Wellington Institute of Technology

DESIGN OF A BIOGAS CAPTURING SYSTEM ON A SMALL DAIRY FARM

Final Report for the MG7001: Engineering Development Project
Bachelor of Engineering Technology Programme
Mechanical Major

A study to develop a design and analyse the feasibility of installing a biogas capturing system on a dairy farm to create sustainable and renewable energy on site, to reduce greenhouse gas emissions and to reduce energy costs.

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Executive Summary

This report documents the research into the feasibility of retrofitting a biogas system onto a dairy farm. The biogas is used as a fuel for heating the dairy farm's hot water. The areas to focus on were the energy required, the biogas yield, and the effluent collected from the milking shed and cost feasibility of the project.

The report covers a detailed section on the process of anaerobic digestion and biogas production. The case study is a dairy farm of 370 cows located in Woodville, the details of the farm are stated including energy requirement and annual electricity cost. A brief look into energy efficiency equipment is explored. In conclusion hot water insulation is recommended to conserve energy.

The design process is explained, which includes the description of the prototype and gas collection experiments. The experiments suffered difficulties due to various reasons. Site visits were also made to operating biogas plants. The site visits helped to design the operating system and clarify worked calculations.

The final design includes specifications, energy balance, components description, cost analysis, safety and regulations and an evaluation of the design and project.

Overall the energy required is 60 kWh per day to heat the hot water. The biogas yield is 22 m^3/day, at an efficiency of 90% the energy out is 127.2 kWh / day, this sufficient. The temperature and low effluent volumes were not a problem in the end, as the system was designed and sized appropriately.

The cost however for this simple system reached $45,000.00. This price does not include labour or consultancy fees. The labour can be sourced internally which is why it was not included. The savings for subsidising the heating load from the electricity bill is approximately $3,700.00. This gives a payback time of just over 12 years.

Due to the long payback period the motivation for this project must be based on more than cost. Motivation could come from the desire to be sustainable and reduce the greenhouse gas emissions. Also, people may be keen to produce an excellent fertiliser, to possibly claim back on carbon tax or set up a system that could be expanded to generate electricity. This would be if the herd size were to grow. Eventually this may mean going completely sustainable.

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Key Words

Anaerobic Digestion, Methane, Covered Anaerobic Pond, Biogas, Volatile Solids, Hydraulic Retention Time, Organic Loading rate

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1 Project Description

The design of a biogas system on a small sized dairy farm is a final year project for the Wellington Institute of Technology (Weltec) Bachelor of Engineering Technology degree, under the mechanical major. The project was completed over a year with supervision from Weltec tutors.

This project analyses the feasibility of incorporating a biogas system on a dairy farm, which is used to fuel a boiler in the dairy shed supplying hot water for equipment and vat washes. The biogas is produced from cow waste collected from the milking pad that is pumped into a covered anaerobic digester pond. The use of biogas reduces the electricity demand for hot water offering sustainability on the dairy farm and reducing greenhouse gas emissions.

1.1 Problem Statement

There are very few biogas systems installed on New Zealand dairy farms. This may be due to a lack of knowledge however there are also other issues that restrain the motivation for building these systems. Issues relating to the temperate climate of New Zealand, the complexity of building and maintaining the systems and the low quantity of cow effluent collected on milking pads and thus low biogas production.

Therefore the issues can be stated as the following:

1. Low operating temperatures in the digester (and therefore long Hydraulic Retention Times)
2. Complex and high maintenance systems
3. Low volumes of effluent collected and low volumes of gas

Solutions to these issues look into the following:

1. Design for passive solar heating in the digester
2. Designing a simple system that uses the biogas directly
3. Calculate energy balance for biogas produced and energy required

1.2 Scope and Design Requirements

This project is based on solving the issues stated and developing a biogas system that meets the heating requirements of a small dairy farm.

The project bases its work and results gathered from the 'Cook Dairy Farm'. This farm is located in Woodville and is owned by Mrs and Mr J Cook, son of Frank Cook (supervisor). Mr J Cook agreed to the access and analysis of his dairy farm.

The project includes the feasibility assessment of installing a biogas plant on the dairy farm however the implementation stage of the project has only been briefly included in the recommendations.

Specifically the process of the project includes an energy and organic waste analysis to determine the energy demand of the farm and how much organic waste can be collected. A prototype biogas system was built and an experiment for gas collection was carried out on the existing effluent pond. This was for testing purposes to evaluate gas quality and confirm production rate.

The design includes the flow process from collection to digestion to gas handling and finally gas use. The type of digester designed is based on a covered anaerobic pond this is due to its low maintenance and cost, compared to manufactured tanks or heated systems. The gas use is for heating purposes thus using the gas directly. The design for biogas compatible equipment such as boilers was not part of the scope. Estimated pricing is included to give a fair evaluation of the design.

Recommendations given for the project cover the implementation stage which involves selecting consultants and engineering companies to install and quote a system. How best to start a biogas system and general biogas recommendations and safety around biogas systems is also included.

The main objective was to design a simple system that takes advantage of available labour and passive solar heating.

Along with the design for the biogas system an analysis for the overall energy consumption of the farm and its energy efficient equipment is also analysed. This section recommends possible upgrades of equipment to reduce energy use.

2 Technical Review

The initiative to install biogas plants on farms has been increasing since the 1970's when oil prices started rising and electricity prices increased. The systems convert farm waste, usually animal waste, into biogas. The biogas like natural gas contains methane which can be used as a direct fuel for heating, cooling or can be converted to electricity.

Key features for the system include manure collection, effluent storage, gas handling and gas use. Gas handling controls the flow of gas throughout the system, it includes piping, gas cleaning and metering. Gas use is a highly important element of the system, determining how best to use this new found fuel efficiently and economically.

The main component of a biogas system is the anaerobic digester. Anaerobic digestion is the most common way to produce biogas from organic waste. It is a naturally occurring process that allows "anaerobic bacteria to decompose and treat the manure while producing biogas" this is done in the absence of oxygen (US Environmental Protection Agency, 2004).

There are two main types of digesters, either batch fed or continuous feed. The batch fed digesters are loaded once, the substrate is broken down, gas is collected, then it is emptied and loaded again. The continuous feed digesters are as the name suggests continuously fed with substrate and as it fills the pond, the older substrate exits into a holding pond. The continuous feed digesters substrate is usually slurry comprising of 90 - 95% of water and can easily be pumped.

Anaerobic digestion is similar to what happens in the stomach; feed stock or substrate enters the digester and is broken down by bacteria (see figure 2). This process reduces the total solids (TS) and volatile solids (VS) content of the substrate (Huebeck & Craggs, 2010). Total solids are the weight of the substrate after all the water has been removed. Volatile solids are a proportion of the total solids that will be completely digested into its individual elements (carbon, nitrogen, etc.). Fixed solids (FS) is what remains of the total solids, the fixed solids are indigestible. The digestate or effluent is what comes out from the digester which can be used as fertiliser and soil conditioner; it recycles nutrients back into the soil (Bywater, 2011).

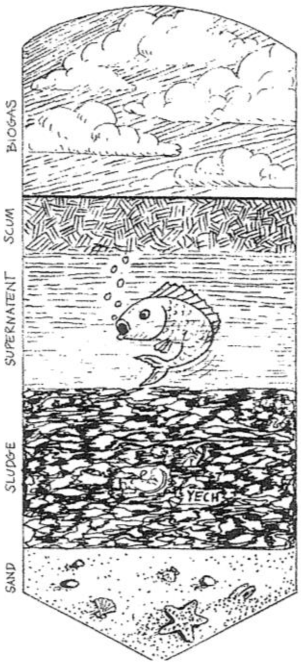

Figure 1: Anaerobic Pond Layers

Within the digester the feedstock which can be a slurry or a liquid settles into different layers; sand, sludge, supernatant and scum (see figure 1). The sand is a layer of indigestible matter that accumulates at the bottom of the pond The accumulations are generally slow and removal could be every 7 – 10 years if at all in large ponds. Sludge has a mud like consistency and is gradually being digested, it will breakdown into the supernatant layer. The supernatant layer is a liquid layer that sits above the sludge; this can be pumped out and used as fertiliser. The scum which floats on top develops differently for various substrates. Plant and fibrous material usually form more scum than manure substrates. Scum can also increase with addition of alkaline supplements. It should generally be avoided because this can restrict gas rise (House, 2010).

There isn't a lot that can be done inside the digester, processes will occur self-sufficiently however having an understanding of them is beneficial for the design process and producing the best biogas yield.

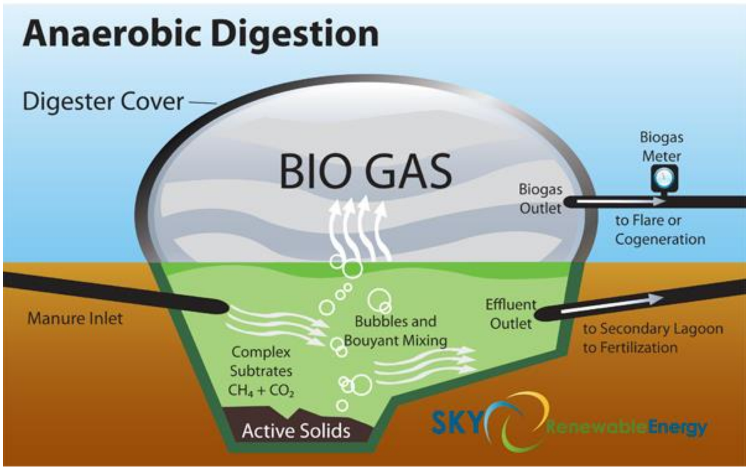

Figure 2: Anaerobic Digestion (Sky Reneable Energy, 2012)

2.1 Biology and Chemistry

The process that occurs in anaerobic digestion occurs in stages with various bacteria groups (see figure 3). The process takes large molecules and breaks them down into smaller molecules. Firstly aerobic digestion occurs which uses up the oxygen that may have entered in with the substrate; carbon dioxide (CO_2) is generated along with a little heat. Next anaerobic digestion starts breaking down the molecules. The broken down molecules are then absorbed by the acid forming bacteria, the molecules from this process are volatile fatty acids, CO_2 and Hydrogen (H_2). Finally the methane forming bacteria absorb the volatile fatty acids and convert it to CO_2, water (H_2O) and Methane (CH_4) (House, 2010).

This process can be categorised into acid digestion and gas digestion. The main bacteria present are acid forming bacteria and methane forming bacteria.

Along with being oxygen intolerant the methane forming bacteria are also sensitive regarding the pH level and sunlight. They prefer the digester to be in the neutral to basic range, approximately 6.8 – 8.5. If the pH falls then the biogas production will drop and consist mostly of CO_2 and hydrogen sulphide (H_2S), this generally happens in the start-up phase, its best to add already digested effluent (seeding) into a new digester to reduce this effect (House, 2010).

Other means of satisfying the pH level is adding a 'buffer'. A buffer is used to resist the change in pH or slow it down. Buffering systems can occur naturally in the digester however chemicals can also be added to replicate the effect. Buffering chemicals are alkaline additives this stabilises the pH. Basic alkaline buffer substances can be lime, ammonia and bicarbonates. Each substance has its advantages and disadvantages.

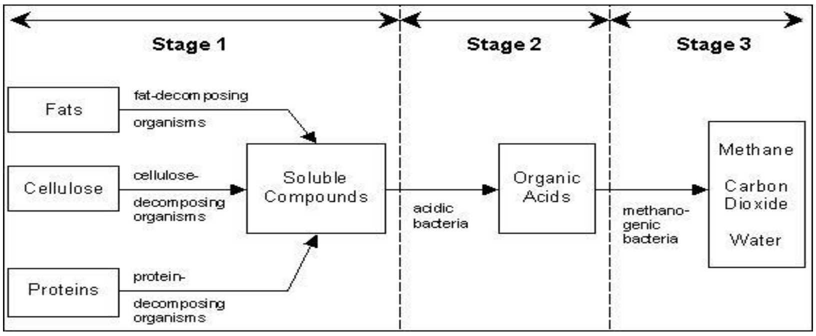

Figure 3: Biological Process for Anaerobic Digestion

2.2 Temperature

Temperature is a controversial area in biogas production. Most resources have suggested that anaerobic digestion is best to occur in mesophilic or thermophilic temperatures. These temperatures are usually generated using supplement heating like heat exchanges or insulation. Mesophilic temperatures range between 20°C - 40°C, thermophilic sits between 40°C - 60°C, while psychrophilic temperatures are below 30°C with operating temperatures dependent on the ambient temperature. Inputting heat energy into the digester is not a viable route to where this project is proceeding as the system is best to be kept simple and at a low cost.

Mesophilic and thermophilic temperatures are usually better because they produce gas in a shorter period and the waste is treated faster. The heat seems to act as an accelerator. However because New Zealand is in a temperate climate, energy would need to be added to achieve these high temperatures. New Zealand anaerobic ponds are generally unheated, unlined and operate in a psychrophilic temperature range.

However this may be, biogas production shouldn't be discouraged. Sources have suggested that with this low temperature, higher concentrations of methane were found in the biogas and the same amount of gas was produced however just over a longer period (McGrath & Mason, 2003). Furthermore as the seasons change into winter biogas production may drop, however after several cycles, the methane forming bacteria become accustomed to this and the biogas production stabilises. The gas production rate simply has to meet the demand of the site.

2.3 Organic Loading Rate & Hydraulic Retention Time

The organic loading rate (OLR) and hydraulic retention time (HRT) are parameters used to size a digester. On a dairy farm the substrate is gathered during the milking times. It comprises of equipment wash water, yard wash down water, manure, milk and traces of other matters bought in by the cows.

The loading rate is a number based off the mass of the volatile solids entering the digester daily divided by the volume of the digester (see equation 1). As mentioned earlier volatile solids are the proportion of the substrate that can be completely digested, and the amount fed in must be balanced to what the methane forming bacteria can handle. Acid forming bacteria can generally process at high rates and will produce a lot of fatty acids, however the methane forming bacteria work slower and if the pH level drops due to the high acidity then the biogas production will also drop. Therefore its best to under load .There are recommended loading rates for different types of substrate as shown in table 1.

$$Loading\ Rate = \frac{volatile\ solids\ (kg)}{volume\ of\ digester\ (m^3)} / day$$

Equation 1: Loading Rate

Substrate (Manure)	VS Loading rate (kg/m³/day)	TS Loading Rate (kg/m³/day)
Cattle	3.8	4.5
Human	1.8	2.5
Pig	3.2	3.8
Poultry	3.0	3.6

Table 1: Recommended Loading Rate values

The hydraulic retention time (HRT) is the time that the substrate must stay in the digester to completely digest and produce biogas. The longer the substrate is in the digester, the bigger the digester will have to be to hold the continuously fed substrate. The HRT is also dependant on the temperature of the digester as mentioned earlier the warmer the digester the faster the process. Hydraulic retention times can be as little as 12 – 20 days at temperatures around 35^{o}C. Typical HRT's for psychrophilic temperatures are around 40 days. It is also stated that more biogas is produced in the first half of the hydraulic retention time, implying that even if the substrate stays in the digester for its full HRT the biogas yield won't be much higher than if was in there for only half of the time (House, 2010).

2.4 Substrates & Bi-products

Dairy cow manure properties are shown in table 2, note that biogas yield depends on many variables therefore the value shown is an estimate.

Property	Value	Unit
Manure / cow / day	65	kg/day
Manure / cow / milking	6.5*	kg/day
Density	1000	kg/m^3
TS	6.1	%
VS	4.6	%
FS	2.4	%
Estimated biogas yield	0.20	m^3/kg VS

Table 2: Diary Cow Manure Properties (House, 2010) (Birchall, Dillon, & Wrigley, 2008)

*Approximately 10% of total cow manure is captured on milking pad (Birchall, Dillon, & Wrigley, 2008)

Bi-products from anaerobic digestion are biogas, fertiliser, CO_2, H_2O, H_2S and other small traces of gases. The fertiliser from the digester has 60 – 70% less volatile solids and is suitable for land application, however has reduced nitrogen levels this must be supplemented. H_2S however is corrosive and toxic to humans and has a detectable smell of rotten eggs. Its presence can be detected at 1 part per 10 million and is unsafe at 13 parts per million (ppm). Scrubbing of the gas will reduce the presence of H_2S. Biogas produced from dairy cows on the other hand has very low traces of H_2S compared to pigs.

2.5 Biogas characteristics

Biogas is a mixture of several gases; table 3 shows the properties of biogas from covered anaerobic pond digesters (not to be taken as dairy farm specific).

Property	Value	Unit
Calorific Value	23	MJ/N*m^3
Density	1.1	kg/N*m^3
CH_4	60 - 70	Vol -%
CO_2	30 -40	Vol -%
H_2S	<500	ppm
H_2	<1	Vol %
O_2	<1	Vol %
N_2	<1	Vol %

Table 3: Biogas Characteristics (Swedish Gas Centre, 2012)

*Normal conditions, 20 ^{o}C, 101 kPa

2.6 Existing Technology & Case Studies

There are several types of digesters; covered ponds, complete mix, plug flow and fixed film. Covered ponds are as the name suggests ponds in the earth that hold the organic waste and are fitted with a cover to capture any gas. Complete mix, plug flow and fixed film digesters are engineered tanks. They each differ in regards to being heated, the state of the waste it can handle and the position it is in the ground (US Environmental Protection Agency, 2004).

Most existing biogas farms use biogas to generate electricity; these systems include expensive generators that can have high maintenance. The greatest motivation for installing these systems seems to be for cost savings, offensive odour control, sustainability and beneficial bi-products.

A study in the United Kingdom showed that most biogas plants were treated as living organisms and profitable investments, not simply a mechanical piece of plant. The digesters were fed with grains as well as manure; they were all insulated or heated, mixed and maintained regularly. Most of the farm digesters were also given grants and farm owners took advantage of feed in tariffs (Bywater, 2011).

2.7 Issues & Benefits

Financial return is one of the main issues with this specific project as small to medium sized dairy farms are considered as uneconomical due to the restricted effluent collection and low energy demand. The installation can be expensive and at the moment has no funding available for farm owners in New Zealand. Without the support from government departments farm owners struggle to gain any motivation to invest in these systems.

Furthermore New Zealand dairy farms require new methods of waste management to decrease environmental pollution. Effluent ponds and effluent irrigation are issues involved with this, as the raw waste can contaminate the groundwater, leach nutrients from the soil and pathogens are not always destroyed to the environmental standard (Earthscan, 2005).

Currently with uncovered ponds the produced methane is released into the atmosphere. Methane is 20 times worse than carbon dioxide and therefore contributes highly to the impact of greenhouse gas emissions. Burning the methane converts it to carbon dioxide.

The benefits with biogas systems are numerous and include the following:

1. Sustainable / renewable energy resource
2. Less reliance on fossil fuels for electricity
3. Heat energy demand mitigated on electricity bill
4. Effluent pollution reduced or eliminated by alternative effluent disposal
5. Long term savings
6. Extra water capturing benefits (using a covered pond)
7. Reducing greenhouse gas emissions – methane is converted to carbon dioxide
8. Possible credit for carbon tax
9. Odours decreased when irrigating with processed effluent
10. Fertiliser as output has a better quality (less BOD)

With research into biogas systems on dairy farms, interest could be sparked, benefits are:

11. Other parties may investigate into biogas systems on their farms (become a trend)
12. More research is carried out to increase ease of installation - other systems developed
13. Government funding / organisation funding may increase to promote biogas systems

3 Case Study Details

The Cook dairy farm is the case study farm that was used to design the biogas system. Below is site specific data for the farm. See figure 4 for the farm layout.

Farm Features

Cows	370
Milking System	Herringbone

Location and Climate

Location	302 Condoit Rd, Woodville	
Latitude and Longitude	40^{o} 17’ 56.2” S, 175^{o} 53’ 48.5” E	(-40.3, 175.9)
Mean annual Rainfall	967mm	(1971 – 2000 period)
Mean annual Sunlight hours	1733 hours	(1971 – 2000 period)
Mean annual Temperature	$13.3^{o}C$	(1971 – 2000 period)
Very highest Temperature	$33^{o}C$	(1971 – 2000 period)
Very Lowest Temperature	$-6^{o}C$	(1971 – 2000 period)
Mean annual Earth Temperature (10cm)	$12.8^{o}C$	(1971 – 2000 period)
Mean annual Radiation	13.5 MJ/m^2	(1971 – 2000 period)

Table 4: Cook Farm Data (NIWA, 2000) Climate information is based off Palmerston North

Energy Factors

Mean Yearly Electricity Use		52.5 MWh
Mean Yearly Electricity Cost		$13,368.82
Contact Energy Charges	Daily	$2.004 / day
	Anytime	$0.2392 / kWh
	Electricity Levy	$0.00146 / kWh
Water supply		10 - $15^{o}C$
Water Usage	Equipment and Vat Wash	2 600 L / day
	Yard wash down	20 000 L /day
Hot Water Cylinders	Equipment wash	400 L @ $85^{o}C$
	Vat Wash	250 L @ $85^{o}C$
Heating Energy	Load	56.9 kWh / day
	Cost	$3,639.98 / year

Figure 4: Cook Dairy Farm taken from Google maps

Daily Milking and Cleaning Procedure – Cows are milked twice a day, 2 hours in the morning and 1.5 hours in the afternoon. The equipment is washed after every milking with a cold rinse. A hot wash is done every mornings.

Weekly Cleaning Procedure – Typically two alkaline washes each week.

Yearly Milking Procedure – Milking will stop during the months of June and July.

See Appendix I a schematic of the farm shed equipment and appendix A yearly power bill graph.

3.1 Energy Collection

Actual electrical energy data was collected from the dairy shed to analyse the heating load of the dairy farm. A Weltec data logger was installed for several days collecting the dairy sheds total electrical energy usage over three phases. The data was downloadable in excel format and the three phases were graphed and visually analysed to determine the heating load. Knowing when the washes occur helped to determine when the hot water cylinder heaters were used. Each cylinder had two 3kW heaters. It showed that phases 2 and 3 had heating loads and the sum of these added to 46.5 kWh, see figures 5 and 6. Phase 1 showed no sign of a heating load, all three phases can be seen in appendix A.

As a check a basic thermodynamic heat transfer equation was performed, see equation 2.

$$Q = 650 \times 4.2 \times (85 - 10) = 204.75\ MJ = 56.88\ kWh$$

Equation 2: Hot Water Load

This showed a difference of 10 kWh which could be due to a higher inlet temperature, for conservative reasons 60 kWh is used to compare with the biogas energy.

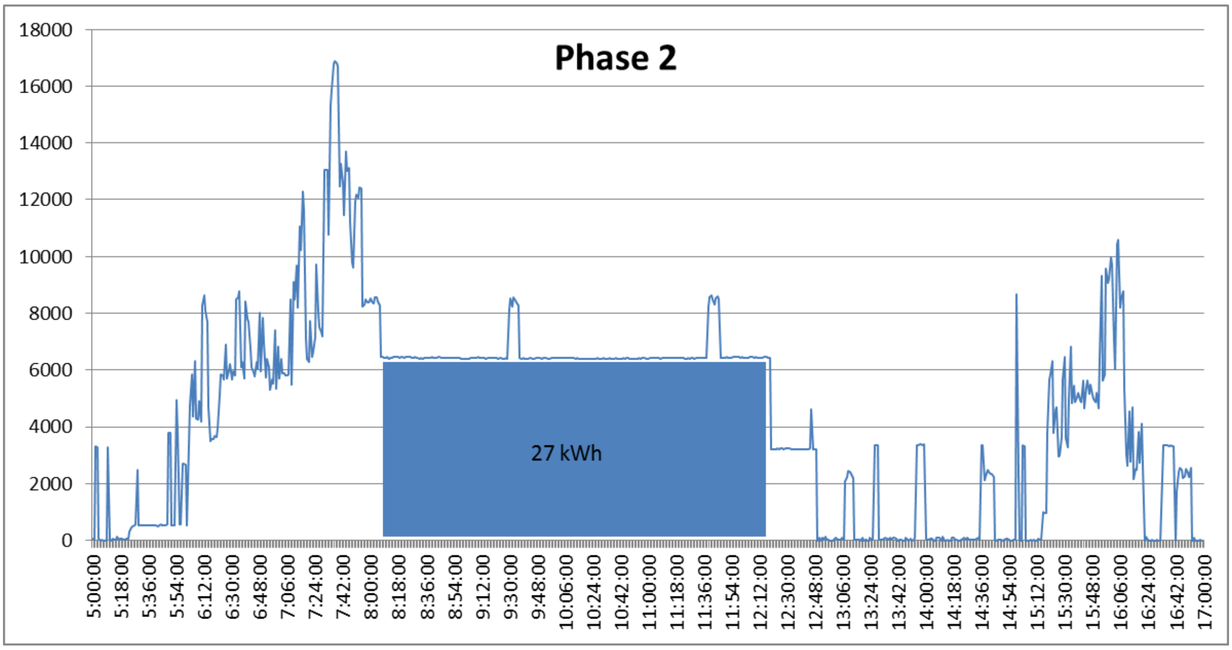

Figure 5: Phase 2 Dairy Shed Energy Data

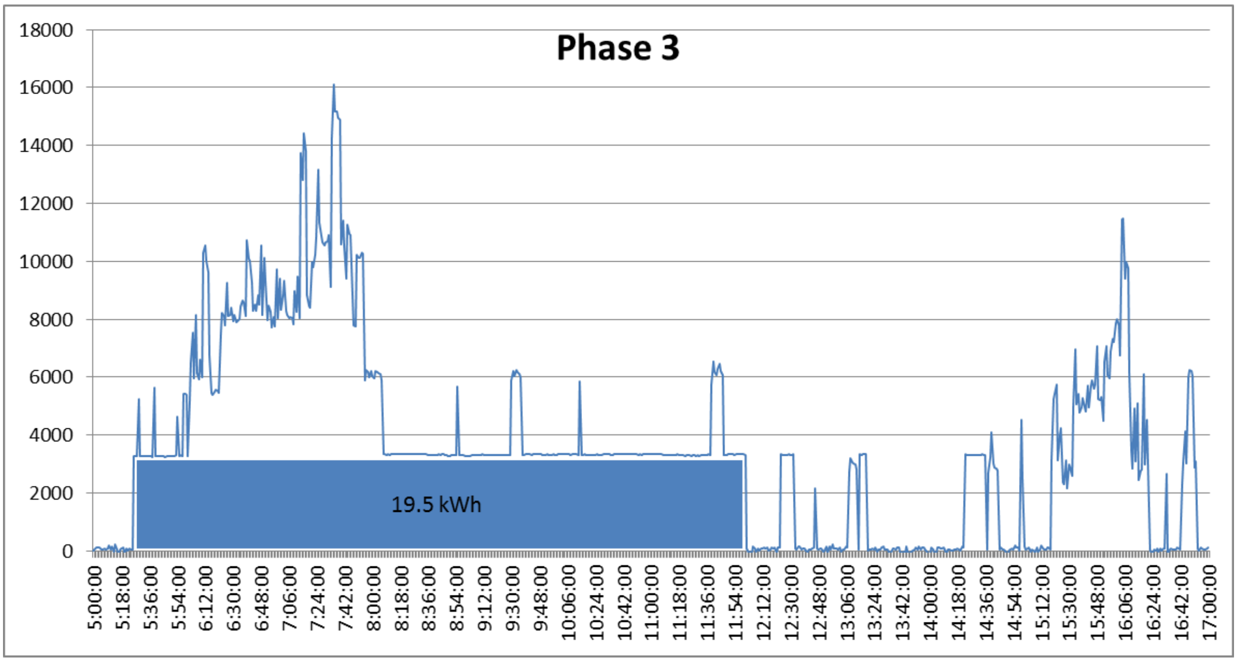

Figure 6: Phase 3 Dairy Shed Energy Data

3.2 Energy Efficiency Upgrade Analysis

One of the objectives for this project was to investigate into energy efficient equipment to install on the farm so that the energy load may be reduced. The options revised were the following:

1. Hot Water Cylinder Insulation – This is a viable option as it was estimated to cost $60.00 per cylinder to insulate and would reduce heat lost. Currently the hot water cylinders are used once a day and heated just before use.
2. Reduce Water use Volume – Reducing the water use was a problematic option because it would require the water to be either hotter or more chemicals would have to be added to satisfy hygienic requirements.
3. Heat Recovery Systems – The heat recovery system would be installed to recover heat from the refrigeration system to preheat the hot water cylinders. There are many types of these systems and sources implied that not all systems would be viable for every farm due to energy usage, herd size and utility company plan (Fonterra, MAF, EECA Buisness, 2011).

Hot water cylinder insulation is recommended, especially with a biogas heating system because it will retain the heat longer in the cylinders.

Reducing the hot water usage is not recommended because to increase the temperature in the hot water will require more energy and adding chemicals into the water could be toxic to the feedstock that will enter into the digester.

The heat recovery system was quoted by Maverick Energy who specialise in renewable energy systems, including bio-methane effluent digesters and diary shed heat recovery systems. On the website was a case study of a Waikato dairy farm that had similar specifications to the Cook farm, with a promising 2.5 year payback and 25% reduction in electrical energy usage.

The system operates using the heat rejected from the refrigeration unit to heat water that is stored in the 300L litre storage tank and automatically fills the hot water cylinders when required. The water is preheated to 50 - 70^{o}C and the existing hot water cylinders will heat the water to 85^{o}C. The system uses around 1kWh per day and could save 25% of the overall power consumption if the heating power load were 35% of the power bill.

The system was estimated to cost $12,000 - $15,000 with a quoted payback time of 3 – 4 years if the annual yearly power bill is $20,000. However attached in appendix A shows the estimated annual energy usage from the power bill is actually around $12,000 - $13,000 per annum. Taking all the assumptions into account from the quote the payback time is looking to be more like 4 – 5 years and with an additional biogas heating system being attached the payback time for the entire package may be even more.

Therefore it is not recommended at this time to install a heat recovery system along with a biogas system. In the mean time hot water cylinder insulation would be an appropriate step to increase the efficiency of the heating energy.

4 Design Process

The design process for this project used information from many different sources to review its feasibility and final design. Sources comprise of a home built batch fed prototype digester, actual gas collected from the existing effluent pond, site visits to operating biogas farms and help from biogas experts, including the National Institute of Water and Atmospheric Research (NIWA) and Energy for Industry (EFI) engineers.

4.1 Prototype

The prototype was built to understand the biogas system and test gas produced from cow effluent. The design was a 200 L batch fed digester made from an old plastic drum from the dairy farm. There were two holes, one for gas collection with a ball valve, the other for pressure relief, see appendix B.

The substrate was collected from a local farm in Wellington to avoid transporting cow manure from Woodville. 6 kg of the poo was mixed with 200 L of water to have a composition of 3% solids as simulated for a slurry mixture. The digester was uninsulated and kept under cover in a shed.

Unfortunately no gas was collected. After many weeks of no gas the digester was pressurised to pump the gas into a testing gas bag. Once pressurised the effluent liquid started to leak out of the ball valve hole. Regrettably the drum was not sufficiently gas tight to seal the drum, therefore the gas produced most likely escaped. The experiment was during the winter months and the liquid did not get over 10^{o}C.

To reflect on the prototype, the experiment could be improved by ensuring tight seals using O-rings as well as silicon and to test for leaks with soapy water. The prototype should also have been tested in a warmer season and be positioned in the sun to take advantage of the solar heat.

4.2 Gas collection & Gas testing

Gathering actual data from the effluent pond was a good experiment to monitor the gas characteristics from the gas currently being produced. It would have given a good indication of how much gas was being produced. The method of capturing the gas was to float a plastic cover over a section of the pond and allow the gas to be collected underneath for several weeks. After that time the gas was to be fed into a gas bag where the volume of gas could be measured and tested.

To achieve this, a cover was lent from Weltec tutor Bob McGrath and funding was given from the Todd Foundation which helped buy the pipework and other components to secure the cover over the pond. Labour was volunteered from several people to help assemble the cover and pipework as well as position the cover onto the pond; Paul Freeman, Jan De Kock and farm owner Jules Cook.

Table 5: Main Costs for gas collection

Components	Description	Cost
Cover	20m x 3m, with loops	-
Pipework	PVC 48m 50mm NB	$463.25
Rope	80m	$313.23
Gas Hose	3m	$60.00
Hose Fittings	40mm – 15mm	$35.48
Biogas gas bag		$17.00
Testing Gas Bag	Supplied from CRG Energy	$20.00
Gas Testing	CRG	$160.00

The cover was positioned on 30th September 2015 and gas collection attempted on 21st October 2015, see appendix C for photos of site. Unfortunately upon arrival to the dairy farm the cover was partly submerged and gas could not effectively be collect. It was also not possible to send for testing because there was not enough pressure to force the gas into the testing gas bag. A blower would have been required to force the gas in. The predicted reason for the failure is most likely due to the weather and holes in the cover. It is suspected that the inflatable edges of the cover filled with water and dragged the cover under the pond. The weather blew the cover around and it was not sturdy enough to resist.

To improve on this experiment a more sturdy gas collection container should be used for example a halved plastic barrel that floated on the water. A small sized blower to suck in the gas would also improve the experiment so that enough gas could be sent to the testing laboratory.

4.3 Site visits

Site visits were again sponsored by the Todd Foundation funding. I had the opportunity to visit working biogas systems in New Zealand and meet with biogas engineers to help with the dairy farm biogas design. In total I visited three biogas systems; Lepperton piggery in Taranaki, Silverstream landfill in Lower Hutt and a joint visit to the NIWA offices to meet Stephan Heubeck a biogas engineer and a dairy farm biogas system in Hamilton. Main questions asked for the site visits were the following:

1. When was the system installed?
2. What is the substrate? What is the loading rate (kg VS/day)?
3. What is the HRT?
4. How is the gas collected? How much gas is collected?
5. How is the biogas used?
6. How much energy is produced?
7. What is the maintenance?
8. Is gas scrubbed? How is gas scrubbed?
9. How much did the system cost?
10. What was the motivation for the system install?
11. What advice can be offered for this dairy farm project?

Lepperton Piggery

Farm owner Steve Lepper installed his biogas system in February 2010 and collects all waste from 4000 pigs on his piggery farm. The waste is flushed out with 35m^3 of water and put through a 2mm solids separator. The fluid is piped to the digester daily and solids sold as compost. The volatile solids loading rate is not measured and the HRT is 40 days. The digester is a 60 x 20 x 6 m covered anaerobic pond, see figure 8. It has a perforated pipe running along the perimeter to capture the gas, the system uses on average 181m^3 of gas daily.

Figure 7: Lepperton Piggery Farm

The biogas is used to run a 40kW generator and provides 380 kWh of daily power for the farms electricity needs, which subsidies 30% of the farms total energy needs. In the future a heat exchanger will be set up to utilise the rejected heat, this will be used to heat the piglet pens. The gas use is a manual process, if it is evident that there is gas under the cover the generator will be turned on, the generator is regularly used.

The generator has regular maintenance with oil changes and the farm workers are capable to fix occasional problems. The gas is scrubbed with a woodchip and rust mixture that the gas flows through, this removes the H_2S, the CO_2 is not removed and there are multiple condensate drains to remove water moisture. In total the cost of the system was over $125k, he received funding of $40-50k. A lot of the work was carried out by local contractors and himself. The payback for the system was 3 – 4 years.

The motivation for the system was primarily the odour that was released from the pond; there was the option of just installing a flare however Steve saw the benefits of generating electricity also. The advice given from Steve was to use a blower instead of a gas compressor to avoid regulations, be aware of chemicals and antibiotics from cows and use non-corrosive materials like stainless steels, aluminium and plastic.

Silverstream landfill

The visit to the Silverstream landfill was useful to see an operation of a commercial biogas plant. The plant was installed in 1995 with Mighty River Power. The gas is produced from weekly rubbish waste from the Hutt region. Hundreds of wells are drilled into the landfill that sucks out the gas. It produces 800-900 m^3 of biogas daily with a composition of around 50% methane. The gas is run through 2 generators, with a third for back up. The electricity is used to power the landfill plant. The plant is maintained daily by 2 full time EFI employees. Components are very expensive to replace up to thousands of dollars. The motivation for the installation was to reduce greenhouse gas emissions as per government regulations.

NIWA Office

The purpose of visiting the NIWA offices in Hamilton was to meet Stephan Heubeck, an environmental engineer who has worked on many biogas farm systems and written many reports on the use of biogas. In the visit the biogas design and estimated biogas figures were reviewed and improved.

Advice was given regarding the size of the digester pond for practicality in construction as well as advice for removing sludge without taking off the cover. Calculations were adjusted for conservative values and more information was given regarding the anaerobic process. Heubeck also commented on the fact that biogas production only slightly depends on the pond temperature, however irregular feeding of the digester can cause larger biogas production fluctuations.

Estimations for the cost of boilers, covers and earthworks was given and he commented that rebuilding and covering a smaller pond can be the equivalent cost of covering a large existing pond. When rebuilding a smaller pond it can be better suited for a digester design. This advice was highly used in the concept development, to be discussed later.

Hamilton Diary Farm

Along with the visit to NIWA, a 600 cow dairy farm installed with a new biogas system was also visited. The system installation started early this year, the farm owner is Dave Sing. The waste that is collected from the milking shed and feed pad from 600 cows and flushed with recycled effluent into the digester pond, see figure 8. The volatile solids is not measured, the HRT is 40 days. The gas is collected similar to the Lepperton farm, with a perforated gas pipe that runs along the perimeter of a 1542 m^3 covered effluent pond. The digester pond is directly connected to a 4000m^3 storage pond.

Gas collection has not officially started; the content is approximately 56% methane. The biogas will be used to power a generator, see figure 9, the electricity is aimed to provide 75% of the dairy sheds electricity needs as well as using the reject heat to heat 900L of hot water for the hot washes. The maintenance will also be similar to the Lepperton generator as well as sludge removal every 3 – 4 years through 4 sludge removing pipes. The gas is not scrubbed, this is due to the low H_2S that is produced from cow waste, pig waste has considerable high contents of this. The system has cost over $100k to build so far and it aims to have a 3-4 year payback.

Discussions with the farm owner and NIWA have been occurring for several years to design a biogas system; however he required at least 600 cows. Therefore the farm grew and a brand new dairy farm constructed along with a biogas system. More motivation for the project was due to grid connection which cost $10k for a transformer and a further $10k for actual connection to the grid,

Figure 8: Hamilton Dairy Farm Digester

Figure 9: Hamilton Dairy Farm Generator

along with regular payments for electricity. The owner primarily wanted sustainability and independency from the utility companies. The benefit of lower greenhouse gas emissions was also a great incentive. Ideas taken from this farm were used for the final design. Sludge removal pipes and a smaller digester pond directly connected to a storage pond as well as the use of a compact gas blower instead of a compressor. The cost also gave good indications for the costing of this project and the similar characterises for biogas composition.

4.4 Concept Development

Two main concepts were developed for the design of this biogas system. The aim of each design was to create a simple system that is practical, holds a minimum 40 of days of dairy farm waste, collects and stores gas under a flexible cover, takes advantage of the solar heat, processes the cow waste anaerobically to collect the biogas and reduces the biological oxygen demand of the waste before it is applied to the land.

Currently the farm is arranged as shown in appendix I: Detailed drawings.

The first concept is a new digester pond that is a lot smaller than the existing pond and is constructed to accommodate a little more than 40 days cows waste with 1000 m^3 yard wash down water. It is linked with the existing pond so that the supernatant layer can over flow into storage. The collection sump pump has a split valve to allow flow of waste to the digester and flow of waste from the storage pond for irrigation. The gas is collected from a perforated pipe and run underground to condense the moisture in the gas. The gas is then fed into a biogas boiler through a blower to heat the hot water, see drawing BG-2015-001-1 in appendix I. The benefits with this are a smaller cover and gas pipework and thus lower cost and starting from a new digester enables an easier construction. The disadvantage is re-installing pipework from the collection sump and connecting to the storage pond. There will also be shorter sludge removal periods.

The second concept is similar to the first except the existing pond is covered instead of constructing a new digester, a trench is still required to hold down the cover. The effluent pipework thus stays the same, see drawing BG-2015-026-1 in appendix I. The benefits are no effluent pipework. However the disadvantages are the cost of a larger cover, having to build a trench around a full effluent pond and the associated cost of this, along with more material required for gas pipework around the larger ponds perimeter.

5 Final Design Description

The final design is a modification of concept one with a new digester pond constructed. It is developed from advice given from NIWA and ideas taken from the site visited biogas systems.

The process of the system will be as follows:

1. The cows waste is collected from the milking shed twice a day
2. 20 m^3 of yard wash down water and plant wash flushes the waste into the collection sump
3. The collection sump pump, pumps the total amount of waste into the covered digester

4. The waste is anaerobically digested over a 40 day hydraulic retention time
5. The overflow flows down an inclined connecting pipe from the supernatant layer of the pond into the storage pond
6. The storage pond is piped to the collection sump as well to be irrigated on the land
7. The gas is collected under the plastic flexible cover
8. When required the gas is sucked through perforated pipework around the perimeter of the pond by a blower
9. The gas travels through underground pipework to cool
10. As the gas cools the water moisture condenses and is collected in a condensate drain, this is the lowest point in the gas pipework
11. The gas is burned in a biogas boiler to heat 650 L of hot water, the heated water is recirculated until it comes up to 85 degrees Celsius

5.1 Specifications

Specification	
Substrate	2.4 ton/day cow manure, 110.63 kg VS daily, 20 m^3 yard wash water
Pond Size	17 x 28 x 3.5 m, 1:1.5 m batter angle
Hydraulic Retention Time	40 Days
Organic Loading Rate	0.1143 kg VS/m^3/day
Gas Collection Process	90m perforated pipe around pond perimeter
Expected Gas Production	22 m^3/day
Gas Scrubber	Not Applicable
Biogas Use	Heating – 650 L water to 85^{o}C = 60 kWh /day
Energy Output	127.22 kWh / day - 90%
Gas Build up Safety Feature	
Effluent Overflow Process	Connecting pipework to storage pond
Sludge Removal	four sludge removal pipework, removed every 3 – 4 years
Temperature	Psychrophilic < 30 ^{o}C
Components	Pond
	Cover
	Effluent pipework
	Gas pipework
	Blower
	Boiler
	Condensate drain
	Others
Total Cost	From $45,000.00
Pay back	12 – 13 years (annual savings ~ $3,700.00)

5.2 Components

Pond: the digester pond as stated is 17m wide, 28 m long and 3.5m deep with a batter angle of 1:1.5m, this will give floor dimensions of 6.5m wide and 17.5m long, see figure 11 for Diary

NZ pond calculations. Earthworks are performed to dig out the pond and trench. The pond is clay lined as per the existing pond; the earthworks can be contracted out to a local earthworks company. The pond has a total pond volume of 968m^3 allowing 66m^3 for sludge accumulation and 222m^3 for freeboard. The pond will have a total surface area of 476m^2. The estimated price for the pond and trench is $10,000.00, see appendix E for all estimated prices of biogas system.

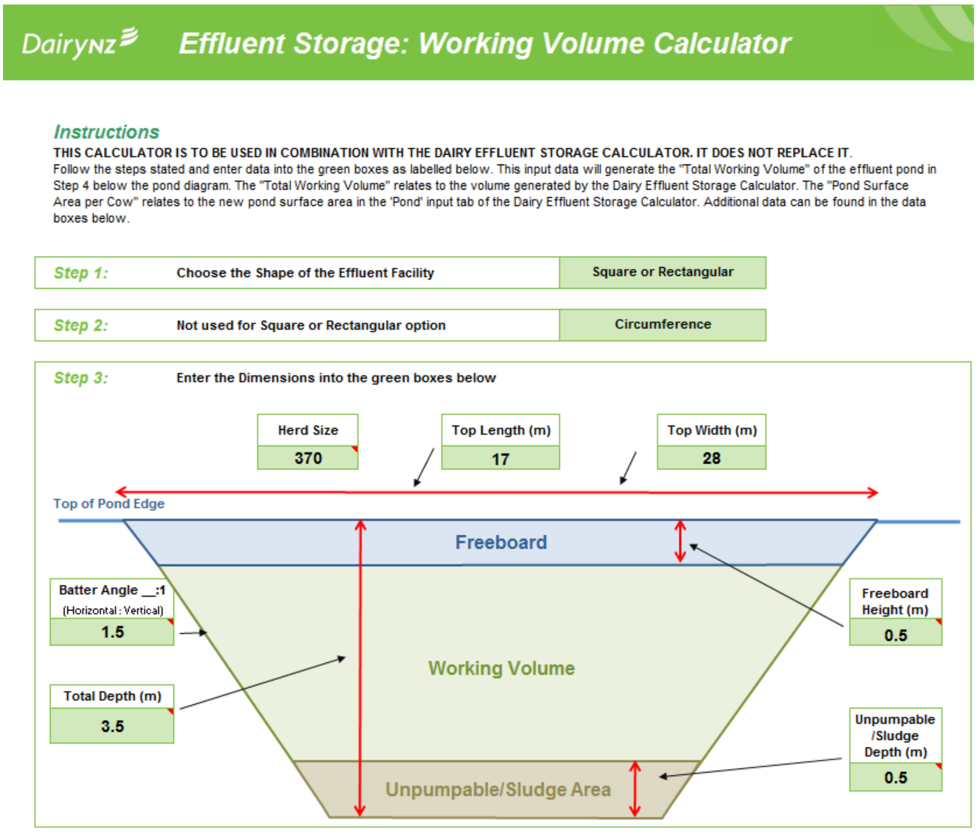

Figure 10: Dairy NZ Pond Size Calculator

Cover: The cover will be made from black high density polyethylene (HDPE). Characteristics are high flexibility, dark colour, environmental stress crack resistance, thermal aging characteristics, its resistance to UV and durability to exposed conditions (AEL, 2015). It will be secured in the trench under 2 meters of dirt. The size will be approximately 23m x 34m and cover the entire pond surface area. The cover can be bought and installed by Aspect Environmental Lining Ltd (AEL Ltd); the estimated price is $10,000.00. The cover will be used to collect and store the gas.

Effluent Pipework: The effluent pipework will connect both the digester pond and storage pond to the collection sump. This allows flow into the covered pond for digestion and, flow out of the holding pond for irrigation. The joining pipe will be located from the supernatant level or higher to only allow the cleanest water to pass into the storage pond the pipe will be angled down into the storage pond for natural gravitational flow. The material will be general PVC pipework and supplied from a local contractor, estimated costing $5,000.00 and installed by farm owner or similar, to reduce costs. A valve to adjust flow from digester and from storage pond is also required.

Gas Pipework: The gas pipework around the pond perimeter will be made from biogas grade PVC, it will be cut in slits at angles to each other for both gas collection and allowing water to fall back into the pond, see figure 12 for example from Waikato biogas system. The pipework to the boiler will also be made from PVC and be piped underground. The ground stays relatively cool and the water in the hot gas will condense and be collection in the condensate drain, removing the water from the gas. The pipework can be supplied from local contractors and estimated to cost approximately $4,000.00.

Figure 11: Perforated Pipe from Waikato Dairy Farm

Blower: The gas blower will be a Nu-way Technology GB3160 blower. It's a small compact blower that attaches between the pipework located at the dairy shed and before the boiler. The blower will suck the gas from the digester to the boiler at a suitable speed. The price is approximately $12,000.00 and a variable speed drive should be connected to adjust speed and pressure.

Boiler and Burner: The boiler and burner will be a Ferroli / Atlas 32kW diesel boiler and a fitted Bentone STG 146 burner, see figure 13 and 14 (Bentone Enertech Group, 2015) (Waterware, 2015). Both are suitable for biogas but it is recommended when installing to discuss the application with the supplier first. It will be used to heat the diary shed hot water from 10^{o}C to approximately 85^{o}C. The estimated cost is $4,000.00.

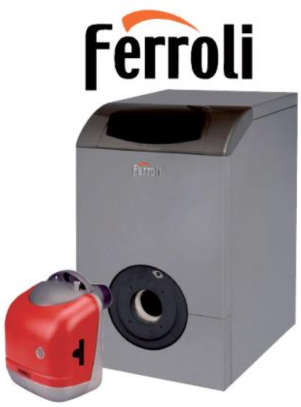

Figure 12: Ferroli Boiler

Figure 13: Bentone Burner

Condensate Drain: The condensate drain can be made from non-corrosive materials from the farm, it is simply a drum used to collect the condensed water from the gas. The condensate drain is placed at the lowest point of the system the angle from the blower is 4 degrees and the angle from the digester is 21 degrees. There will be a ball valve that is manually opened to drain the water periodically. It can be constructed and placed by the farm owner or similar.

Others: Other components include the level indicator sump which is used to show the level in the digester. There will be four sludge removal pipes protruding from the bottom of the pond to be used to clear the sludge periodically without having to remove the cover. Weighted pipework may be useful to secure the cover from blowing around in the windy weather; they are placed across the width. A water pump may also be used to remove the rainwater build up on the pond cover; this water may be useful for storage in the farm water tanks.

5.3 Energy balance

Energy required to heat the hot water has been estimated at 60 kWh daily this is to heat two hot water cylinders holding 650 litres heated to 85^{o}C. This is converted to a heating load of 204.75 MJ/day. With biogas having a calorific value of 23 MJ/m^3 and the boiler being 90% efficient the volume of biogas required is 9.9 m^3 daily. According to the biogas yield the digester will produce 22m^3 daily over supplying by 224%. Therefore the total heat load can be substituted with biogas energy. In winter the milking shed shuts down for 2 months which is also when biogas production slows taking this into account the energy balance is well suited for the dairy farm.

5.4 Cost & Savings Return

Upon choosing the best concept for the biogas system the cost was compared against proposal one, constructing a new digester pond and proposal two, covering the existing pond, see tables in appendix E for summary of estimated cost. The results showed that the difference was minimal. However the benefit of building a new digester allowed for better design and construction for a biogas digester. Benefits included incorporating sludge removal pipework and having a storage pond. Construction of the trench and installing pipework and the cover could also be done easier.

In total the estimated system costs $45,000.00, with a saving per year of $3,700.00 and a payback of 12 years and 132 days. However this is the minimum cost, only including materials. Labour and consultancy fees have not been included as the dairy farm owner of the Cook farm is an ex-plumber and could install a lot of the pipework himself and having contacts with others the other trade services can be sourced internally. NIWA consultancy or biogas expert consultancy fees could add thousands to the biogas system budget.

5.5 Safety and Regulations

Biogas in all instances is considered flammable and hazardous, to ensure best working practice there are strict regulations and guidelines to follow to minimise risk. There are several standards and documents that have been designed that are easy to follow and highlight the key aspects of biogas generation these include the following:

- NZS 5228: Part 1 and part 2, the production and use of biogas farm scale operation, production of biogas and uses of biogas. These standards are mostly outdated but contain useful safety regulations especially in regards to safety zones and best working practice, see appendix F (New Zealand Standard, 1987)

- Code of Practice (CoP) for On-farm Biogas Production and Use at Piggeries (Australian Pork) (Australian Pork Limited, 2015). This document explains best practice for piggery biogas however contains very useful recommendations for general biogas production on all farms. The majority of the recommendations may not apply to this particular project due to the reference of Australian regulators and standards.

General advice found from these documents is found in appendix F.

5.6 Evaluation

Overall the project has solved the problems as stated in the problem statement. Energy required for heating is 60 kWh every morning to heat 650 litres to 85 degrees Celsius. The gas produced from the anaerobic digester has a yield of $22m^3$/day with a calorific value of 23 MJ/m^3. When burned with a 90% efficient boiler it provides 127.2 kWh of heat energy. Thus the gas produced is sufficient to heat the hot water.

The temperature in the digester will be psychrophilic / unheated. The black cover will absorb the suns heat during the day and the ground will insulate and steady the temperature. The system does not require a gas scrubber; this is due to the low Hydrogen sulphide in the cow produced biogas.

The components of the design include earthworks for the new pond and trench, a cover, effluent pipework, gas pipework, blower, boiler, labour and consulting. The total cost is estimated to be $45,000.00 and the savings per year are $3,639.98 this will give a payback of 12 years 132 days.

Due to the long payback period the motivation for this project must be based on more than cost. Motivation could come from the desire to be sustainable and reduce the greenhouse gas emissions. It could also be to produce an excellent fertiliser or to possibly claim back on carbon tax. As well as setting up a system that could expand to generate electricity if the herd size were to grow. Eventually the dairy farm could go completely sustainable.

6 Recommendations

The final design is solely for the purpose of demonstration; the main purpose of this report was to establish if enough biogas could be produced from the existing effluent pond and therefore collection of waste from the milking pad. From the results and feedback from NIWA engineers there is sufficient and excess gas to heat the dairy shed hot water. Undertaking this design it is recommended to consult advice and guidance from experienced engineers from NIWA or similar.

Other recommendations include the following:

- Use alkaline buffers to stabilise the pH in the digester upon start up
- Seed the digester with old waste with fresh waste

- Use the feed pad to capture more cow manure and thus produce more biogas if required
- Start-up digester just before or during the warmer seasons to allow methane forming bacteria to flourish and keep pace with the acid forming bacteria to avoid low pH levels
- Consult with NIWA for design and advice, visit operating biogas farms
- Try to carry out as much of the work as possible to reduce costs and become familiar with system
- Look out for second-hand equipment for boilers, burners, blowers etc.
- Consider recycling storage water for yard washes to reduce fresh water use
- Ensure to watch out for cows on antibiotics, as the waste from these cows could kill off the anaerobic bacteria, groups of more than 50 can decrease gas production
- Continue to feed digester through shut down periods in winter, irregular feeding effects biogas production more than winter temperature drops

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8 Appendices

8.1 Appendix A: Energy Data Collected and Annual Power Bill

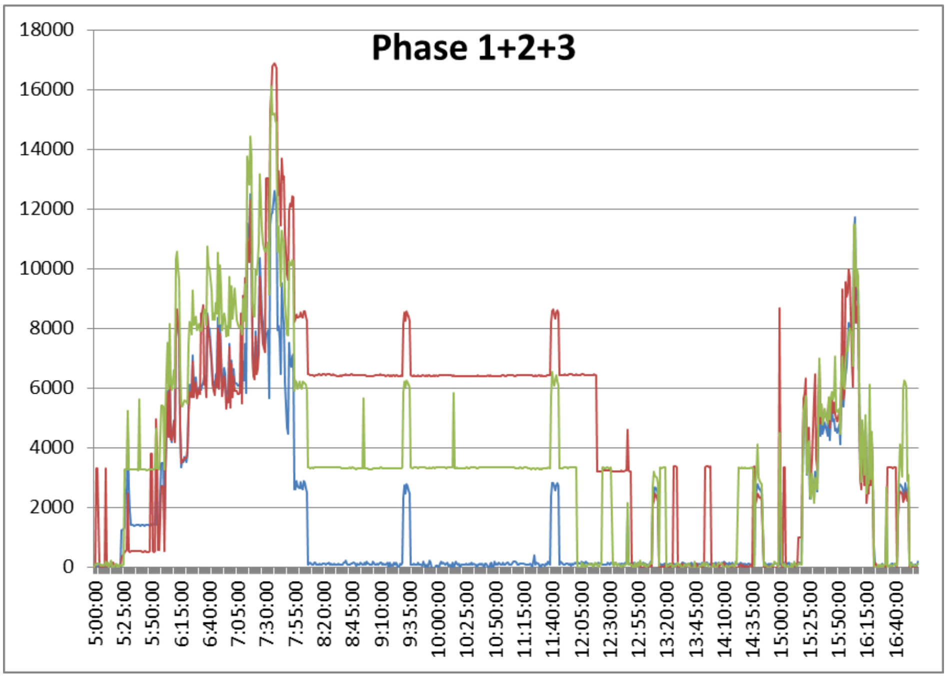
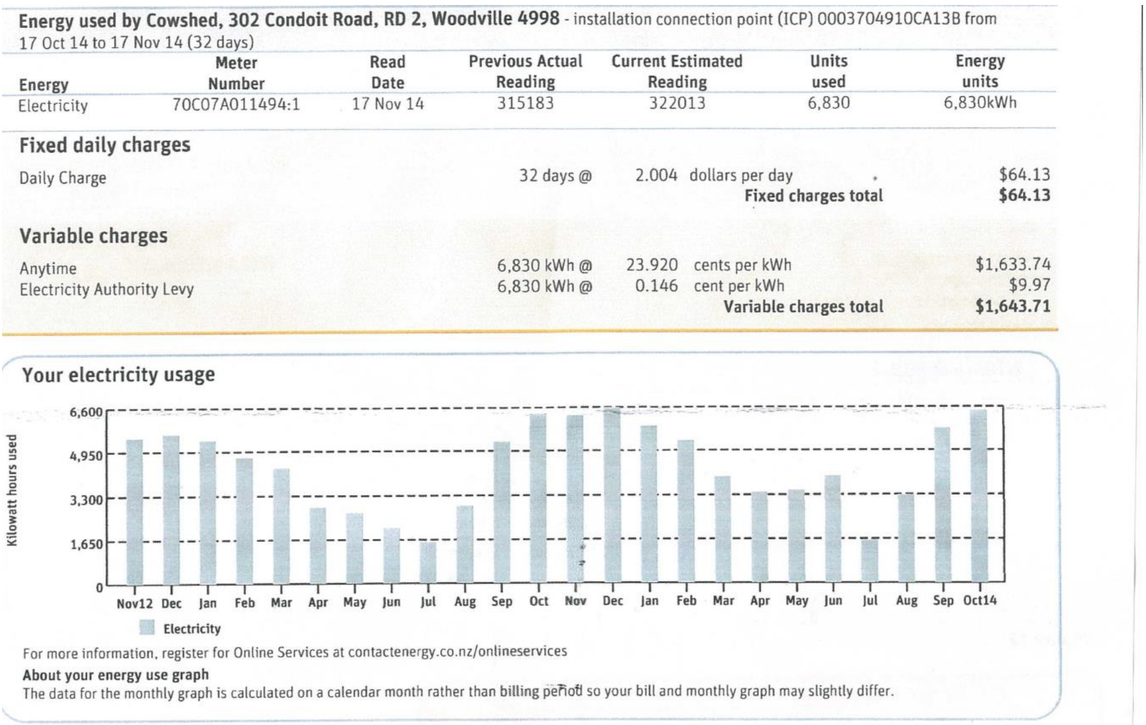


Figure 14: Electricity Data Collected for Dairy Shed



Energy used by Cowshed, 302 Condoit Road, RD 2, Woodville 4998 - installation connection point (ICP) 0003704910CA13B from 17 Oct 14 to 17 Nov 14 (32 days)

Energy	Meter Number	Read Date	Previous Actual Reading	Current Estimated Reading	Units used	Energy units
Electricity	70C07A011494:1	17 Nov 14	315183	322013	6,830	6,830kWh

Fixed daily charges

Daily Charge	32 days @	2.004	dollars per day	$64.13
			Fixed charges total	**$64.13**

Variable charges

Anytime	6,830 kWh @	23.920	cents per kWh	$1,633.74
Electricity Authority Levy	6,830 kWh @	0.146	cent per kWh	$9.97
			Variable charges total	**$1,643.71**

Your electricity usage

For more information, register for Online Services at contactenergy.co.nz/onlineservices

About your energy use graph
The data for the monthly graph is calculated on a calendar month rather than billing period so your bill and monthly graph may slightly differ.

Figure 15: Annual Energy bill

8.2 Appendix B: Prototype Experiment

Figure 16: Components of Prototype

Figure 17: 6 kg of Cow Manure

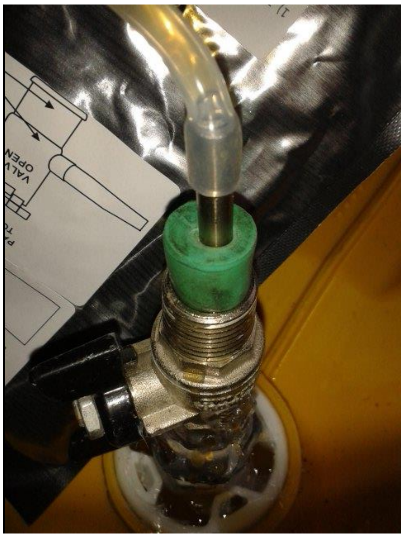


Figure 18: Assembled Prototype Located in Shed

Figure 19: Gas Collection after Several Months

Figure 20: Photo of Leak around gas outlet

8.3 Appendix C: Gas collection Experiment

Figure 21: Day 1 - Installation

Figure 22: Day 3 - Cover Check

Figure 23: Week 4 - Gas Collection

8.4 Appendix D: Design Calculations

Biogas Calculations

Poo and Biogas

Factor	Value	unit	Reference
cows	370	-	Farm
Poo Data			
poo / cow / day	65	kg	Dairying for Tommorow
total solids concentration	6.1	%	Dairying for Tommorow
volatile solids concetration	4.6	%	Dairying for Tommorow
fixed solids concentration	2.4	%	Dairying for Tommorow
poo / cow / day (milking)	10	%	Dairying for Tommorow
poo / cow/ day (milking)	6.5	kg	-
TS / cow / day (milking)	0.3965	kg	-
VS / cow / day (milking)	0.299	kg	-
Total poo / day	24050	kg	-
Total poo / day (milking)	2405	kg	-
total TS / day (mikling)	146.71	kg	-
total VS / day (milking)	110.63	kg	-
poo denstiy	1000	kg/m³	Dairying for Tommorow
volume total poo / day (milking)	2.405	m³	-
volume TS / day (milking)	0.1467	m³	-
volume VS / day (milking)	0.1106	m³	-
Water Data (Gen)			
water / day (shed)	3.5	m³	Farm
water / day (yard)	20	m³	Farm
total water / day	23.5	m³	-
poo concentation	10.234	%	-
ts concentration	0.6243	%	-
vs concentration	0.4708	%	-
Sizing Calcs - MUST BE >800M3			
Total volume / day (water + poo)	23.5	m³	-
HRT	40	days	House
Digester volume	940	m³	-
Digester volume	968	m³	17 x 28 x 3.5 - 1:1.5 Batter
Loadng rate	0.1143	kg/m³/day	-
Biogas Calcs			
biogas / VS	0.2	m³ / kg VS	House
biogas yield	22.126	m³ / day	-
biogas calorific value	23	MJ/m³	Swedish Gas Centre
potential energy avaliable	508.9	MJ / day	
potential energy avaliable	458.01	MJh/day	90%
	Kwh	MJ	
kWh to MJ	2	7.2	
MJ to kWh	127.22	458	

Biogas Calculations

Energy and Electricity Price

Factor	Value	Unit	Reference	
Daily Charge	2.004	$/ day	Contact Energy	
Anytime charge	0.2392	$/ kWh	Contact Energy	
Electricity levey	0.00146	$ / kWh	Contact Energy	
Annual Power Usage	52.5	MWh / year	Contact Energy	
Annual Power Bill	$13,368.82	$ /year	Contact Energy	
Daily Power Usage	8.2	kW/ day	data logger	
Daily Power Usage	196.8	kWh/day	-	
Daily Power Bill	49.365888	$ / day	data logger + contact	
Heating Load				
Q = mc(T2 - T1)			thermo	
heat capcity of Water	4.2	kJ/kg*K	thermo	
volume of water	650	L	farm	
T1	10	°C	farm	
T2	85	°C	farm	
Heating Load	204.75	MJ/day	-	
Heating Load	56.875	kWh / day		Below biogas yeild OK
Time to heat	5	hrs / day	data logger (roughly?)	
daily power usage	12	kW /day	farm	
daily power usage	55	kWh / day	-	
annual power usage	15.125	MWh	275 days / year	
Daily power savings	55	kWh/day	-	
Daily cost savings	13.2363	$/day	contact energy	
Annual power savings	15.125	MWh	-	
Annual cost savings	$3,639.98	$	contact energy	

Energy Required		
Heating Load	204.75	MJ/day
biogas calorific value	23	MJ/m³
Efficiency	90	%
Volume required	9.8913043	m³ / day

8.1 Appendix E: Cost Estimation

Proposed 1

Service	Quantity	Description	Company	Cost
Earthworks	17x28x3.5x1.5 angle	Digester pond = 968 m3	Local Contractor	10000
Earthworks	32*19*2 = 264m3	Trench = 264 m3	Local Contractor	
Cover		17*28 + trench	AEL	10000
Effluent pipework		Digester to collection sump	Local Contractor	5000
Gas Pipework		Perforated pipe	Local Contractor	2000
Gas Pipework		Digester to diary shed	Local Contractor	2000
Blower		Fan blower for gas	Nu-way	12000
Boiler and burner		Boiler for gas	Ferolli	4000
Total				45000

Payback / year	$3,639.98				
Year			Years		Days
1	41360.0175	12.3626968		12	132.38
2	37720.035				
3	34080.0525				
4	30440.07				
5	26800.0875				
6	23160.105				
7	19520.1225				
8	15880.14				
9	12240.1575				
10	8600.175				
11	4960.1925				
12	1320.21				
13	-2319.7725				

Proposed 2

Service	Quantity	Description	Company	Cost
Earthworks	64x34x2=752 m3	Trench	Local Contractor	5000
Cover		17*28 + trench	AEL	20000
Gas Pipework		Perforated pipe	Local Contractor	2000
Gas Pipework		Digester to diary shed	Local Contractor	2000
Blower		Fan blower for gas	Nu-way	12000
Boiler and burner		Boiler for gas	Ferolli	4000
Total				45000

Payback / year	$3,639.98				
Year			Years		Days
1	$41,360.02	12.3626968		12	132.38
2	37720.035				
3	34080.0525				
4	30440.07				
5	26800.0875				
6	23160.105				
7	19520.1225				
8	15880.14				
9	12240.1575				
10	8600.175				
11	4960.1925				
12	1320.21				
13	-2319.7725				

8.2 Appendix F: Safety Points

- Typical pressures under a covered anaerobic pond are low ranging between 50-100 kPa. A blower is necessary to convey the gas to the boiler/ generator / flare
- Hydrogen sulphide is a toxic gas and is a minor ingredient in biogas composition. It can cause major health effects in humans, effects range from detection of 'rotten egg' odour at concentrations of 0.003 – 0.02 ppm, to unconsciousness at concentrations of 700 – 3000 ppm. However H_2S content is dairy cow biogas is fairly low and with proper ventilation is avoidable.
- Ensure that planning includes; following gas regulations (Gas Safety and measurement regulations 2010, hazardous substances act), considering installing an emergency gas flare.
- There should always be safe access points, shut off and fail safe equipment available for emergency and monitoring requirements
- Appropriate and unambiguous signage identifying hazards (e.g. no smoking/ no naked flame) and instructing no entry or required protective equipment and clothing
- Ensure all biogas equipment is explosion proof as per appropriate NZ standards
- Follow AS/NZS 60079.10 Explosive atmospheres – classification of areas – explosive gas atmospheres standard
- Note that the responsibility of the hazard zone classification is with the organization or person in charge of the biogas installation. They are often guided by the equipment's manufacturers classification
- All trade services employed for the biogas system installation must be made aware and understand the potential danger of hydrogen sulphide in the biogas
- Detectors may be required for H_2S detection in enclosed spaces as it is denser than air and sinks to floor level
- Do not over load the digester in regard to organic loading rate and be aware of effects that containments can have to the digester including heavy metals and co-generation
- Materials must be chosen appropriately, see appendix G for recommended and avoidable materials table
- All pipelines must be appropriately labelled including the use of colour identification
- Be careful with condensate draining as it will contain traces of H_2S. This water must not be feed into the digester again
- All biogas equipment must be designed and installed by qualified persons and should have incorporated into the systems the following: isolation valves, safety shut down devices and fail safe switches
- Upon commissioning, all gas containing equipment must be checked for tightness and pipelines purged of air to avoid explosive mixtures this is best done by installer
- Work safe regimes as per any dangerous job should be followed (Work Safe New Zealand)
- Monitoring is a good way to keep records for system, including: pH levels, volatile solids loading, biogas composition, sludge accumulation

8.3 Appendix G: Safety – Hazardous Areas and Zones

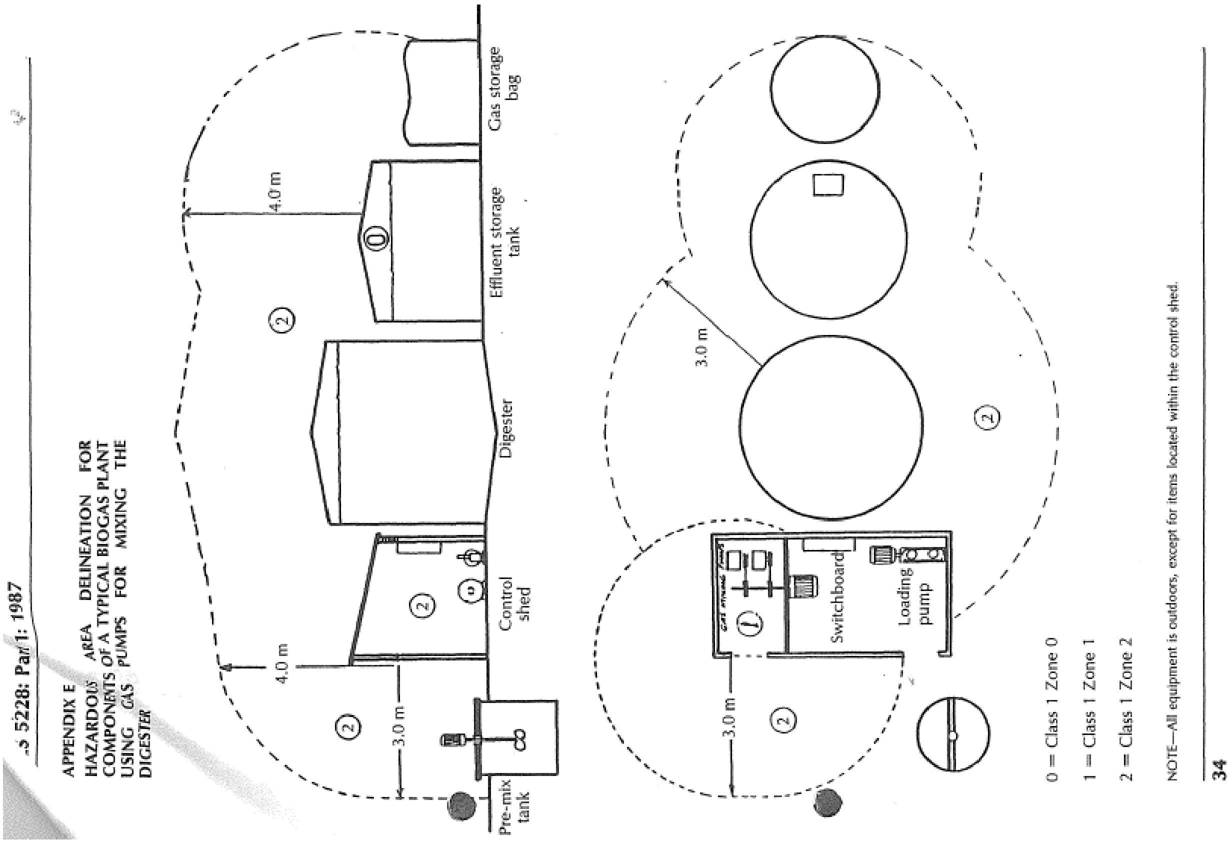


Figure 24: NZS 5228: Hazard Zones

8.4 Appendix H: Recommended Material Selection

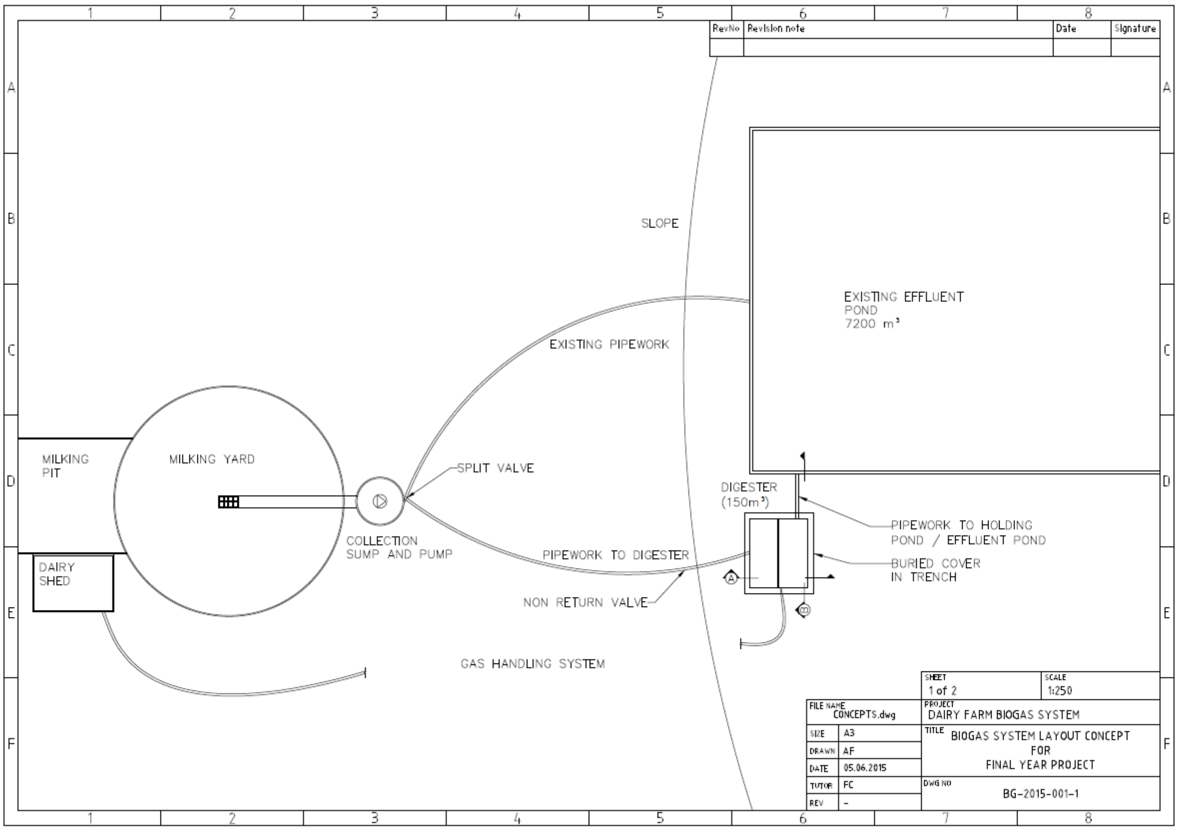
Table 6: Materials performance in contact with manure (Australian Pork Limited, 2015)

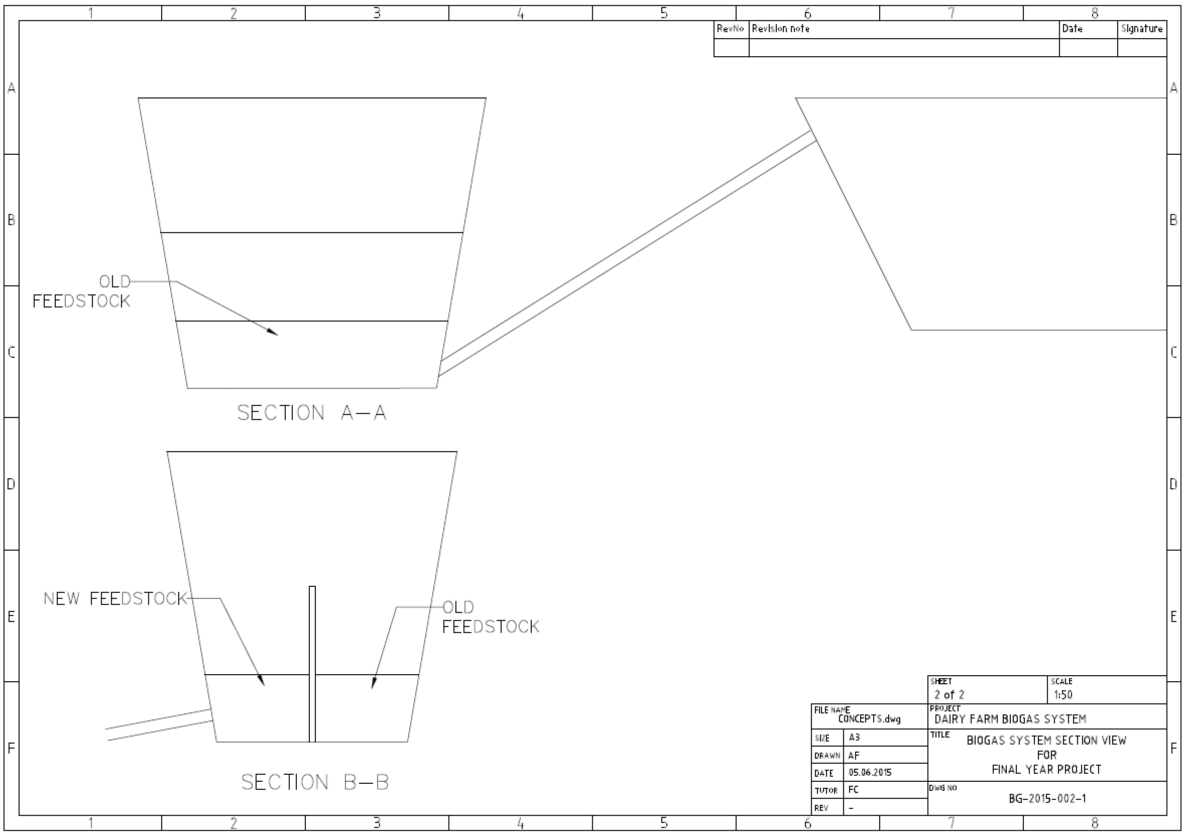
Material Status	Material List
Recommended	Polyethylene, polypropylene (PP), UV resistant PVC effluent piping Most stainless steel grades, clay concrete
Not Recommended	Copper, brass and aluminium. Uncoated steel other than stainless steel PVC shall not be used for lagoon or covers Polypropylene shall not be used when significant quantities of fats and oils are present (e.g. whey)

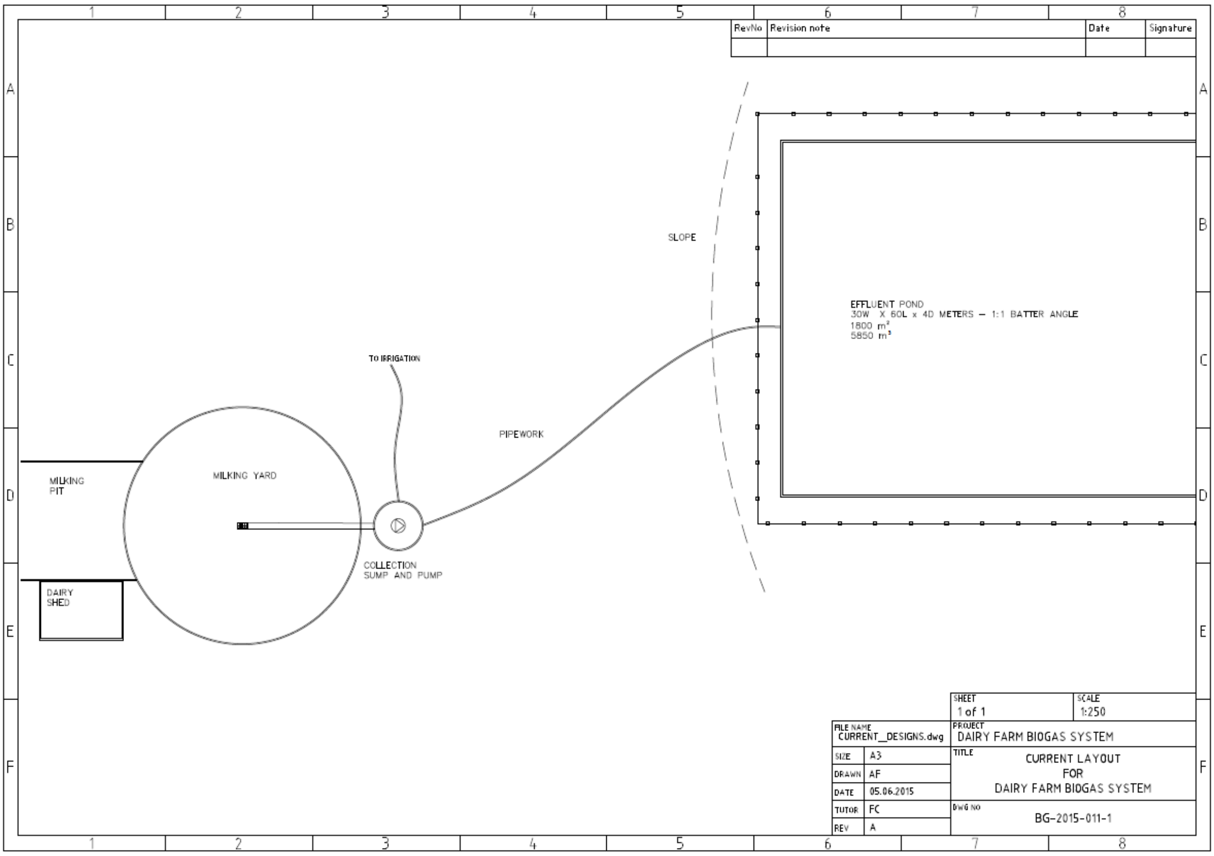
Table 7: Materials performance in contact with biogas (Australian Pork Limited, 2015)

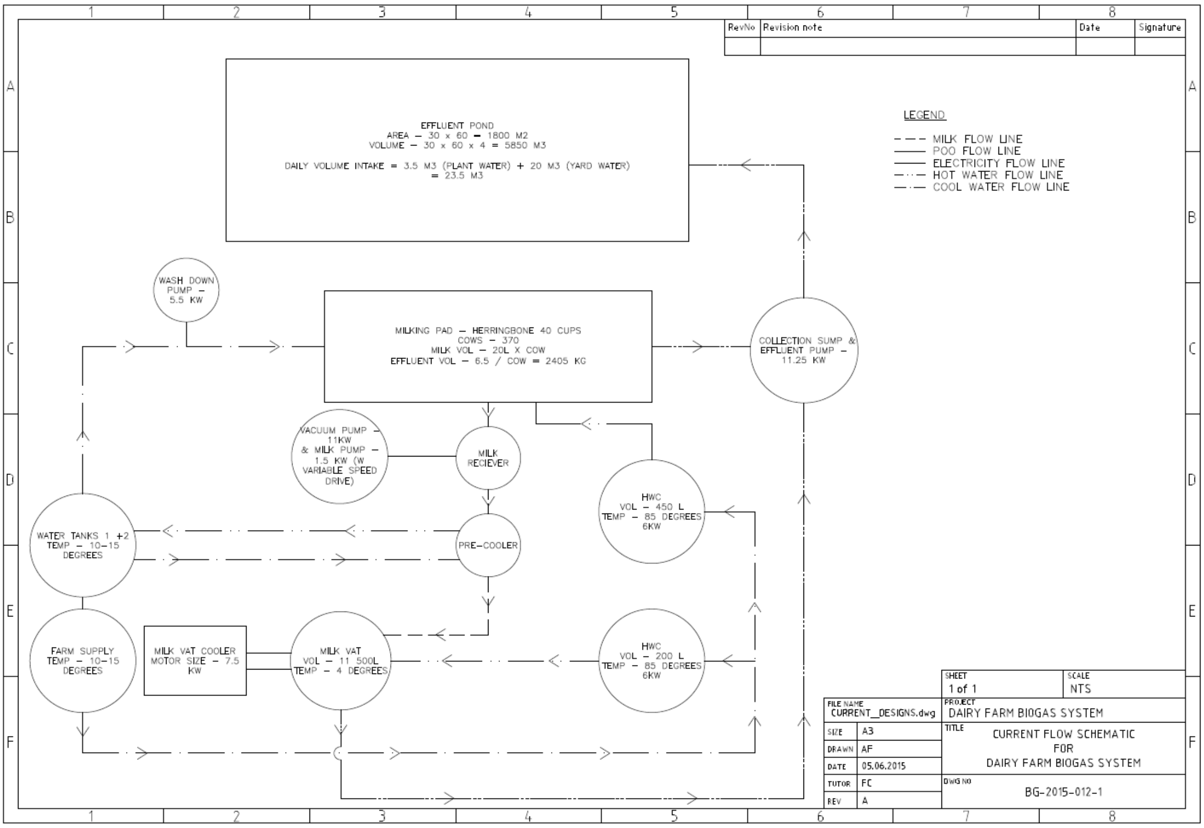
Material Status	Material List
Recommended	Plastic pipework and fittings below ground level e.g. polyethylene, PCV or polypropylene (only if no fat is present in waste being digested) Most stainless steel
Not Recommended	Copper, steel other than stainless steel, brass, traditional butyl rubber galvanised iron, plastic pipework and fittings above-ground

8.5 Appendix I: Detailed Drawings






RevNo
Revision note
Date
Signature
SLOPE
EFFLUENT POND
30W X 60L x 4D METERS – 1:1 BATTER ANGLE
1800 m²
5850 m³
TO IRRIGATION
PIPEWORK
MILKING PIT
MILKING YARD
COLLECTION SUMP AND PUMP
DAIRY SHED
SHEET 1 of 1
SCALE 1:250
FILE NAME CURRENT_DESIGNS.dwg
PROJECT DAIRY FARM BIOGAS SYSTEM
SIZE A3
DRAWN AF
DATE 05.06.2015
TUTOR FC
REV A
TITLE CURRENT LAYOUT FOR DAIRY FARM BIOGAS SYSTEM
DWG NO BG-2015-011-1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Revision note
Date
Signature
EFFLUENT POND
AREA – 30 x 60 – 1800 M2
VOLUME – 30 x 60 x 4 = 5850 M3
DAILY VOLUME INTAKE = 3.5 M3 (PLANT WATER) + 20 M3 (YARD WATER) = 23.5 M3
LEGEND
MILK FLOW LINE
POO FLOW LINE
ELECTRICITY FLOW LINE
HOT WATER FLOW LINE
COOL WATER FLOW LINE
WASH DOWN PUMP – 5.5 KW
MILKING PAD – HERRINGBONE 40 CUPS
COWS – 370
MILK VOL – 20L X COW
EFFLUENT VOL – 6.5 / COW = 2405 KG
COLLECTION SUMP & EFFLUENT PUMP – 11.25 KW
VACUUM PUMP – 11KW & MILK PUMP – 1.5 KW (W VARIABLE SPEED DRIVE)
MILK RECIEVER
HWC VOL – 450 L TEMP – 85 DEGREES 6KW
WATER TANKS 1 +2 TEMP – 10–15 DEGREES
PRE–COOLER
FARM SUPPLY TEMP – 10–15 DEGREES
MILK VAT COOLER MOTOR SIZE – 7.5 KW
MILK VAT VOL – 11 500L TEMP – 4 DEGREES
HWC VOL – 200 L TEMP – 85 DEGREES 6KW
SHEET 1 of 1
SCALE NTS
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PROJECT DAIRY FARM BIOGAS SYSTEM
SIZE A3
DRAWN AF
DATE 05.06.2015
TUTOR FC
REV A
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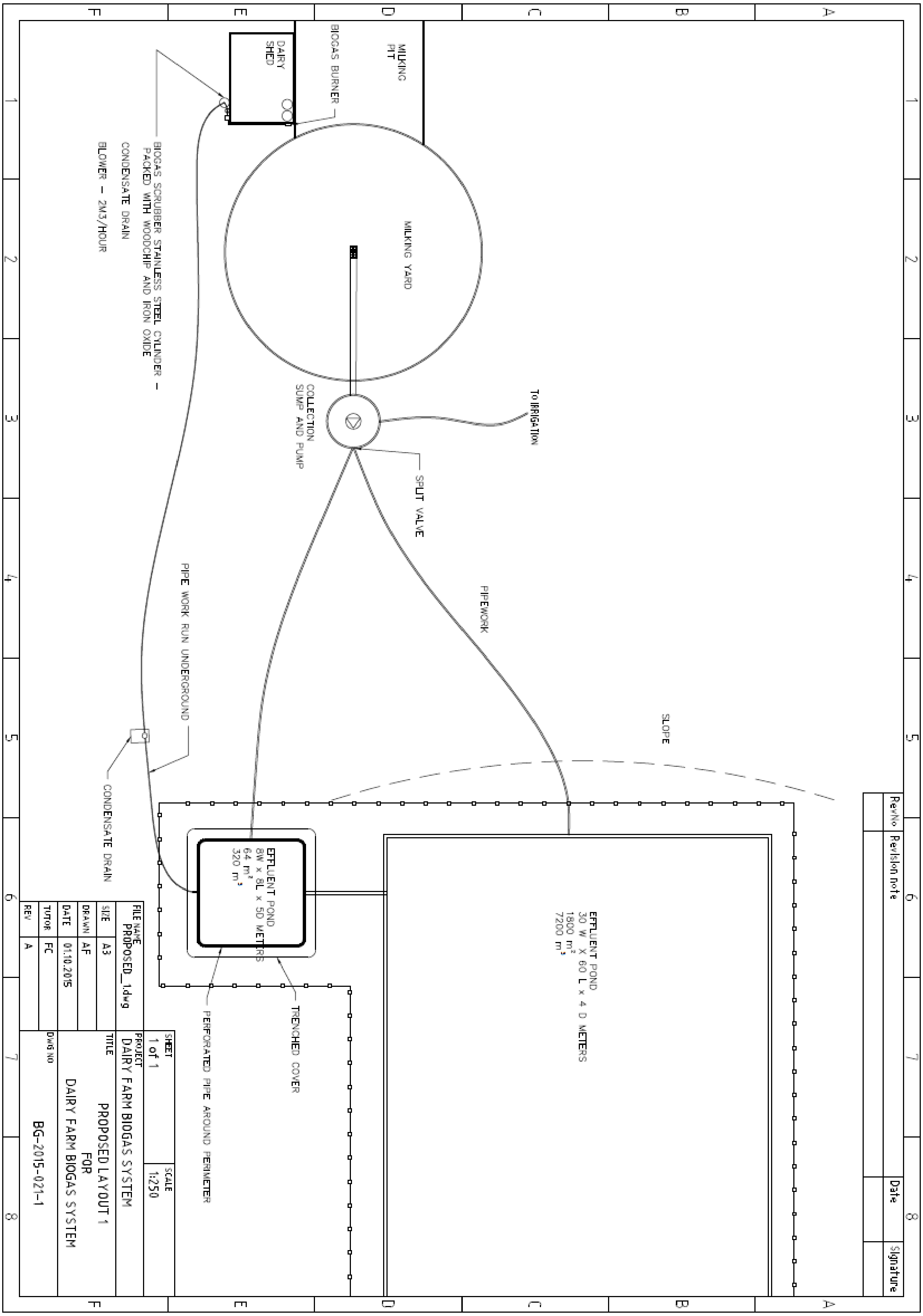
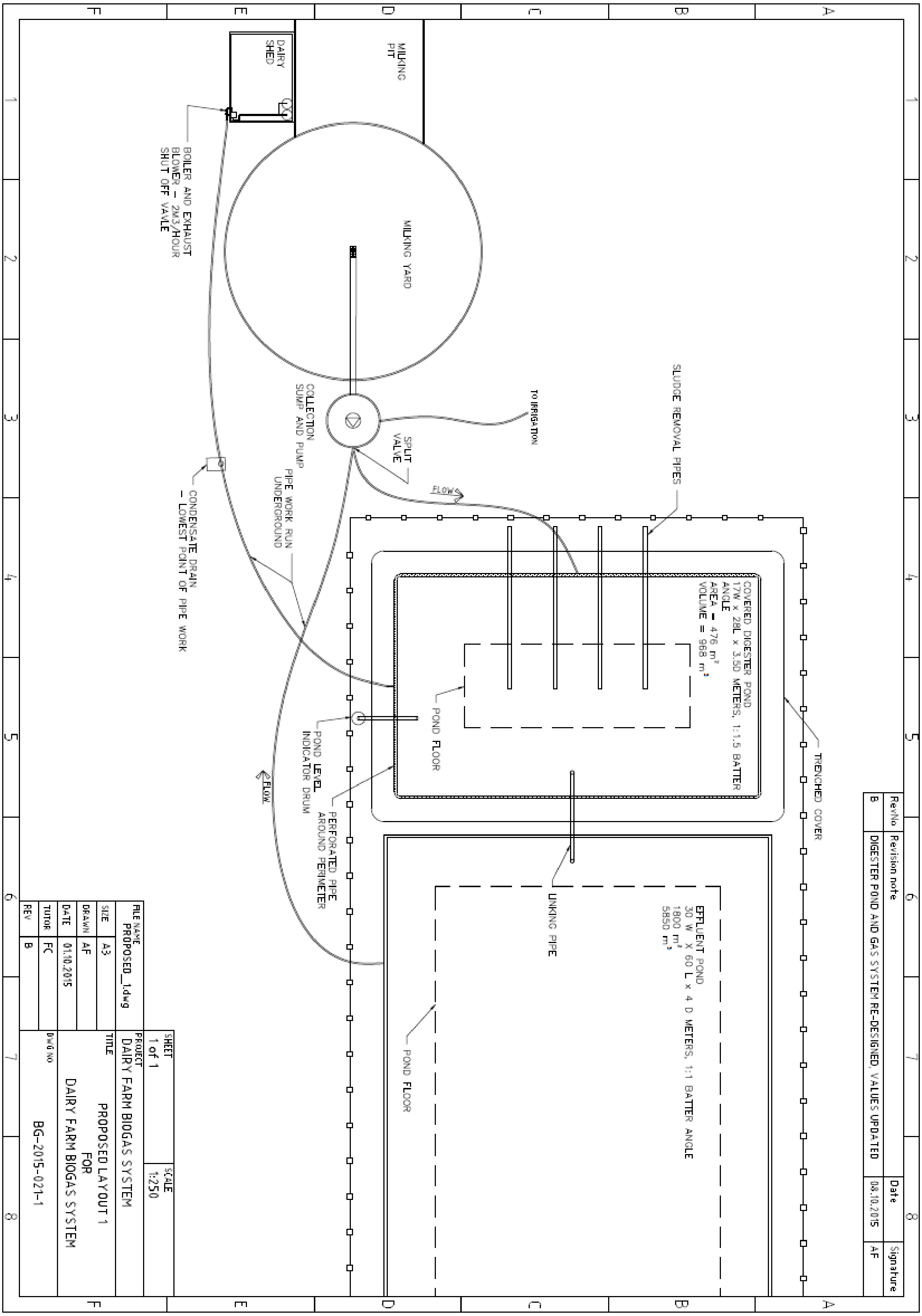
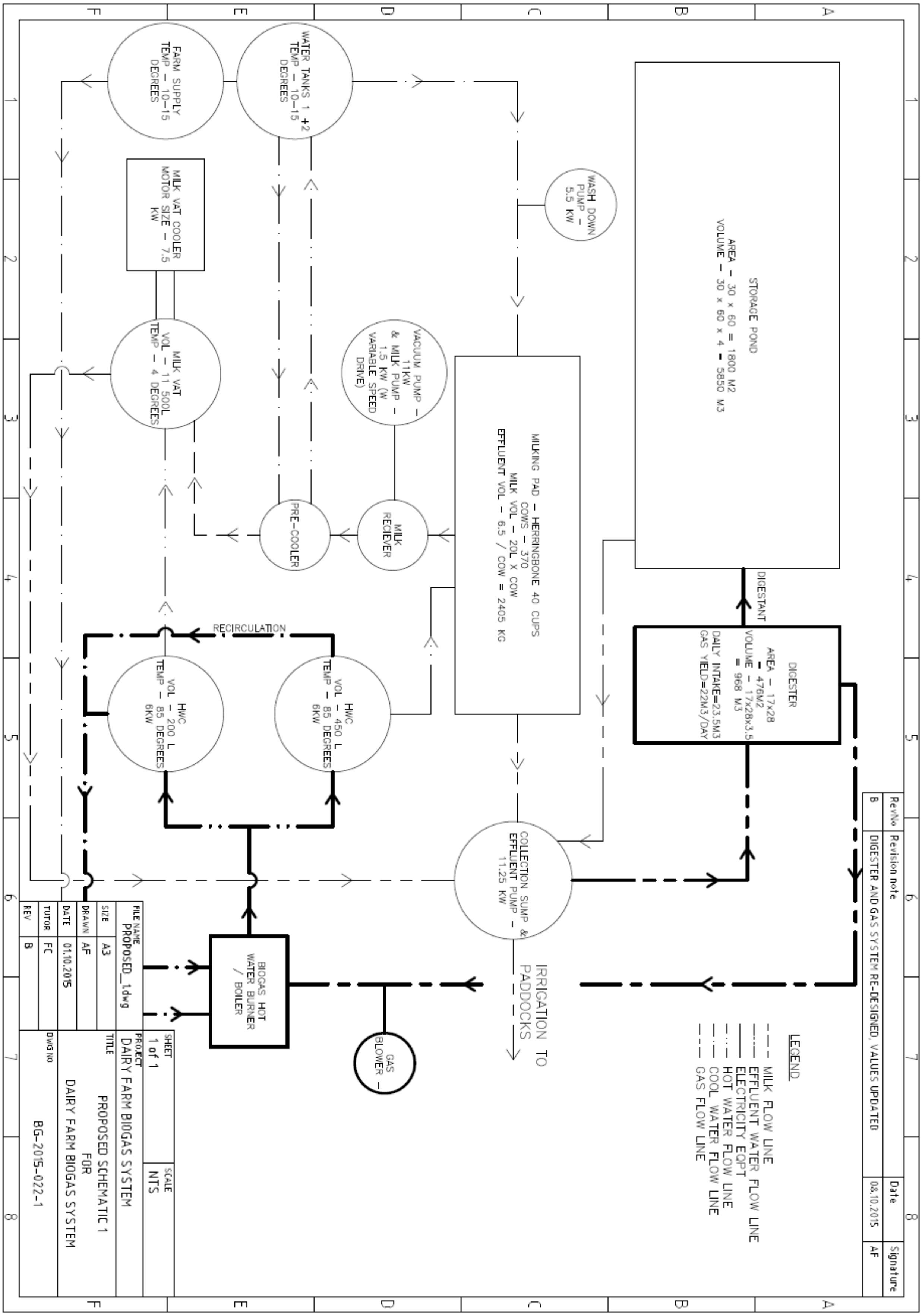
DWG NO BG-2015-012-1


MILKING PIT
DAIRY SHED
BIOGAS BURNER
BIOGAS SCRUBBER STAINLESS STEEL CYLINDER – PACKED WITH WOODCHIP AND IRON OXIDE
CONDENSATE DRAIN
BLOWER – 2M3/HOUR
MILKING YARD
COLLECTION SUMP AND PUMP
To IRRIGATION
SPLIT VALVE
PIPEWORK
PIPE WORK RUN UNDERGROUND
CONDENSATE DRAIN
SLOPE
EFFLUENT POND
8W x 8L x 5D METERS
64 m²
320 m³
EFFLUENT POND
30 W X 60 L x 4 D METERS
1800 m²
7200 m³
TRENCHED COVER
PERFORATED PIPE AROUND PERIMETER
RevNo
Revision note
Date
Signature
FILE NAME
PROPOSED_1.dwg
SIZE
A3
DRAWN
AF
DATE
01.10.2015
TUTOR
FC
REV
A
SHEET
1 of 1
SCALE
1:250
PROJECT
DAIRY FARM BIOGAS SYSTEM
TITLE
PROPOSED LAYOUT 1
FOR
DAIRY FARM BIOGAS SYSTEM
DWG NO
BG-2015-021-1


DAIRY SHED
MILKING PIT
MILKING YARD
BOILER AND EXHAUST
BLOWER – 2M3/HOUR
SHUT OFF VAVLE
TO IRRIGATION
COLLECTION SUMP AND PUMP
SPLIT VALVE
SLUDGE REMOVAL PIPES
FLOW
PIPE WORK RUN UNDERGROUND
CONDENSATE DRAIN
– LOWEST POINT OF PIPE WORK
COVERED DIGESTER POND
17W x 28L x 3.5D METERS, 1:1.5 BATTER ANGLE
AREA = 476 m²
VOLUME = 968 m³
POND FLOOR
POND LEVEL INDICATOR DRUM
PERFORATED PIPE AROUND PERIMETER
TRENCHED COVER
LINKING PIPE
EFFLUENT POND
30 W X 60 L x 4 D METERS, 1:1 BATTER ANGLE
1800 m²
5850 m³
POND FLOOR
RevNo
Revision note
Date
Signature
B
DIGESTER POND AND GAS SYSTEM RE-DESIGNED, VALUES UPDATED
08.10.2015
AF
FILE NAME
PROPOSED_1.dwg
SIZE
A3
DRAWN
AF
DATE
01.10.2015
TUTOR
FC
REV
B
SHEET
1 of 1
SCALE
1:250
PROJECT
DAIRY FARM BIOGAS SYSTEM
TITLE
PROPOSED LAYOUT 1
FOR
DAIRY FARM BIOGAS SYSTEM
DWG NO
BG-2015-021-1


FARM SUPPLY TEMP – 10–15 DEGREES
WATER TANKS 1 +2 TEMP – 10–15 DEGREES
WASH DOWN PUMP – 5.5 KW
STORAGE POND
AREA – 30 x 60 = 1800 M2
VOLUME – 30 x 60 x 4 = 5850 M3
MILK VAT COOLER MOTOR SIZE – 7.5 KW
MILK VAT VOL – 11 500L TEMP – 4 DEGREES
VACUUM PUMP – 11KW & MILK PUMP – 1.5 KW (W VARIABLE SPEED DRIVE)
MILKING PAD – HERRINGBONE 40 CUPS
COWS – 370
MILK VOL – 20L X COW
EFFLUENT VOL – 6.5 / COW = 2405 KG
PRE–COOLER
MILK RECIEVER
DIGESTANT
DIGESTER
AREA – 17x28 = 476M2
VOLUME – 17x28x3.5 = 968 M3
DAILY INTAKE=23.5M3
GAS YIELD=22M3/DAY
RECIRCULATION
HWC VOL – 200 L TEMP – 85 DEGREES 6KW
HWC VOL – 450 L TEMP – 85 DEGREES 6KW
COLLECTION SUMP & EFFLUENT PUMP – 11.25 KW
IRRIGATION TO PADDOCKS
BIOGAS HOT WATER BURNER / BOILER
GAS BLOWER –
LEGEND
MILK FLOW LINE
EFFLUENT WATER FLOW LINE
ELECTRICITY EQPT
HOT WATER FLOW LINE
COOL WATER FLOW LINE
GAS FLOW LINE
RevNo Revision note Date Signature
B DIGESTER AND GAS SYSTEM RE-DESIGNED, VALUES UPDATED 08.10.2015 AF
FILE NAME PROPOSED_1.dwg
SIZE A3
DRAWN AF
DATE 01.10.2015
TUTOR FC
REV B
SHEET 1 of 1
SCALE NTS
PROJECT DAIRY FARM BIOGAS SYSTEM
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DWG NO BG–2015–022–1
A B C D E F
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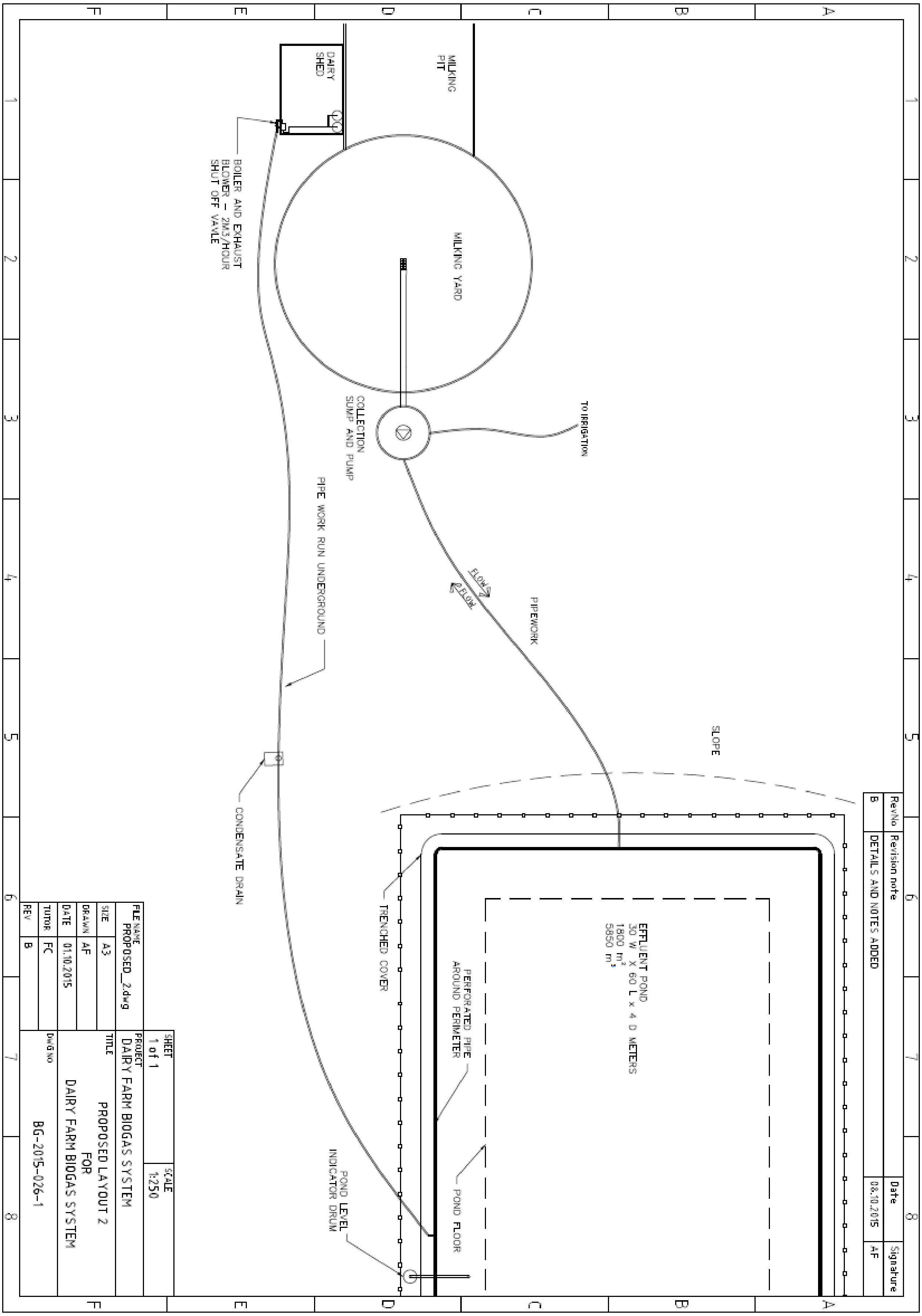
DAIRY SHED
MILKING PIT
MILKING YARD
BOILER AND EXHAUST BLOWER – 2M3/HOUR SHUT OFF VAVLE
COLLECTION SUMP AND PUMP
TO IRRIGATION
PIPE WORK RUN UNDERGROUND
PIPEWORK
FLOW
FLOW
SLOPE
CONDENSATE DRAIN
TRENCHED COVER
EFFLUENT POND
30 W X 60 L x 4 D METERS
1800 m2
5850 m3
PERFORATED PIPE AROUND PERIMETER
POND FLOOR
POND LEVEL INDICATOR DRUM
RevNo
Revision note
Date
Signature
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DETAILS AND NOTES ADDED
08.10.2015
AF
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SIZE A3
DRAWN AF
DATE 01.10.2015
TUTOR FC
REV B
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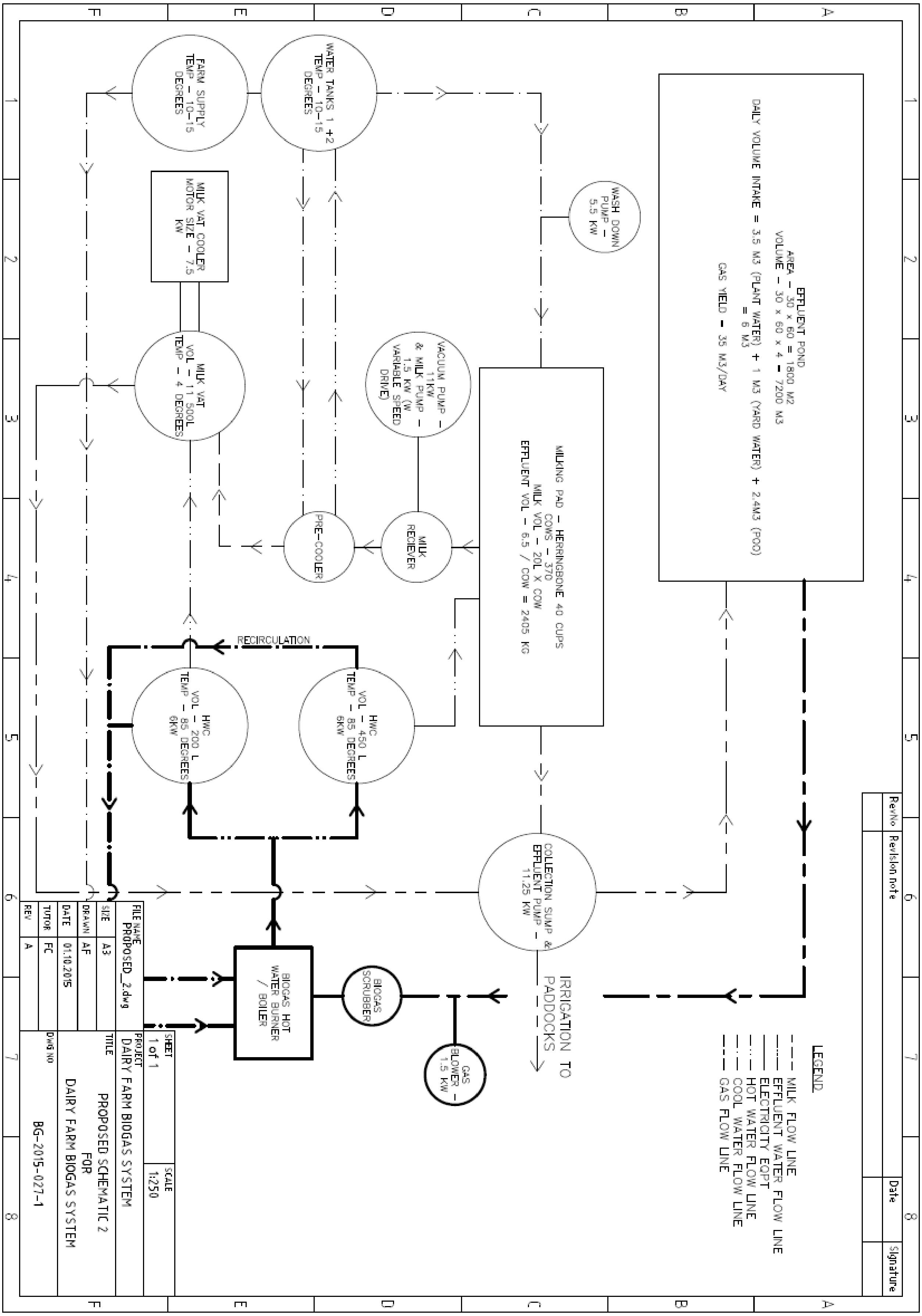
DWG NO BG-2015-026-1


EFFLUENT POND
AREA – 30 x 60 = 1800 M2
VOLUME – 30 x 60 x 4 = 7200 M3
DAILY VOLUME INTAKE = 3.5 M3 (PLANT WATER) + 1 M3 (YARD WATER) + 2.4M3 (POO) = 6 M3
GAS YIELD = 35 M3/DAY
WATER TANKS 1 +2
TEMP – 10–15 DEGREES
FARM SUPPLY
TEMP – 10–15 DEGREES
WASH DOWN PUMP – 5.5 KW
MILK VAT COOLER MOTOR SIZE – 7.5 KW
VACUUM PUMP – 11KW & MILK PUMP – 1.5 KW (W VARIABLE SPEED DRIVE)
MILK VAT
VOL – 11 500L
TEMP – 4 DEGREES
MILKING PAD – HERRINGBONE 40 CUPS
COWS – 370
MILK VOL – 20L X COW
EFFLUENT VOL – 6.5 / COW = 2405 KG
MILK RECIEVER
PRE-COOLER
RECIRCULATION
HWC
VOL – 450 L
TEMP – 85 DEGREES
6KW
HWC
VOL – 200 L
TEMP – 85 DEGREES
6KW
COLLECTION SUMP & EFFLUENT PUMP – 11.25 KW
IRRIGATION TO PADDOCKS
BIOGAS HOT WATER BURNER / BOILER
BIOGAS SCRUBBER
GAS BLOWER – 1.5 KW
LEGEND
MILK FLOW LINE
EFFLUENT WATER FLOW LINE
ELECTRICITY EQPT
HOT WATER FLOW LINE
COOL WATER FLOW LINE
GAS FLOW LINE
RevNo
Revision note
Date
Signature
FILE NAME PROPOSED_2.dwg
SIZE A3
DRAWN AF
DATE 01.10.2015
TUTOR FC
REV A
SHEET 1 of 1
SCALE 1:250
PROJECT DAIRY FARM BIOGAS SYSTEM
TITLE PROPOSED SCHEMATIC 2 FOR DAIRY FARM BIOGAS SYSTEM
DWG NO BG-2015-027-1

8.6 Appendix J: Solid Works Drawings

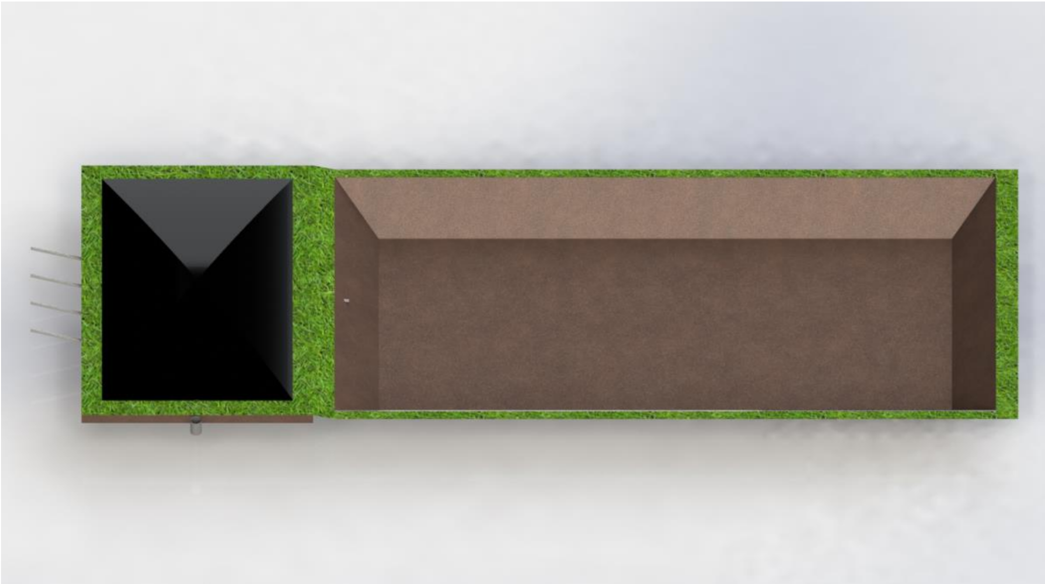


Figure 25: Full View of Digester Pond and Storage Pond

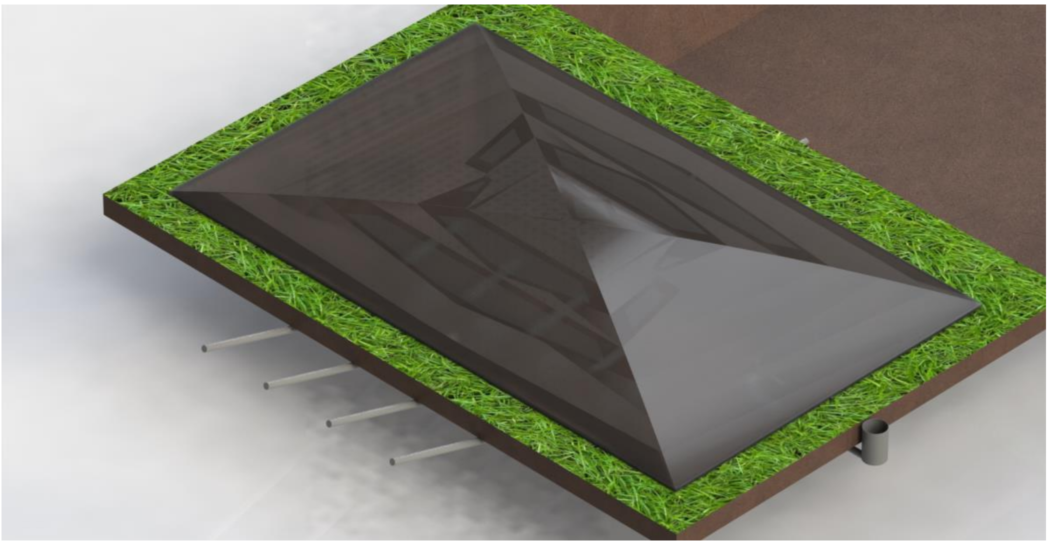


Figure 26: Close up view of Digester with Cover

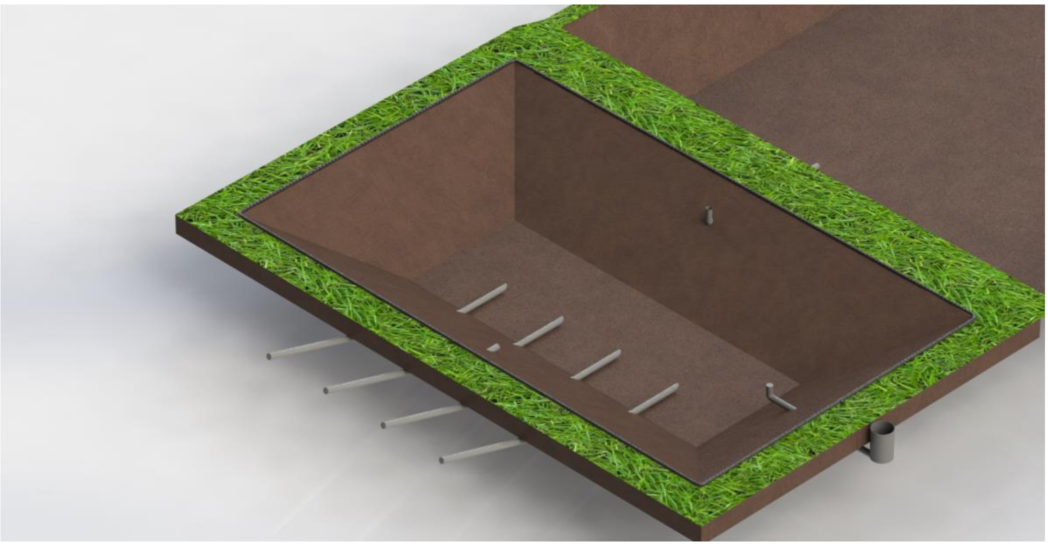


Figure 27: Close up view of Digester uncovered, showing sludge removal pipes, level drum and linking pipe

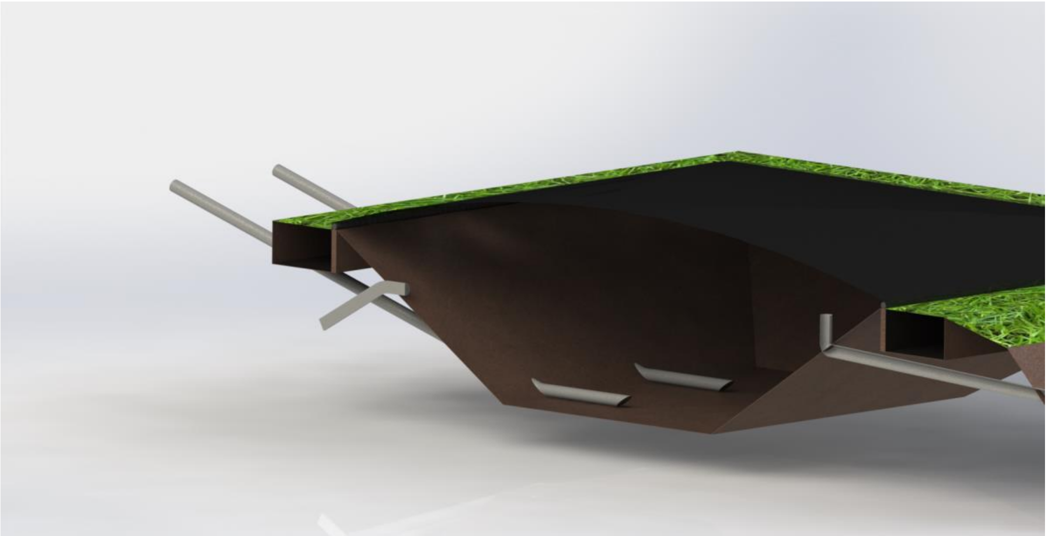


Figure 28: Cross section view of Digester