12 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.

12.1 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.

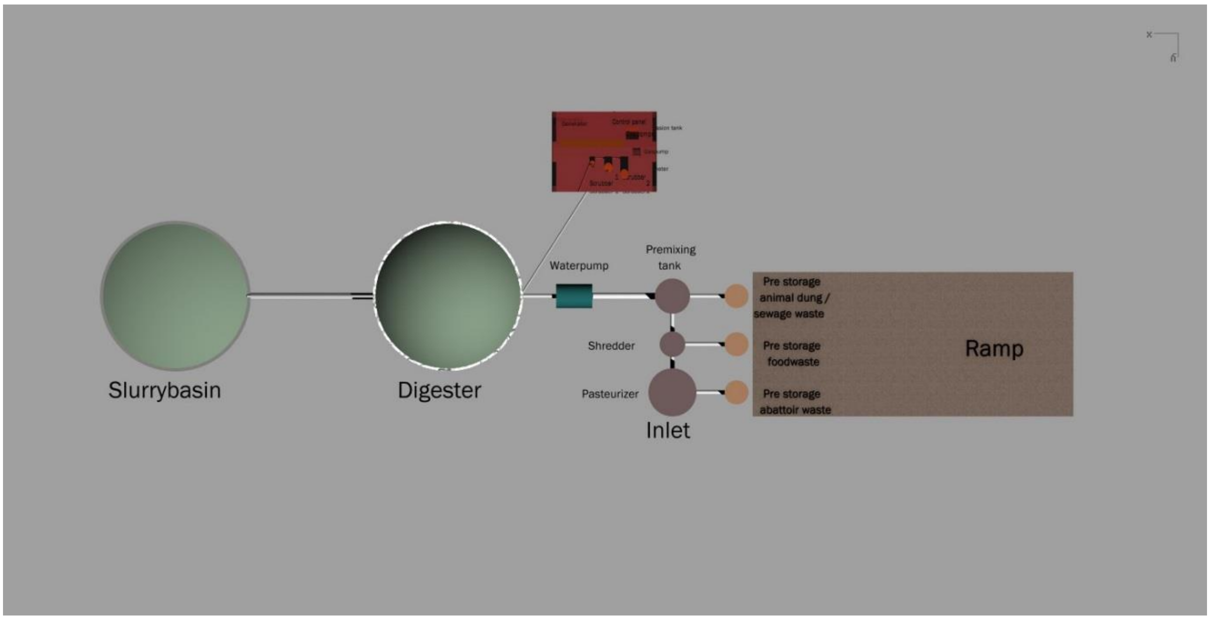

FIGURE 4 TOP VIEW BIOGAS PLANT

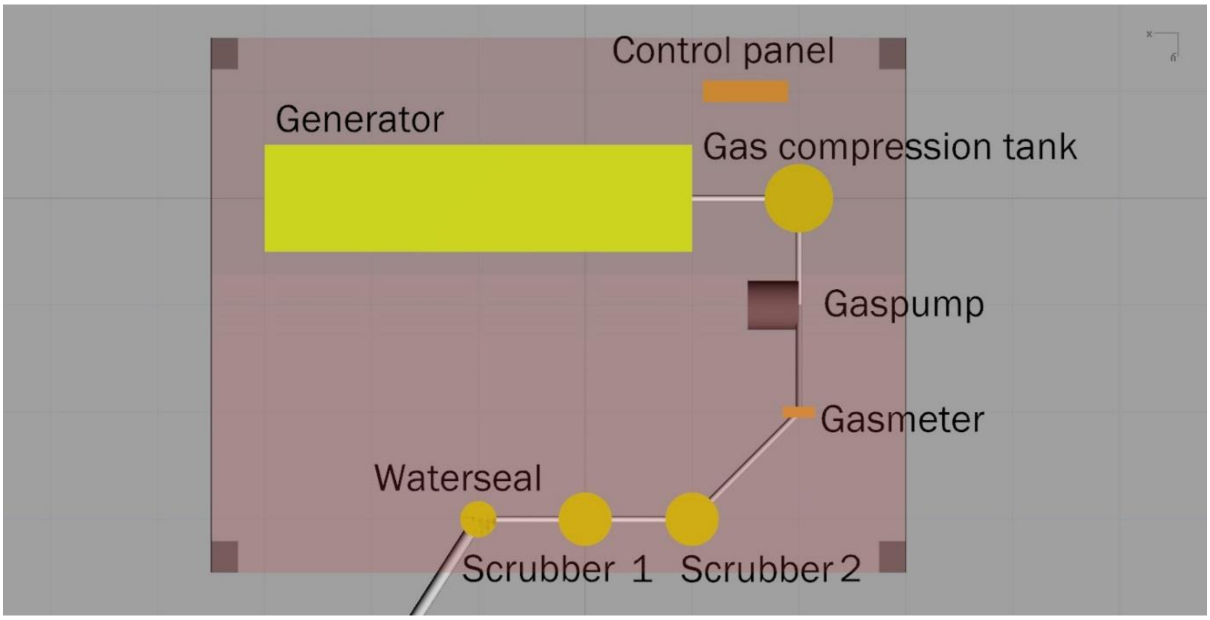

FIGURE 5 TOP VIEW GAS TREATMENT & GENERATOR HOUSING

12.1.1 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.

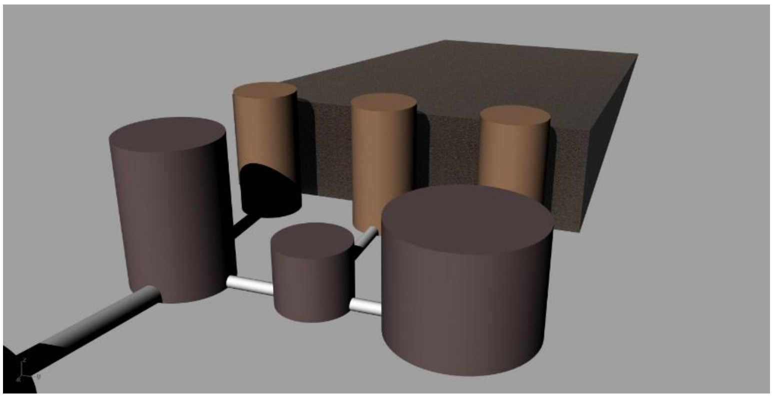

FIGURE 6 FEED-IN

12.1.2 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 23 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

12.1.3 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.

12.1.3.1 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 24 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 7 PASTEURIZER

12.1.3.2 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 25 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 8 SHREDDER

12.1.3.3 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 26 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 9 MIXING TANK

12.1.3.4 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 10 WATERPUMP

12.1.3.5 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 27 PIPING PROPERTIES

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

FIGURE 11 PVC PIPING

12.1.4 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. The tables below demonstrate the conditions the digester will be operating at, the proposed geometry, and the input and output (mass balance).

12.1.4.1 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 28: 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 12.

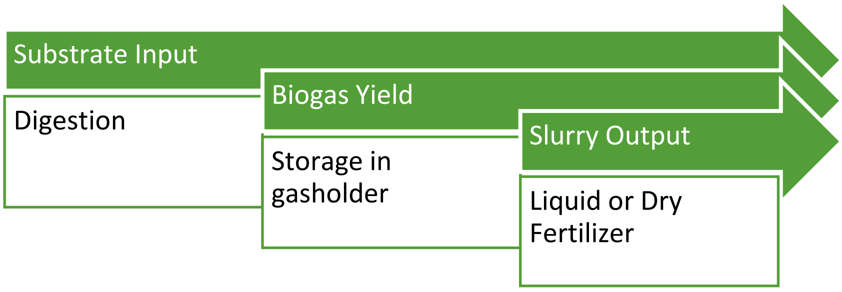

FIGURE 12: FLOW-CHART DEMONSTRATING THE SUBSTRATE CONVERSION INTO 2 PRODUCTS.

Table 29 shows the most important input and output values. The calculations of these values can be found in Energy Potential.

TABLE 29: 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 30 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**

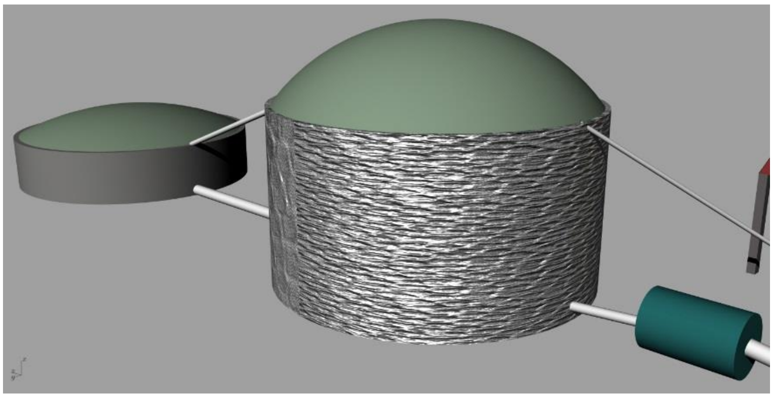

FIGURE 13 DIGESTER TANK AND POST STORAGE TANK

12.1.4.2 External Gas Storage

Functional Requirements

The back-up storage will be a gasbag designed to hold approximately 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 **Error! Not a valid bookmark self-reference.**. The costs still have to be researched.

TABLE 31: PARAMETERS THE GAS STORAGE IS DESIGNED FOR.

Description	Value	Unit
Biogas Storage Capacity	12	H
Maximum pressure difference	5	Mbar

Volume	260	m³

FIGURE 14 FLEXIBLE BAG

12.1.4.3 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 32 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 15 AIRFOIL AXIAL AGITATORS

12.1.4.4 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 33 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 16 HEAT EXCHANGER MHTA-5

12.1.5 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 34.

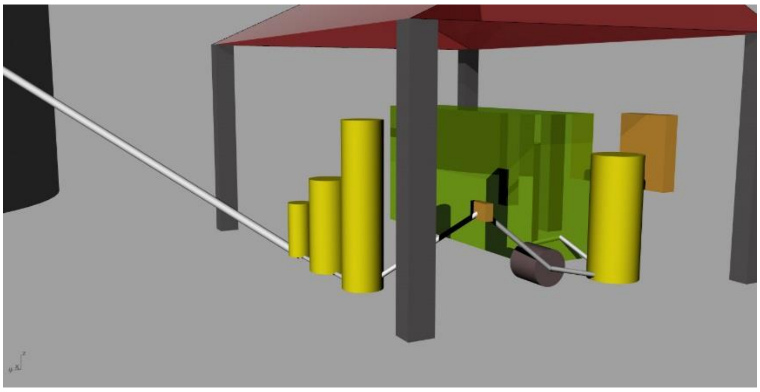

FIGURE 17 GENERATOR AND GAS TREATMENT HOUSING

TABLE 34: 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 18 CHP OPEN TYPE

12.1.6 Gas Treatment

When biogas is formed in the digester it will be led to the gas treatment installation which contains a water seal, flare, H2S removal (scrubbing), gas storage and pressure boosting. The gas treatment will be housed together with the generator.

12.1.6.1 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.

12.1.6.2 Scrubbing

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 two-column plant 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.

TABLE 35 H2S REMOVAL PROPERTIES

H_2S Removal Properties			
Description	**Value**	**Cost**	**Comment**
Iron oxide pellets	5 m^3	R 15,820	
Scrubbing with oxygen	Small compressor	R 1060	This is the price of a small compressor, while oxygen is free.

The oxygen is provided by injection of air in the top of the digester, done with the help of a very small compressor. The air injection pipes inside the digester should be positioned on the opposite side of the biogas output, in order to avoid blockage of the output pipe (Biogas Handbook, 2015). The small compressor will be bought in South Africa itself at a company called TechnoPro (Compressor, Pricecheck, 2015).

FIGURE 19 IRON OXIDE PALLETS

FIGURE 20 COMPRESSOR

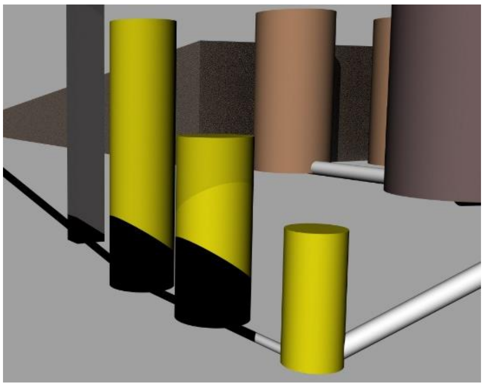

FIGURE 21 GAS TREATMENT

12.1.6.3 Pressure Boosting System

The biogas has to be fed in at a certain pressure in the generator. This will be done by a pressure boosting system which consists of a gas pump and a compression tank with pressure regulation. The properties of the pressure boosting system still have to be researched.

FIGURE 22 GAS COMPRESSION TANK

FIGURE 23 GAS PUMP

13 Site plan

The location of the digester is influenced by various factors. First of all, security has to be taken into account. Since there is a risk of explosion, the digester tank has to be at certain distance from residential homes. Secondly, for practical reasons it is preferred to build the biogas plant near boreholes and a transformer. At last a flat open surface is necessary, without too many obstacles with a good accessibility by truck.

Three options are considered. Each option has advantages and disadvantages that will be discussed. The project owner, Mr. Mofokeng, should choose which option is most suitable.

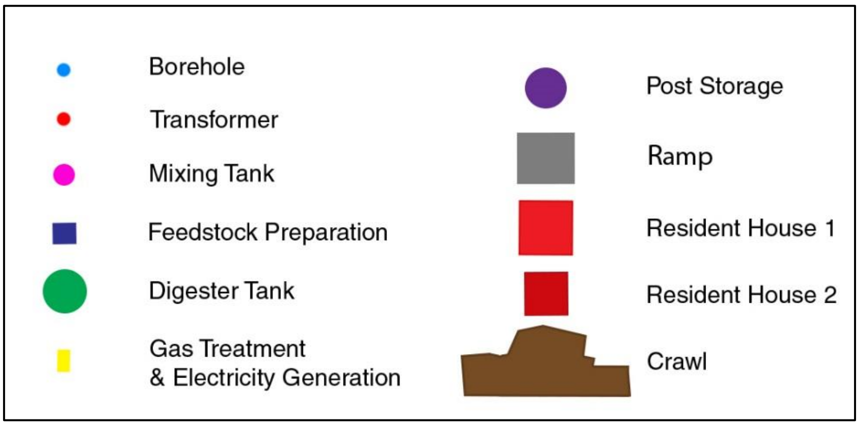

FIGURE 24 LEGEND

13.1 Option 1

In option 1, the biogas plant will be built next to the smaller residential house. Nearby two water boreholes and a transformer. Since there is already a concrete cylindrical tank on location, this will be used as a post storage tank. An optional second post storage tank is needed if a bigger post storage volume is needed. This has to be further researched when fertilizer market research is being done. The security risk is given a little less priority than the practicality, because the post storage will be directly next to the smaller residential house. The digester tank itself will be far enough from the house, so it can be considered as safe. This option will reduce investment costs, since a post storage tank is already available. Because it is near the crawl the feed-in of the cattle manure of the farm can be shoveled in shorter time.

FIGURE 25 SITE PLAN OPTION 1

13.2 Option 2

In the second option the biogas plant will be built near two water boreholes and a transformer. The site is accessible by truck and has a flat open area. The security risk is relatively low.

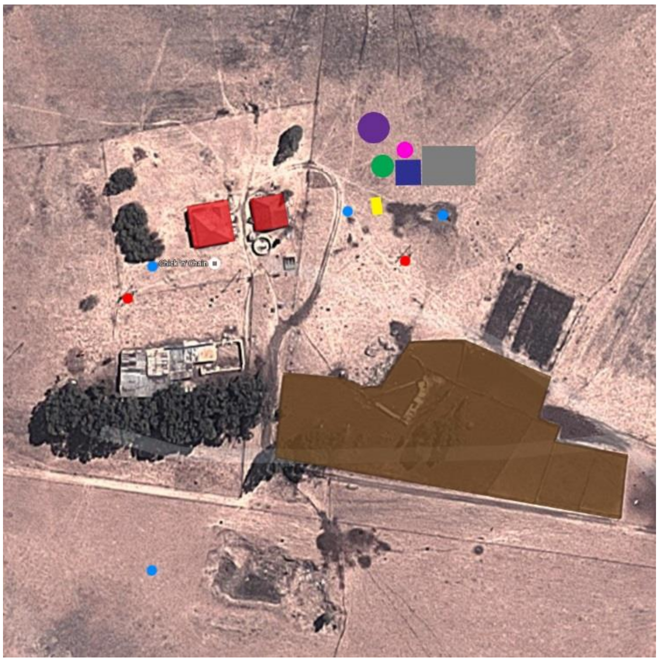

FIGURE 26 SITE PLAN OPTION 2

13.3 Option 3

The third option is building the biogas plant nearby the transformer and the water borehole next to residential house 1. This site is easy to access by truck and has a flat open area. The security risk is relatively low, since it has a greater distance to the residential houses than in option 1.

FIGURE 27 SITE PLAN OPTION 3

13.4 Site plan route map

In the following figure a route map is given for the different site plan options. The biomass collected from Devon Abattoir is transport through a private road which leads directly to the abattoir. Gravel roads have to be constructed for the accessibility of the biogas plant in any case.

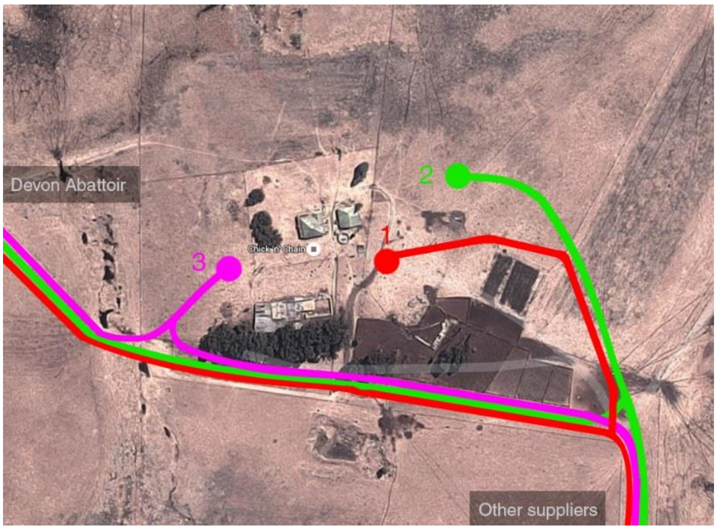

FIGURE 28 SITE PLAN ROUTE MAP