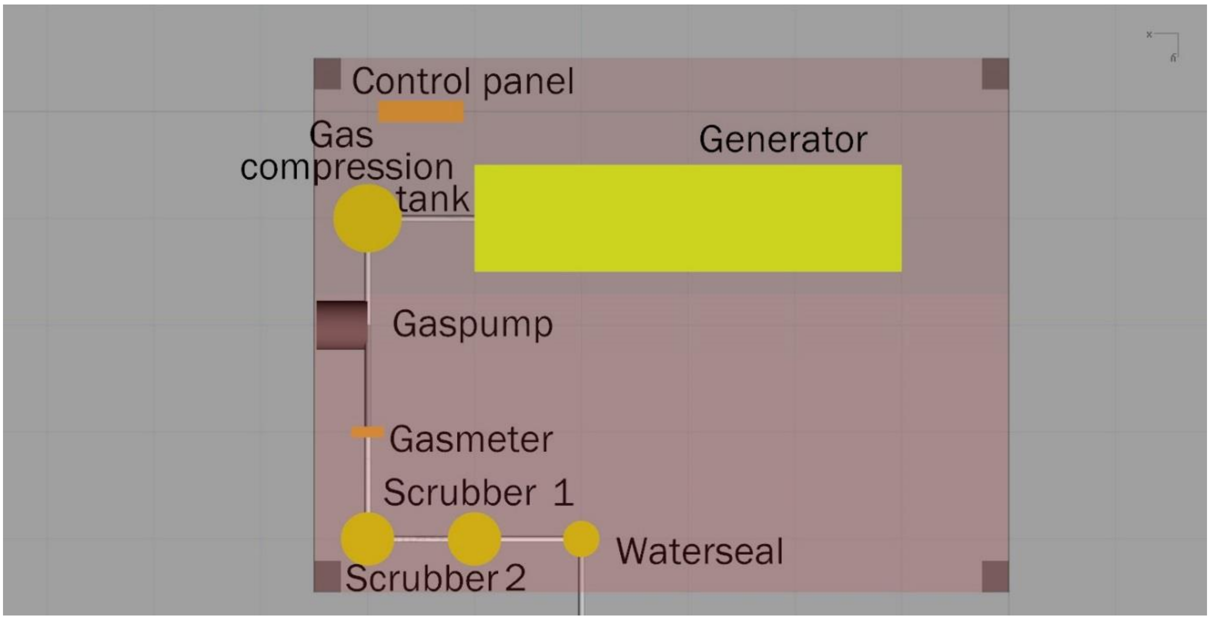

FIGURE 9 TOP VIEW GAS TREATMENT & GENERATOR HOUSING

13.1.1 Pre Storage

For a temporary storage of the different feedstocks (food waste, manure and slaughterhouse waste) the three silos who are already on the farm will be used. This means that the silos who were used for the chicken house, can be useful for pre-storage. This means that no extra costs will be made. The silos each have a capacity of 6 m^3.

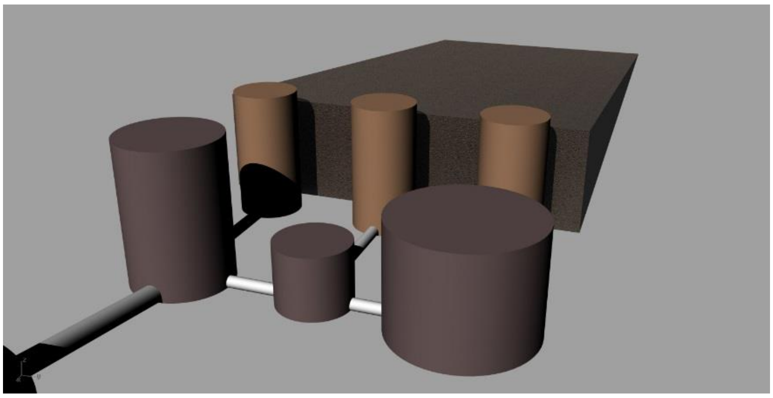

FIGURE 10 FEED-IN

13.1.2 Post storage

The already existing silo next to the house will be used for the post storage. There will still be gas production in the post storage. A PVC membrane will be needed (PVC, Alibaba, 2015) to capture this. The gas will be pumped back into the flair or into the gas storage depending on the quality.

TABLE 25 POST STORAGE PROPERTIES

Post Storage Properties	
Type	Post Storage
Diameter	9 m
Surface	89 m^2
Membrane material	PVC
Price	30 ZAR/m^2
Price in total	1350 ZAR

13.1.3 Feed Preparation

Biomass of different types are being used for digestion. Some types have to be prepared before fed in the digester. Also the biomasses have to be mixed before fed in the digester.

13.1.3.1 Pasteurizer

A tank will be used as a pasteurizer with the usage of heat of the engine, to heat the tank for 1 hour at 70 degrees C. The pasteurizer is needed to ensure a sufficient percentage of pathogens in the feedstock are removed. It also prevents any bacterial competition in the digestion stage, since abattoir waste can be hazardous if not done. The pasteurizer will be heated by the hot water generated by the CHP boiler of the generator.

TABLE 26 PASTEURIZER PROPERTIES

Pasteurizer Properties	
Daily slaughterhouse waste	3500 kg
Daily slaughterhouse waste	3500 L
Work Volume pasteurizer	5000
Tank Dimensions	1,910 x 2,0 (m x m)
Total height	3850 mm
Insulated layer	60 mm
Diameter of inlet & outlet	51 mm
Total Cost	**ZAR 15,678**

FIGURE 11 PASTEURIZER

13.1.3.2 Shredder

The food waste shredder is an optional object. A shredder is needed to shred food waste into small pieces to avoid blockage in the tubing or pumps. If a more budgeted option is required, it is possible to buy a smaller shredder, shred the food and then put it into the digester (Food Waste Shredder, Alibaba, 2015).

TABLE 27 SHREDDER PROPERTIES

Shredder Properties	
Type	Food Waste Disposer
Volume	0.226 m^3
Capacity	1 ton/hour

Power	2.2 kW
Height	1.35 m
Diameter (valve)	80 mm
Total Cost	8,900 ZAR

FIGURE 12 SHREDDER

13.1.3.3 Mixing Tank

A mixing tank is needed to ensure a homogeneous sludge is fed in the digester with the right biomass proportions. A capacity of 12 m^3 is needed, since the daily substrate input is 9.46 m^3 and a safety factor of 1.2 is used. A horizontal submersible mixer has to be used for mixing the substrate.

TABLE 28 MIXING TANK PROPERTIES

Mixing Tank Properties	
Mixing Tank Type	Water tank
Dimensions	
Slurry level	1.5 m
Radius	1.6 m
Volume	12 m^3
Mixer type	Horizontal submersible mixer
Cost Tank	ZAR 12,000
Cost Mixer	ZAR 17,000
Total Cost	**ZAR 29,000**

FIGURE 13 MIXING TANK

13.1.3.4 Pumps

Between the mixing tank and de digester a sludge pump will be used to feed the biomass into the digester. The properties of this pump still have to be researched.

FIGURE 14 WATERPUMP

13.1.3.5 Piping

The pipes, which will be used for connections of the digester, will be bought in South Africa. For the digester PVC pipes will be used and a length of 50 meters is estimated (Piping, 2015).

TABLE 29 PIPING PROPERTIES

Piping Properties	
Type	PVC Piping
Estimated length	50 m
Total Cost	**ZAR 1500**

FIGURE 15 PVC PIPING

13.1.4 Digestion

The team recommends the construction of a concrete 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. Table 30 and Table 31 below demonstrate the conditions the digester will be operating at, the proposed geometry, and the input and output (mass balance).

13.1.4.1 Digester Tank

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 $S_{tank} = 1{,}2$ as a factor for additional height of the digester was chosen. Thus determining the ultimate height and volume of the digester.

A zinc aluminium water tank with a volume has been chosen for the digester. The tank itself costs ZAR 140,000. A concrete ring will need to be added around the lower layer to prevent corrosion. This will cost an additional ZAR 55,000.

TABLE 30: KEY GEOMETRICAL DATA OF THE PROPOSED DIGESTER DESIGN.

Description	Value	Unit
Digester Volume	324	m^3
Slurry Volume	290	m^3
Buffer Volume	34	m^3
Radius	4.52	M
Thickness	0.15	M
Digester Height	5.06	M
Slurry Level	4.52	m

Input and Output

The input and output of the biogas digester is based on a mass balance as visualized in Figure 16.

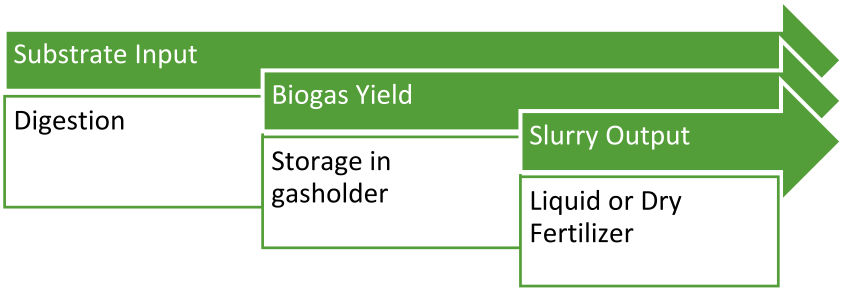

FIGURE 16: FLOW-CHART DEMONSTRATING THE SUBSTRATE CONVERSION INTO 2 PRODUCTS.

Table 31 shows the most important input and output values. The calculations of these values can be found in Energy Potential.

TABLE 31: INFLOW AND OUTFLOW VALUES OF THE DIGESTER.

Description	Value	Unit
Substrate input	9.6	m^3/day
Liquid fertilizer output	8.9	m^3/day
Dry fertilizer output	1318	kg/day
Biogas yield	649	m^3/day

Insulation

The current design has a diameter of approximately 9.04 m and a height of 5.06 m. The surface to be insulated will be 144 m^2. With a thickness of 20 mm, polystyrene sheeting will cost approximately ZAR 2630.

Flexible dome

The biogas will be Before the gas goes from the digester into the gas treatment it is stored in the digester itself. Therefore a flexible dome is needed to keep the gas in the digester. (PVC, Alibaba, 2015)

TABLE 32 DIGESTER TANK PROPERTIES

Digester Tank Properties	
Digester tank type	Zinc Aluminium Water tank
Tank Dimensions	
Radius	4.52 m

Height	5.06 m
Volume	325 m^3
Dome material	PVC
Dome Surface	23.3 m^2
Dome Thickness	15 mm
Cost Tank	ZAR 140,000
Cost Concrete Ring	ZAR 55,000
Cost Insulation	ZAR 2,630
Cost Flexible Dome	ZAR 360
Total Cost	**ZAR 197,990**

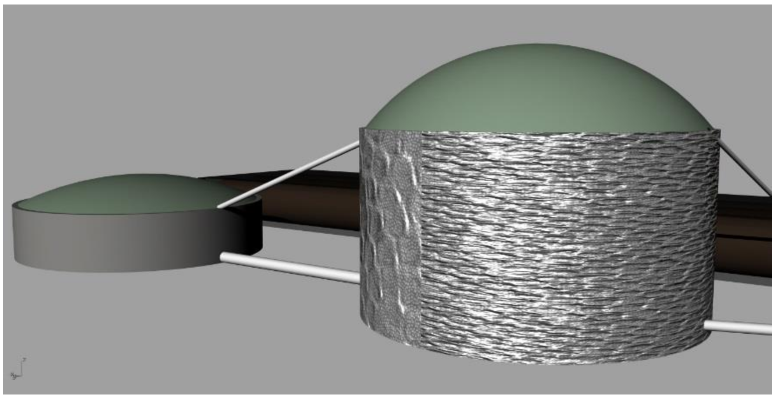

FIGURE 17 DIGESTER TANK AND POST STORAGE TANK

13.1.4.2 External Gas Storage

Functional Requirements

The back-up storage will be three gasbags designed to hold approximately a total of 8 hours, $t_{storage}$, of gas produced per day to compensate for the load duration of 16 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 33. The costs still have to be researched.

TABLE 33: EXTERNAL GAST STORAGE PROPERTIES

External Gast Storage Properties	
Type	Flexible Biogas Holding Bag
Biogas Storage Capacity	12 h

Maximum pressure difference	5 Mbar
Volume	260 m^3
Dimensions	3x Ø 2 x 28 m
Material Surface	547 m^2
Cost	ZAR 58.5/m^2
Total Cost	**ZAR 32,000**

FIGURE 18 FLEXIBLE BAG

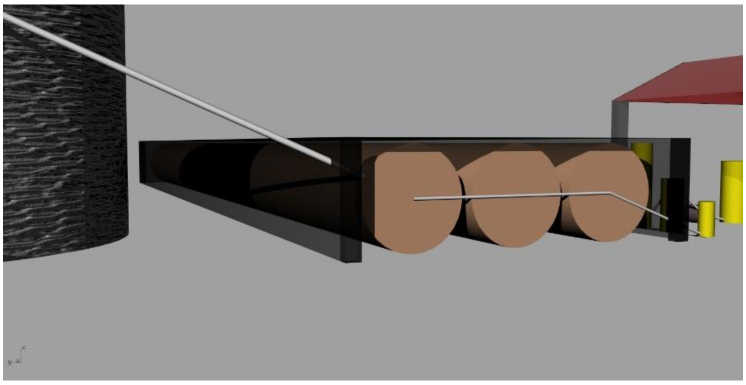

FIGURE 19 GAS STORAGE HOUSING

13.1.4.3 Mixing system

According to Energies journal research (Lemmers et al, 2013) highest agitator efficiency can be achieved with inclined axial agitators. According to experts (Chemicalprocessing, 2015) the size of the impellers should be 25% of the tank diameter. While the tank diameter is 4,72m an agitator with a diameter of 1,00 m would be fitting for this digester. Therefore two agitators of both a diameter of 0,5m will be used for this project (Agitator, Alibaba, 2015)

TABLE 34 MIXER PROPERTIES

Mixer Properties	
Type	Airfoil Axial Agitator
Speed	10-420 RPM
Power	0,75 kW
Material	Stainless steel
Propeller Diameter	500 mm
1 x Agitator Cost	17,000 ZAR
Total Cost	34,000 ZAR

FIGURE 20 AIRFOIL AXIAL AGITATORS

13.1.4.4 Heat Exchanger

Within the Digester tank a heat exchanger will be placed to maintain the working temperature of 35°C. The heated water from the CHP will pass through this exchanger at a rate of 7.5 m^3/h. A titanium corrosion resistant tubular heat exchanger will be used (Heat exchanger, Alibaba, 2015).

TABLE 35 HEAT EXCHANGER PROPERTIES

Heat Exchanger Properties	
Type	Heat exchanger MHTA-5
Liquid Flow Rate	7.5 m^3/h
Heating capacity	17 kW
Heat Transfer Coils Material	Titanium
Transfer Coils Dimensions	ø12.7 x 20,000 mm
Total Cost	6,000 ZAR

FIGURE 21 HEAT EXCHANGER MHTA-5

13.1.5 Electricity Generation

The team recommends installing a generator of the power of 91 kW. This combined heat and power engine will generate electricity and the needed heat to keep the pasteurizer and digester at respectively 70 degC and 37 degC. The maximum estimated power generation is 91 kW and will run 20 hours per day. A safety factor of 1.2 has led us to choose for a generator of 120 kW prime power. An open generator is chosen above a silent generator due of the cost. The generator will be placed in a housing together with the gas treatment installation. The heat cogeneration option costs an extra USD 8733 resulting in the total cost of USD 37,333 (Generator, Alibaba, 2015). The global generator design parameters, can be found in Table 36.

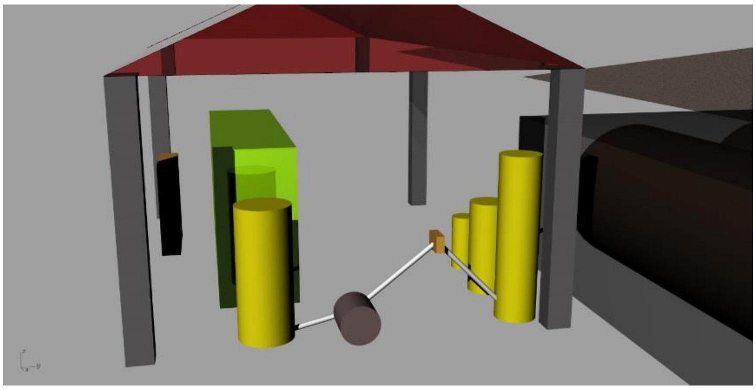

FIGURE 22 GENERATOR AND GAS TREATMENT HOUSING

TABLE 36: GENERATOR PROPERTIES

Generator Properties	
Type	CHP Open Type
Prime/continuous power	120kW/100kW
Fuel consumption	56.92 m3/h

Cogeneration(heat) efficiency	85%
Electric efficiency	~30%
Service life	30 years
Dimension	2950 x 1100 x 1800 mm
Cost Gas Generator	ZAR 480,000 (USD 28,600)
Cost Heat cogeneration	ZAR 147,000 (USD 8,733)
Total Cost	**ZAR 627,000 (USD 37,333)**

FIGURE 23 CHP OPEN TYPE

13.1.6 Gas Treatment

When biogas is formed in the digester it will be led to the gas treatment installation which contains a water seal, flare, biogas purification with pressure boosting and external gas storage. The gas treatment will be housed together with the generator.

13.1.6.1 Water seal and flare

To prevent biogas from flowing back into the digester a water seal is placed at the biogas outlet. Furthermore a flare is placed at the biogas outlet for security reasons. It is essential for every biogas installation to have a flare as a fail-safe. In the case of the gas levels exceeding the capacity of the storage and generator, the flare will dispose of the gas in an environmentally friendly fashion. Burning the excess gas will prevent methane from entering the atmospheres. This will only be used when there is no other option.

Our gas holder has a capacity of 150 m3. The gas production is 32m3 per hour. Multiplying this by a safety factor of 125%, a flare is chosen with a capacity of 40m3 per hour.

TABLE 37 BIOGAS FLARE

13.1.6.2 Biogas Purification System

To prevent corrosion downstream in the installation, the content of H_2S (hydrogen sulphide) in the gas should be reduced. H_2S reacts easily with iron oxide or hydroxide which is usually bound on wood chips or red mud pellets to increase the reaction surface. In a skid-mounted biogas pre-treatment system one column binds H2S whereas the other is regenerated. The use of iron pallets is a solid and cheap method to remove hydrogen sulphide (Scrubber, Alibaba, 2015). The iron pallets will be placed in a scrubber tank where the biogas will be led through. Furthermore, the biogas will be dehydrated. The biogas will be led through the system by a gas blower which is included in the system.

Since there are three empty tanks available on the farm that can be used for the biogas purification system, the cost of the biogas purification system will be decreased. In Table 38 the properties of a biogas purification system are listed. In the total cost of the system the cost of the tanks are not included.

TABLE 38 BIOGAS PURIFICATION SYSTEM PROPERTIES

Biogas Purification System Properties	
Type	Biogas Purification System/Biogas Scrubber
Gen – Set power	24 kW
Gas Blower Power	1.1 kW
Gas Flow	30 – 50 m^3/h
Pressure	10 kPa
Dimension	2000 x 1600 x 2160 mm
Gen-set Cost	ZAR 100,200 (USD 6000)
3x Tank Cost	ZAR 7,515(USD 450)
Total Cost	**ZAR 92,685 (USD 5550)**

FIGURE 24 IRON OXIDE PALLETS

FIGURE 25 BIOGAS PURIFICATION SYSTEM

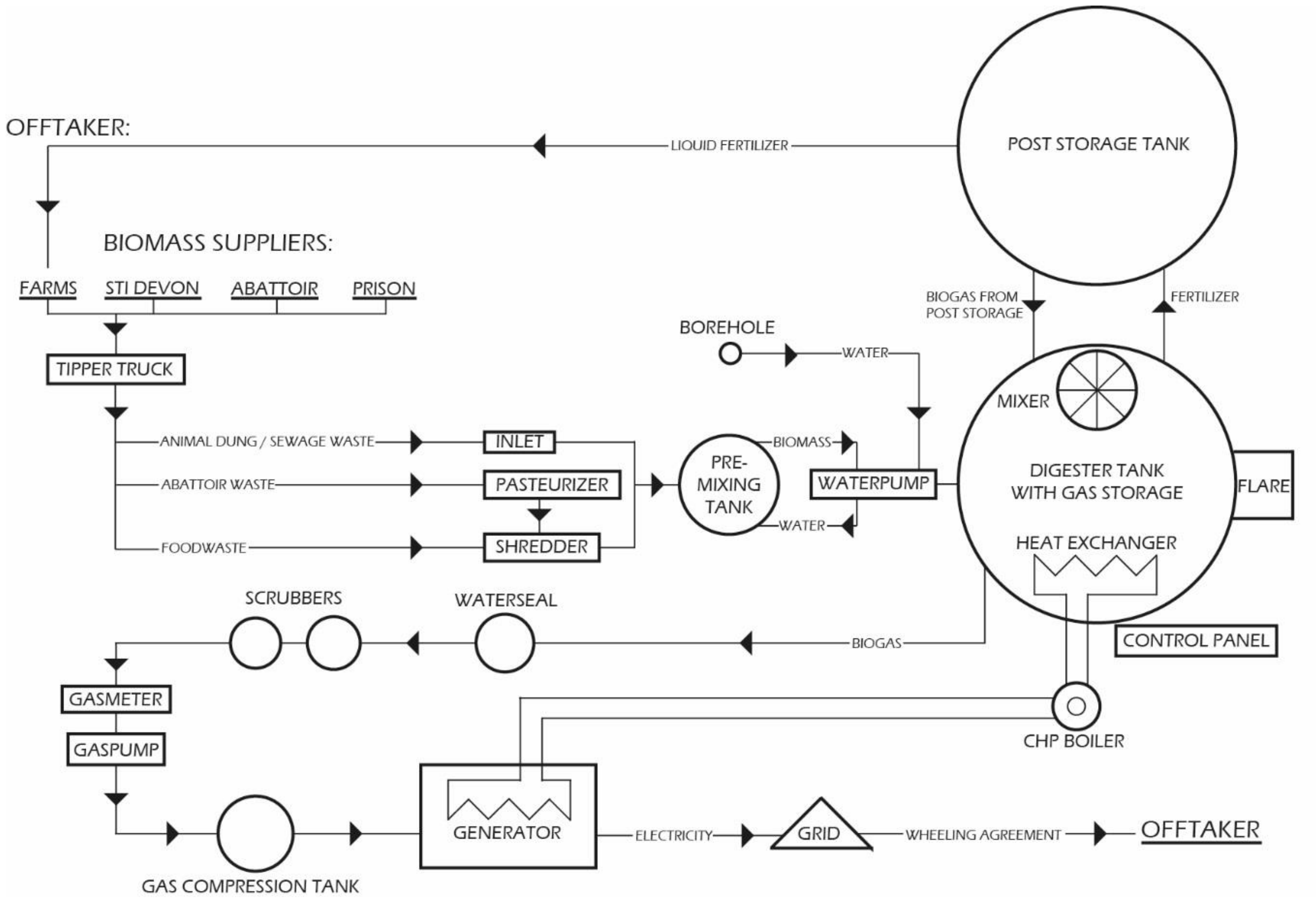

Figure 26 Flow Chart Biogas Plant