# Analysis of alternative uses for biogas in Cambodia

# Initial assessment report on field mission

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Project: Reduction of GHG emission through promotion of commercial biogas plants in Cambodia

# Table of contents

## Executive Summary

Originally, the field mission conducted in April 2018 by Fachverband Biogas, UNIDO and BTIC aimed at assessing the feasibility of the alternative uses of biogas as defined in the report "Analysis of alternative uses for biogas in Cambodia" (Grope, Scholwin and Hofmann, March 2018) in specific locations in Cambodia.

However, it was rapidly determined, that none of these are relevant for the locations in question. The reasons for this are varied and include:

- missing knowledge and risk aversion from the owner of the location,
- the energy resources are already used otherwise,
- no possibility to feed electricity to the grid,
- small biogas production volumes do not allow for economies of scale regarding the investment to happen,
- geographical location of these sites, away from consumer hotspots.

Therefore, this report introduces some general remarks about the functioning of fattening farms in Cambodia and general technical and safety recommendations applicable to those locations which already have an operating biogas plant. The second part assesses each location individually, including a description of the current situation, biogas potential and the recommended electrical capacity. The following table is a summary of the most important findings and recommendations for each location.

| Name of the location | Size (heads of pigs) | Installed biogas system (if any) | Estimated biogas production ($m^3/a$) | Recommendations |
|---|---|---|---|---|
| Farm No1 | 4,500 | Lagoon system with 2 gensets of 100 $kW_e$ capacity each (operational) | 101,400 | • Gas quality measurements<br>• Digestate outflow control<br>• Safety training for the staff<br>• Fix membrane to the ground<br>• Improve electrical installations<br>• Avoid mechanical hazards<br>• Warn about explosive atmospheres |
| Farm No 2 | 2,200 | None | 49,500 | Due to low energy requirements and low cost for electricity, it is not recommended to invest into a biogas plant |
| Farm No 3 | 2,200 | Lagoon system with 2 modified gensets of 25 $kW_e$ capacity each (not operational) | 49,500 | • Gas quality measurements<br>• Install a new genset (10 kWe) or urgently install a gas flare to avoid biogas scaping to the atmosphere<br>• Safety training for the staff<br>• Fix membrane to the ground<br>• Improve genset connection and electrical installations<br>• Avoid mechanical hazards<br>• Warn about explosive atmospheres |

| | | | | |
|---|---|---|---|---|
| Farm No 4 | 5,000 | Two lagoon systems (one in operation and one in start-up phase) with 2 operational gensets of 400 and 300 $kW_e$ capacity. | 112,500 | • The gensets installed have a greater capacity than what it can be expected from the biogas production. Use of other feedstocks should be considered.<br>• Safety training for the staff<br>• Fix membrane to the ground<br>• Improve genset connection and electrical installations<br>• Avoid mechanical hazards<br>• Warn about explosive atmospheres<br>• Take special measures during start of operation. |
| Farm No 5 | 1,200 | Lagoon system in construction | 27,000 | • Recommended installed capacity according to biogas production 10 $kW_e$.<br>• Sieve the soil at the bottom of the lagoon to avoid damages to the membrane. |
| Tapioca processing factory Farm No 6 | - | Lagoon system (not in operation) | 3,942,000 | • An appropriate dismantling of the lagoon is necessary. |
| Rubber production factory Farm No7 | - | None (however, there is a lagoon where effluents of the process are taken to) | Unknown | • Analysis of waste water is necessary to further calculate biogas potential. |
| Rubber production factory Farm No 8 | - | None (however, there is a lagoon where effluents of the process are taken to) | Unknown | • Analysis of waste water is necessary to further calculate biogas potential.<br>• Energy balance calculation (biogas potential vs. energy requirements) |
| Farm No 9 | 2,000 | None | 45,000 | Due to low energy requirements and low cost for electricity, it is not recommended to invest into a biogas plant. |
| Farm No 10 | 2,000 | None | 45,000 | Due to low energy requirements and low cost for electricity, it is not recommended to invest into a biogas plant. |

For biogas to have this positive effect, it is necessary that methane emissions into the atmosphere are as low as possible. This was not the case in the biogas plants visited in Cambodia during this field mission. Usually, it is standard for biogas plants to have a gas combustion unit, e.g. a gas flare to burn the biogas that is produced and cannot be stored during for example CHP or motor down-times. Another situation that was observed in the biogas plants visited was the absence of a HDPE membrane at the bottom of the lagoons, which would prevent leakages of liquid material into the ground, thus emissions to the groundwater. FvB recommends UNIDO and BTIC to create awareness among the owners of these biogas plants, so they can understand the importance of avoiding emissions into the atmosphere, soil and water sources from the biogas plant.

In Cambodia there is no incentive system in place to promote biogas, the conditions to sell surplus of electricity to the grid are challenging, and therefore the possible revenues for biogas production are very limited. However, this should not be used as an argument in detriment of human and environmental safety.

# Introduction

As part of the contract "Analysis of alternative uses for biogas in Cambodia" a field mission to 12 different locations in Cambodia was done by UNIDO, Biogas Technology Information Center in Cambodia (BTIC) and Fachverband Biogas (FvB) from March 27th until April 5th 2018. The locations visited included pig fattening farms and three factories (rubber industry / tapioca processing).

The objective of the field mission was to determine the feasibility of alternative uses of biogas in the given locations. The alternative uses are defined as other uses of biogas as electricity production. In the context of this contract those are: biogas backpacks, biogas pipelines and upgrading biogas to biomethane quality and distribution in pressurised cylinders. More information on those alternative usages can be found in the report: "Analysis of alternative uses for biogas in Cambodia, task 1 – 3".

During the field mission the team observed that none of these alternative usages are relevant in practice at the locations visited. Furthermore, most of the owners of the visited locations expressed no interest in investing into a biogas plant. Thus, a cost-benefit analysis for those locations would not be relevant. Following this, the team agreed that the content of this Initial Assessment report should be adapted and focus on the following topics:

1. Analysis of the relevance of the alternative uses of biogas for the locations visited.
2. Detailed description of the locations visited, including:
    - General description of the location,
    - Rough estimation of possible biogas production,
    - Specific technical and safety recommendations for optimization of the biogas plant for those locations where a biogas plant already exists.
3. Environmental aspects of biogas plants.
4. Rough estimation on costs for biogas plants that can operate safely and environmentally friendly.

Therefore, this initial assessment report contains a description of what was observed during the field mission, a short analysis of the biogas potential at each location and recommendations. Since some of the locations already had an installed lagoon biogas plant, recommendations on safety and operation of those are given.

## General remarks

In this chapter, general remarks about different topics that are applicable to all or most locations are presented with the purpose of giving the reader more information about the environment and general situation of the locations.

### 1. Pig fattening farms and feedstock availability

There is an "all in – all out" strategy to fatten piglets in Cambodia. All visited farms follow that strategy. The process starts with small piglets which are put in long stables, usually several stables, with about 600 – 700 pigs per stable. Each stable is divided in about 24 compartments, holding about 25 pig each. The fattening period takes 5 – 6 months. After fattening the pigs are sold and the stable cleaned and sanitized which takes about one month. Afterwards new piglets are put in. Therefore, there is manure production for only about 10 months a year.

For biogas plant operation this "all in – all out" strategy results in varying amounts of feedstock (manure) followed by varying biogas production. Piglets produce small amounts of manure, grown pigs on the other hand produce higher amounts of manure per day. For this study an average manure production of 0.25 kg manure per head per day is assumed. As biogas yield 300 $m^3$ biogas per tons of dry matter manure is assumed. Both figures are based on estimations from an international UNIDO biogas expert or other biogas literature sources[1].

It has to be emphasized that the biogas production yields are influenced by several factors, like hydraulic retention time, temperature, quality of input material, among others. The biogas yield calculations in this report are based on general assumptions. It is to be considered that normally biogas yields in practice can differ very much from the theoretical calculations. Thus, the accuracy of the biogas yield calculations shown in this report should be considered as average values, which in practice may have deviations of up to ± 50%.

### 2. Biogas utilization

Feeding the produced electricity from the biogas plant into the grid is difficult in Cambodia. Some energy providers would only accept electricity during the dry season when electricity production from water power is low. Electricity prices are low in comparison to the operation costs of a biogas plant. Finally, other energy providers do not offer the possibility to feed electricity into the grid at all without a licence, which cannot be easily obtained. In short, the possibility of feeding electricity surplus into the grid is generally not an option and the farmers were not informed about the conditions under which this might be possible.

Therefore, for the locations visited the most probable biogas use will be to cover the own electricity demand of the agro-industry. Thus, for this report it can be assumed that the main income from a biogas plant would be the reduction of the own electricity bill, or savings from the use

[1] Bart Frederiks and "Guide to Biogas", published by FNR, https://mediathek.fnr.de/broschuren/fremdsprachige-publikationen/english-books/guide-to-biogas-from-production-to-use.html

of other fuels (e.g. diesel for electricity generation). Hence, it can be inferred that on farms with high electricity consumption (e.g. in case of closed stables) a biogas plant will generate more income/savings.

### a) Relevance of alternative uses of biogas

As described above one original (but amended) intention of the field mission was to investigate if the owner of the locations (pig farms, rubber industry, tapioca processing) are interested to use biogas in an alternative way (biogas upgrading, biogas bottling, biogas backpacks or biogas grids). During the field mission it was not possible to speak with all owners, in several cases it was only possible to get the opinions of the employees regarding the motivation of the owner. However, it was possible to get a general impression of the opportunities and the opinion on alternative uses of biogas.

In general, the visited locations were not interested in investing in alternative uses of biogas. Among the reasons for this are:

1. The core business of the locations is pig fattening, rubber production or tapioca processing, respectively. There is lack of interest and knowledge to judge if the alternative uses could be a good business opportunity. Several owners indicated that they are not able or willing to shift resources to investigate if this option might be interesting. Barrier: Missing knowledge and risk aversion of the private sector.
2. Those locations with an existing biogas plant have already invested into a gas utilization unit, a genset. They are not interested to invest into another alternative. Barrier: energy resources are already utilized.
3. The main income from a biogas plant and genset is achieved through captive energy use. The options of selling energy to the grid are very difficult to estimate under Cambodian circumstances. The traditional use of wood or charcoal for cooking or heat supply is by far more economical compared to the costs for electricity. Thus, for the biogas plant owner is much more interesting to produce electricity, because electricity has a much higher value compared to fuel for cooking.
   Barrier: electricity from biogas cannot be fed into the grid; electricity from biogas can only substitute captive energy use, while grid electricity is relatively inexpensive and biogas electricity needs to be competitive.
4. All pig fattening farms are relatively small, the biogas production is limited. Two of the alternative uses (biogas upgrading to biomethane and biogas grids) are only financially interesting if the produced biogas volume rate is high (above 100 $m^3/h$, according to the report on task 1-3). This size cannot be reached by any of the visited pig fattening farms.
   Barrier: no economies of scale due to small biogas volume.
5. The visited rubber production facilities offer higher potential of biogas production compared to the pig fattening farms. The idea to invest into a biogas plant was new to the owners and thus understandable that they were not enthusiastic to invest into a biogas plant and alternative uses as long as they don't understand the opportunities. The

biogas potential on this site is analyzed in this report, as far as the available data permitted it.
Barrier: Missing knowledge and risk aversion of the private sector.

6. The tapioca processing factory had stopped operation at the time of the visit. Under these conditions it is obvious that the persons are not willing to invest into alternative uses of biogas.
   Barrier: Risk aversion of the private sector.
7. The option of the biogas backpacks would need significant additional logistical effort to fill or distribute the backpacks and to convince energy consumer to buy the biogas in backpacks. During the field mission no person was interested in this option. However, biogas backpacks could be an interesting alternative if an organization would assume this effort. This option will be further investigated in an additional report.
   Barrier: communities near pig farms use collected wood, which is free of costs; urban areas are located often at larger distance.

## 3. Biogas technology

### a) Lagoon biogas plants

Some of the locations visited had already biogas production by means of a covered lagoon. The main reasons to construct lagoon biogas plants are a) the low investment costs and b) the simplicity of its operation. However, this technology also presents serious risks to the environment and persons, which will be further explained in this report.

### b) Technical recommendations

There are various technical solutions for biogas plants and different approaches to match the technical specifications to the requirements of the location or feedstock available. There are expensive high-tech solutions which offer high efficiency and process control and inexpensive low-tech solutions which are mainly motivated to keep investment costs low. It is not within the scope of work in this report to describe the advantages and disadvantages of both kind of solutions. However, it is worth mentioning that one of the biggest challenges for biogas plants in Cambodia are the investment costs. The farmers are not willing and able to invest more than absolutely needed. Yet, there are many biogas plants around the world where low investment costs have resulted in unreliable biogas plant operation and high safety risks.

Developing technical recommendations is a complex issue, there is not just one right option. Technical recommendations in this report are based on the following premises:

- The additional investments and needed know-how should be as low as possible.
- The lower the adjustment to the current technology, the better is the acceptance of the owner.
- The efficiency, controllability and safety of the biogas plants should be enhanced.

There are some technical measures relevant to all the biogas plants visited, these are described as follows:

**Gas quality measurements** are important to understand the composition of the gas being produced, especially meaningful is the **methane** content, as methane is the most valuable component in biogas. Furthermore, it is also relevant to control the concentration of **hydrogen sulfide (**$H_2S$**)**, as this component is very corrosive and might affect the functioning of the motor. The most technically advanced option would be to invest into a measurement instrument that can measure permanently $CH_4$, $CO_2$ and $H_2S$. If the $H_2S$ concentration is high (e.g. above 1000 ppm) measures to reduce $H_2S$ should be adopted, e.g., by blowing some air into the gas storage on top of the lagoon. The amount of air should be dimensioned according to the measured $H_2S$ concentration. As a rule of thumb, it could be said that the injected air could be between 4% (compared to the biogas production rate in $m^3/h$) if the $H_2S$ concentration is very high (above some thousand ppm) and 0.5% if the $H_2S$ concentration is below 1,000 ppm.

The investment costs for measurement instruments depend on the accuracy of measured figures, the lifetime and the options for calibration. Instruments that measure the different gas components ($CH_4$, $CO_2$ and $H_2S$) cost between 1,000 – 10,000 US$.

If investment costs should be reduced, borrowing a **mobile device** might be an option. UNIDO indicated that they will receive a mobile device for $H_2S$ measurement. It is strongly recommended to use this instrument. There should be several measurements, eventually accompanied with optimization measures for $H_2S$ reduction and control of the effects. The costs for simple mobile devices are around 1,000 US$.

There are several other technical options for desulfurization, like chemical and physical processes, biological processes and combined methods. The interested reader will find several publications on the topic. One of those is the “Guide to Biogas” published by FNR.

$H_2S$ reduction is only one parameter of thousands which can be optimized on biogas plants and the reader should be aware that there are several solutions.

## 4. Safety on existing biogas plants

During the site visits, several dangerous situations were observed in those locations which already have a biogas plant. These situations represent threats to the safety of persons working in the immediate area of the biogas plant and in some cases also to the environment.

Biogas is a highly flammable mixture of gases, which can be also toxic to human beings. However, biogas plants can be operated safely, when the dangers are identified and measures are taken to prevent possible dangerous circumstances.

In the following the most prominent situations observed in most biogas plants visited are explained:

a) **Mechanical hazards**: although not specific to biogas technology, mechanical hazards are the most common reason for accidents in biogas plants. These hazards include:

falling, crushing or cutting. This type of hazard was frequently observed in the biogas plants visited and will be described for each location.

b) **Electrical hazards**: through the electrical equipment used in a biogas plant, danger of electric shock, electric or magnetic fields or static electricity are present in a biogas plant. This type of hazard was also often observed and will be described in detail for each location.

c) **Gas hazards**: biogas is a mixture of gases like methane, carbon dioxide, ammonia and hydrogen sulphide in different concentrations depending on the biogas plant in question. The following table shows the properties and hazard of each of these gases:

*Table 1: Properties of the gaseous constituents of biogas.*

*Source: Safety first, Guidelines for the safe use of biogas technology, Fachverband, 2016.*

| | Properties | Hazardous atmosphere | Workplace exposure limit |
|---|---|---|---|
| $CO_2$ | Colourless and odourless gas. Heavier than air. | 8 % v/v, danger of asphyxiation. | 5500 ppm |
| $NH_3$ | Colourless and pungent-smelling gas. Lighter than air. | Above 30–40 ppm mucous membranes, respiratory tract and eyes become irritated.<br>Above 1000 ppm breathing difficulties, potentially inducing loss of consciousness. | 20 ppm |
| $CH_4$ | Colourless, odourless gas. Lighter than air. | 4.4–16.5 % | - |
| $H_2S$ | Highly toxic, colourless gas. Heavier than air. Smells of rotten eggs | Above a concentration of 200 ppm the sense of smell becomes deadened and the gas is no longer perceived.<br>Above 700 ppm, inhaling hydrogen sulphide can lead to respiratory arrest. | 5 ppm |

This type of hazard arises mostly from the construction used to store the gas (see hazard explosive atmospheres right below).

d) **Explosive atmospheres** might happen when biogas concentration in the atmosphere is between 6 and 22 % v/v in the presence of an ignition source. In most biogas plants visited, the HDPE membranes used for covering the lagoons are not fixed reliably to the ground (they are just buried about 1 m deep and 1 m wide). Given this construction, firstly, gas tightness cannot be ensured nor controlled and gas leakages can lead to explosive atmospheres. Secondly, in situations of heavy storms there is danger that the membrane might be blown away or after strong rains, that the soil which is used for fixation of the gas storage is washed away, which would cause additional leakages of liquids into the ground. This type of membranes should be fixed to a foundation or other construction.

e) Training and information of the staff: Most of the hazards mentioned above can be solved technically and some others need to be approached organizationally by providing training and information to the staff that works in the biogas plant or in the immediate environment. Currently, the staff is not aware about possible dangers present on the biogas plant.

Organizational measures in this regard include: develop work instructions, safety instruction, briefing on procedures and emergency plans, definition of requirements for lone working.

Specific safety issues observed are described in the individual assessment of each location in the following section. The recommendations of safety within this report are not at all complete but focus only on the main relevant aspects. The reader can find additional information about safety on biogas plant operation in the publication: www.biogas-safety.com

## Assessment of the locations

The field mission took place between 27th of March and 1st of April 2018. The starting point was a visit to CP Company, which provides agricultural products and equipment to farmers. CP came in 1996 to Cambodia and has approximately 2,000 employees. CP has a food processing factory since 2018 and an animal feed factory. CP supplies about 220 farmers in Cambodia, from which 20-30% have biogas plants. The contracts for biogas plants are provided through CP and CP provides HDPE sheet for the biogas plant. As CP has good contacts to many farmers, they were able to provide the team with several contacts for this field mission.

### Location 1: Farm No 1

Date of the visit: Tuesday, 27th of March 2018

#### a) Description

The farm No 1 is a pig fattening farm with about 4,500 heads. There is an installed lagoon biogas plant. This is about one year old. It is constructed into a lagoon of 50 m x 25 m x 5 m size.

*Picture 1: Lagoon biogas plant at farm No1*

Electricity is generated by 2 gensets of 100 $kW_e$ capacity each. The operation of the gensets is alternating, thus only one is in operation at a time. The lagoon biogas plant is not equipped with any measurement devices (no volume flow, no electricity production, no information about the biogas composition ($CH_4$, $CO_2$, $O_2$, $H_2S$, etc.). There is also no gas flare installed.

*Picture 2: Genset to convert the energy in biogas into electricity*

The outlet of digestate from the biogas plant is done manually once a week. This leads to the situation that the operator probably will have no insight of the filling level of the lagoon. The operator did not have knowledge of the energy consumption of the farm.

## b) Estimation of biogas production

The following table offers an overview of the calculations to estimate the biogas production in the location in question and the assumptions in which those calculations are based on. The calculation methods are the same for all locations.

| Calculations | Assumptions |
|---|---|
| Annual amount of feedstock available<br>4,500 x 0,00025 x 300 = **338 tons DM** | a. Each animal produces an average of 0,25 kg of dry matter of manure per day 0,25 kg = 0,00025 tons of DM.<br>b. Manure production during 300 days a year. |
| Annual biogas production<br>338 x 300 = **101,400 m$^3$**<br>101,400 / 8760 = 11,6 m$^3$ per hour | c. 300 m$^3$ of biogas per ton of DM.<br>d. 8760 hours per year. |
| Annual methane production<br>101,400 x 0,66 = **66,924 m$^3$** | e. Methane content of the feedstock of 66%. |
| Annual energy production<br>66,924 x 10 = **669,240 kWh per year**<br>669,240 / 8760 = 76 kW<br>Thus, gas power of **76 kW** | f. Heating value of methane 10 kWh/m$^{3.}$<br>g. 8,760 hours per year. |
| Annual electricity production<br>669,240 x 0,25 x 0,9 = **150,579 kWh$_e$ per year**<br>Or 669,240 x 0,25 / 8760 = 19 kW$_e$<br>Thus, electrical power of **19 kW$_e$** | h. Electrical efficiency of the motor of 25%.<br>i. 90% motor availability.<br>j. 8,760 hours per year. |

Since variation in biogas production is to be expected and even periods of time in which the genset is not operating and the biogas has to be stored, it is recommended to have a bigger engine than seems necessary for the biogas production. Therefore, an installed electrical capacity of 40 kW$_e$ is recommended for this farm (while currently they have 2 biogas gensets of 100 kW$_e$ capacity each).

## c) Recommendations for optimizing the existing biogas plant

As already explained in the general remarks, gas quality measurements are relevant for all biogas plants visited. Through gas quality measurements, the operator has better control of the process and can improve the performance of the plant.

For the case of the biogas plant at the farm No1, there are other technical adaptations which could improve the plant operation. In the following, these measures are explained:

## 1. Digestate outlet control

The amount of digestate flowing out of the biogas plant is regulated manually. The biogas plant operator opens the outflow about once a week by replacing manually the bigger and higher tube by a smaller, lower one, see pictures 3 and 4.

*Picture 3: Bigger, higher outlet tube*

*Picture 4: Small outlet tube with digestate flowing out*

The plant operator has neither knowledge about the amount of manure pumped into the lagoon, nor about how much material is inside the digester nor about the amount flowing out. In that way, he has no control about the hydraulic retention time (HRT) in the digester which influences the rate of digestion and the biogas yield.

A rough estimation of the HRT is given as follows, in order to provide the operator with additional information, which might help in the daily operation. Assuming 5,000 $m^3$ manure are treated at the biogas plant and considering that the stables are only filled with pigs about 300 days per year, the average manure treatment is of 16.6 $m^3$ per day and maximum 35 $m^3/d$ (because of the different amounts of manure produced by piglets and grown pigs). The total volume of the lagoon is about 6,250 $m^3$ (50 m x 25 m x 5 m), but the active volume is much lower (it is not filled to the top, the walls are not vertical, and sand sedimentation at the bottom). Thus, the active volume can be estimated at about 4,000 $m^3$. The hydraulic retention time of this lagoon is probably slightly above 100 day (4000 / 35 = 114.28 days). This is enough to digest manure, but should not be further reduced, because the operator does not know the real filling level of the lagoon.

It is highly recommended to talk with the planner of this biogas plant and define how the amount of material inside the digester can be controlled. The author of this report is under the impression that the bigger, higher tube once had the function of overflow control. Which means that the level of liquid in the digester was dimensioned according to the height of the bigger tube. If this is the case the operator should never replace the bigger tube with the smaller, but always use the bigger one as (automatic) outflow.

### 2. Expectable biogas production compared to the size of the gensets

The staff of the location did not know how much biogas production was planned originally, however, it seems that the actual produced biogas is much less than what it was expected. Considering the calculations above, about 12 $m^3/h$ biogas could be produced with the amount of feedstock available at the farm; this results in about 19 $kW_e$ power and a genset of 40 $kW_e$ would be enough to convert the energy from the gas into electricity. However, installed were two gensets of 100 $kW_e$ each. It is difficult now to judge how the dimensioning of the plant was done and what was promised to the owner but it is recommended to inform the plant operator about the expected biogas production, as estimated in this report.

### 3. Downtime of the gensets

As pointed out before, it is important to prevent that the biogas escapes into the atmosphere. This is done by guaranteeing that the biogas is used in the motor or by installing a gas flare. There are two gensets installed on this farm. **As long as both are functional and at least one is always in operation the investment in a gas flare is not necessary**. But if only one genset is functional a flare is needed to burn the biogas during the stand still times of the genset, which are probably around thousand hours per year.

### d) Recommendations on safety on the biogas plant

The biogas plant cannot be considered as being safe. Some very obvious aspects are explained in the table below, with some recommendations in order to improve the current situation:

| **Potential hazards** | **Recommendations** |
|---|---|
| **Training of the staff about safety** | |
| Staff is not aware about possible dangers present on the biogas plant. | Staff should be well informed about the main risks which could cause accidents. See general remarks. |
| **Fixation of the membrane** | |
| The membrane, the gas holder, is only buried about 1 m deep in the soil and not technically and safely fixed. Further, the staff doesn't have information on the lifetime of the membrane and how the tear strength might change during years of operation. | One option is using ropes fixed into the soil. Also, the staff should be informed about the dangers and which situations might enhance these (e.g. welding in the surrounding of the biogas plant, smoking, etc.) |
| **Installation of the fan located by the genset** | |
| The genset is cooled by a fan, see picture 2. This fan is not installed safely. The electric wire is exposed. | It should be ensured that the fan cannot fall into the genset. |
| **Electrical installations** | |
| The electrical installation is not appropriate, considering the risks present on a biogas plant. There are many cables lying on the ground or inappropriately installed (see picture 5, where a cable for electricity is hold with a very thin stick of a tree, which does not ensure stable connection, especially not during heavy weather conditions). | There should be no cables lying on the ground which could cause employees to stumble over them.<br><br>Electrical installations should be done according to Cambodian regulations. |
| **Danger of falling** | |
| 1. The footbridge on the outlet lagoon is dangerous (see pictures 3 and 4). If someone slips and falls into the lagoon it is not ensured, that this person could get out by himself.<br>2. The place where the person stands, who is manually opening the digestate outflow is slippery and the person might fall into the lagoon (see picture 3 and 4 at the bottom of the tubes). | 1. A handrail would reduce the danger of falling into the lagoon, better would be a safe constructed footbridge.<br><br>2. The best solution would be if no manual digestate outflow handling is needed, e.g. if only the bigger tube is used as overflow-outlet. If this is not possible, at least the point where the person stands should be constructed to ensure a safe standing. |

| Explosive atmospheres | |
|---|---|
| There are several points where explosive atmosphere (presence of methane, oxygen and a source of fire) could occur. One example is the tube in picture 3. At the bottom of this tank, digestate is being stored and at the top is air, in the middle an explosive atmosphere could occur. | Staff should be aware that they are working near by an explosive atmosphere, better would be a technical construction which ensures that nobody has to work close to explosive atmospheres.<br>An organizational measure would be to install signs that warn staff and visitors about the possible danger. |

Apart from this list of specific measures to be considered, all the measures named in the general remarks of this report should be taken into consideration.

*Picture 5: Electricity connection near the gas holder of the lagoon (hold up with a stick)*

## Location 2: Farm No 2

Date of the visit: Wednesday, 28th of March 2018

### a) Description

The farm No 2 has 2,200 pigs for fattening. Additionally, there are10 chickens which have no substantial influence on potential biogas production because the amount of chicken excrements is low. The farmer started operation in 2012. To limit investment costs only open stables are constructed. The farmer is not convinced to invest into a biogas plant. One reason is that he does not have the financial means to invest. The farmer said that his electricity consumption is about 1,000 kWh per month which would result in about 3,300 US$ (assuming 0.2 US$/kWh$_e$). He did not know if he could sell potential electricity surplus to the grid. Five persons work at the farm, one of them with technical skills.

### b) Estimation of biogas potential[2]

Considering the 2,200 pigs in the farm, about 49,500 m³ of biogas per year or 5.7 m³ biogas per hour could be produced. About 326,700 kWh per year or 37 kW gas power, resulting in about 88,209 kWh$_e$/a of energy or 9 kW$_e$ of electrical power.

Considering the variation in the biogas production, an installed electrical capacity of 20 kW$_e$ is recommended for this farm.

### c) General recommendations

The actual need for electricity in the farm is about 10,000 kWh and the cost for electricity is about 3,300 US$ per year. The potential electricity production with biogas is by far higher than the own consumption (by a factor of almost 10) but the electricity surplus could probably not be sold to the grid, at least not at interesting income rates.

A safe and environmentally friendly biogas plant in the recommended size would cost about 160,000 US$ (10,000 US$ per installed kW x 20 kW$_e$ minus 20%). Assuming a weighted average of capital costs (WACC) of 10%, only the annual capital costs would be already 16,000 US$. Additional costs would be operation costs. If the income of the biogas plant is about 3,300 US$ per year it is obvious that such an investment is not economically feasible.

Given these facts, i.e. low energy requirements of the farm, low costs for electricity and a farmer with limited resources to invest, it cannot be recommended to invest into a biogas plant at this location.

[2] For simplification purposes, the detailed calculations for this location are not shown here. These are the same, as for the first location.

Location 3 farm No 3

Date of the visit: Wednesday, 28th of March 2018

## a) Description

The farm No 3 is a pig fattening farm with 2,200 heads in open stables. There is a lagoon biogas system installed. The investment for the biogas plant was an obligation to operate the pig farm. It was not an initiative of the farm owner.

The biogas plant is equipped with 2 modified used gensets, 25 $kW_{el}$ each. The gensets are currently not working. The operator said, the reason for this is, that the gensets have to be started with mechanical support instead with a battery, which is too exhausting for him. The author of this report has the impression that the installed genset is very old (25 $kW_{el}$, bought second hand) and partly corroded. The produced biogas is released into the atmosphere! This biogas plant is producing severe environmental damage and it is very strongly recommended that the biogas is burned using a flare.

The energy consumption on the farm is about 1,000 kWh/m which equals about 2,400 US$ per year.

*Picture 6: Lagoon biogas plant at farm No 3*

## b) Estimation of biogas production[3]

The 2,200 pigs could produce about 49,500 $m^3$ biogas per year, that is 5.7 $m^3$ biogas per hour. The total energy is 326,700 kWh per year or 37 kW gas power, resulting in 88,209 $kWh_e$/a electricity or 9 $kW_e$ electrical power. Therefore, a motor with an installed capacity of 20 $kW_e$ is recommended for this farm.

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[3] For simplification purposes, the detailed calculations for this location are not shown here. These are the same, as for the first location.

### c) Recommendations for optimizing the existing biogas plant

In this case, as well, there is a lack of measurement devices at the biogas plant, which limits the control the operator has on it. This and other technical adaptations could improve the plant operation. In the following, these measures are explained:

**Biogas use**

The existing gensets were not in operation at the time of the visit. Therefore, the biogas produced was being released into the atmosphere, which is very harmful for the environment, given methane's high GHG potential. It is very strongly recommended to burn the biogas in order to convert it into the less harmful gas carbon dioxide or to use it properly in a motor.

The existing gensets are also corroded. It is highly recommended to invest into a reliable biogas conversion equipment, e.g. a new genset and a flare to ensure that the produced biogas is used.

*Picture 7: Genset at farm No 3*

### d) Recommendations on safety on the biogas plant

The biogas plant cannot be considered as being safe. Some very obvious aspects are described in the table below and some recommendations are given:

| Potential hazards | Recommendations |
|---|---|
| **Training of the staff about safety** | |
| Staff is not aware about possible dangers present on the biogas plant. | Staff should be well informed about the main risks which could cause accidents. See general remarks. |
| **Fixation of the membrane** | |
| The membrane, the gas holder, is only buried about 1 m deep in the soil and not technically and safely fixed. Further, the staff doesn't have information on the lifetime of the membrane and how the tear strength might change during years of operation. | One option is using ropes fixed into the soil. Also, the staff should be informed about the dangers and which situations might enhanced these (e.g. welding in the surrounding of the biogas plant, smoking, etc.). |
| **Genset installation** | |
| The connection of the gas system to the genset is not installed in a safe way, see Picture 7.<br><br>The genset is constructed in a way that the shaft of the engine is not covered. Persons can be seriously hurt if e.g. fingers get in touch with the rotating shaft. | It should be ensured that the genset is connected appropriately and in accordance with electrical regulations in Cambodia.<br><br>The shaft, like all hot or fast rotating parts, should have a protection to avoid direct contact. |
| **Electrical installations** | |
| The electrical installation is not appropriate, many cables are lying on the ground. | There should be no cables lying on the ground which could cause employees to stumble over them. Electrical installations should be done according to Cambodian regulations. |
| **Explosive atmospheres** | |
| There are several points where explosive atmosphere (mixture of methane and oxygen) could occur. One example is the connection of the gas system to the genset and the condensate trap. In the condensate trap biogas can be released and mixed with air which leads to an explosive atmosphere, see picture 8. | Staff should be aware that they are working near by an explosive atmosphere, better would be a technical construction which ensures that nobody has to work close to explosive atmospheres.<br><br>An organizational measure would be to install signs that warn staff and visitors about the possible danger. |
| | |

*Picture 8: Condensate trap at the farm No 3*

## Location 4: farm No 4

Date of the visit: Thursday, 29th of March 2018

### a) Description

The farm No 4 is a pig fattening farm with 5,000 heads in 8 open stables.

There are already 2 lagoon biogas systems installed. One is in operation, a second one is in the start-up phase. A third lagoon (with fishes) is installed to store the outflowing digestate. The biogas is used in 3 gensets. One with 400 $kW_e$ capacity (operating 8 hours per day), one with 300 $kW_e$ capacity (operating 4 hours per day) and a small genset which was not in operation at the time of the visit.

The staff on the farm do not know the energy consumption of the farm. The tariff for electricity from the grid is 770 KHR per $kWh_e$.

There is a chicken farm nearby (about 64,000 heads) which could in principle allow more input into the biogas plant and higher biogas yields.

*Picture 9: Lagoon biogas plant at farm No 4*

## b) Estimation of biogas production[4]

From the manure of 5,000 pig heads about 112,500 m³ of biogas per year can be produced or 12,8 m³ biogas per hour. This equals 742,450 kWh per year or 84 kW gas power. The resulting electricity production is about 185,612,475 $kWh_e/a$ of energy or 21 $kW_e$ power. Therefore, a total capacity of 40 $kW_e$ is recommended for this farm.

## c) Recommendations for optimizing the existing biogas plant

In this case, as well, there is a lack of measurement devices at the biogas plant, which limits the control the operator has on it. This and other technical adaptations could improve the plant operation. In the following, these measures are explained:

**Biogas use**

The existing gensets with 400 $kW_e$ and 300 $kW_e$ installed capacity are much bigger than the biogas production that can be expected. A genset of 40 $kW_e$ installed capacity would be enough to use the produced biogas. The staff on the farm reported that originally more gas was expected but they had problems with gas production.

According to the biogas potential calculation above the problem is not lower biogas production but probably higher (maybe too high) expectations regarding the biogas yield. In this case it is obvious that the real potential does not match the plant design.

Theoretically, the biogas production could be increased by using the excrements of the chicken farm nearby the biogas plant (resulting in higher biogas yields). However, more information about the kind of chickens being hold there (egg hens, meat production or both) is necessary. Additionally, there is at the moment no information about the use of the chicken manure at the time. Furthermore, the persons at the biogas plant did not have insights into the amount of electricity needed on the farm. We only can speculate that the electricity that can be generated with the biogas plant now is already more than the electricity consumption on the farm. From this perspective, adding more feedstock to obtain more biogas seems to be not recommendable.

## d) Recommendations on safety on the biogas plant

The biogas plant cannot be considered as being safe. Some very obvious aspects are described in the table below and some recommendations are given:

| Potential hazards | Recommendations |
|---|---|
| **Training of the staff about safety** | |
| Staff is not aware about possible dangers present on the biogas plant.<br><br>There are several canisters lying nearby the biogas plant, see Picture 10. These are branded with | This point seems to be less important than some other dangers in this report but it shows that the persons working on the biogas plant don't have awareness about safety aspects. It is very easy |

[4] For simplification purposes, the detailed calculations for this location are not shown here. These are the same, as for the first location.

| | |
|---|---|
| danger signs (caustic and inflammable). Although the contents of these containers are unknown, dangerous substances of this nature should never lie around a biogas plant but must always be stored and disposed safely. | to avoid dangerous situations by informing the staff about the main risks which could cause accidents, as well as providing working instructions. See general remarks. |
| **Fixation of the membrane** | |
| The membrane, the gas holder, is only buried about 1 m deep in the soil and not technically and safely fixed. Further, the staff doesn't have information on the lifetime of the membrane and how the tear strength might change during years of operation. | One option is using ropes fixed into the soil. Also, the staff should be informed about the dangers and which situations might enhanced these (e.g. welding in the surrounding of the biogas plant, smoking, etc.). |
| **Danger of stumbling** | |
| On the right-hand side of Picture 10, there is a gas tube held by a stone. In some places, the tube is not fixed to the ground but hangs in the air.<br><br>Additionally, there is no protection against unintended bump or collision. | All gas holding tubes must be fixed safely to avoid damage to the tube. Possible sources of collision or damages should be avoided.<br><br>This situation shows how appropriate planning and construction help prevent many dangerous situations, while avoiding later investment in solving such issues. |
| **Genset connection** | |
| The connection of the gas system to the genset seems inappropriate. | The appropriate connection of the genset should be ensured, according to the national regulations. |
| **Mechanical installations** | |
| Picture 12 shows a component which probably has the function to cool the engines. The foundation of the construction is not safe and the connection tubes are not fixed but hover in the air, as seen in Picture 10. | All components that are not meant to move during operation should be technically fixed to avoid uncontrolled movement or damages.<br><br>The author does not have insights into Cambodian regulation on hygiene and sanitization of this production but has the impression that the operator of this cooling equipment is not prepared to ensure that the water is not contaminated (like salmonella). |
| **Explosive atmospheres** | |
| There are several points where explosive atmosphere (presence of methane, oxygen and a source of fire) could occur. One example is the condensate trap in Picture 13, where plants are growing, which at some point might prevent the intended function of the trap by clogging the gas pipe. | The growing of plants in the condensate trap should be avoided by regular revisions, as part of the maintenance routine on the biogas plant.<br><br>An organizational measure would be to install signs that warn staff and visitors about the possible danger. |
| **Dangerous states: start of operation** | |
| The start of operation is a very sensitive state of operation. Picture 11 shows how the gas-holding plastic membrane is floating on the liquid surface of the lagoon. This is a typical situation by start of | |

operation of a lagoon biogas plant. The issue from a safety point of view is that the filling of the gas storage cannot be controlled. For example, after rain, water will accumulate in some zones of the membrane, pushing the membrane downwards and in other zones gas will accumulate. Biogas will be produced but might not be readily available for utilization if the zones where gas is stored are not connected with the gas outlet. Furthermore, due to displace of water by produced gas high changes of gas pressure might occur and it is not ensured that all connection devices can operate reliable under those conditions.

*Picture 10: Canisters lying in front of the lagoon*

*Picture 11: Start of operation of a new lagoon biogas plant*

*Picture 12: Cooling system at the farm No 4*

*Picture 13: Condensate trap at the farm No 4*

## Location 5: farm No 5

Date of the visit: Thursday, 29th of March 2018

### a) Description

The farm No 5 is a pig fattening farm with 1,200 heads. The pigs are grown in open stables. A lagoon biogas plant is in construction on that location. The size of the lagoon is 40 m x 20 m x 2.5 m.

*Picture 14: New created lagoon in the foreground, in the background a stable*

The farmer presented one electricity bill for one month which showed 7,191 kWh consumption and 790 KHR per kWh. Multiplied by 12 months this would lead to annual electricity costs of about 17,000 US$. This value is very high compared to other farms; however, this calculation is only based on one electricity bill and it does not show the seasonal variations throughout a year.

In order to understand the real benefits of the biogas plant, the farmer should first understand his annual electricity consumption, since the revenues from the biogas plant are based on savings in the electricity consumption and they influence the choice of equipment.

### b) Estimation of biogas potential[5]

The 1,200 pigs in the farm produce about 27,000 m³ of biogas per year (3 m³ per hour). This amounts to about 178,200 kWh per year or 20 kW gas power and therefore, around 53,460 $kWh_e$/a of electrical energy or 5 $kW_e$ of electrical power. Due to the variations in biogas production and stand still times of the motor, the recommended engine size for this farm is 10 $kW_e$.

### c) Recommendations for technical adaptation

There was no biogas plant constructed when the location was visited, therefore there are no specific technical recommendations for it. Most probable the biogas plant will be constructed in a similar way as the other examples in this report thus most of the technical recommendations, on gas quality and process control, will be relevant for this biogas plant as well.

### d) Recommendations on safety previous the construction of a biogas plant

Although there is at the moment no biogas plant at this location, there is one relevant recommendation in case a biogas plant should be installed. At the moment the soil in which the plastic membrane of the gas holding system will be fixed is not smooth. There are stones and most probable sharp edges that might damage the plastic membrane. It is recommended to sieve the soil to avoid damages to the HDPE-membrane.

*Picture 15: Soil at the location, where the biogas plant would be situated*

[5] For simplification purposes, the detailed calculations for this location and the following locations are not shown here. These are the same, as for the first location.

## Location 6: Tapioca processing factory, Farm No 6

Date of the visit: Thursday, 29th of March 2018

### a) Description

The tapioca processing factory, Farm No 6, was established in 2005. The product of the process is tapioca starch. It was planned to process 105 tons per day and operate 8 months per year. At the time of the visit, the factory was not in operation due to low market prices for tapioca flour. The price for the product dropped in 2012. In that year, a biogas plant was installed. It is a lagoon plant with 10,000 $m^2$ surface. The biogas plant was conceived as a CDM project, i.e. cofinanced by carbon credits. The original tapioca factory had a huge lagoon in which waste water from the process was stored.

The produced biogas was supposed to be used in a genset with an installed electric capacity of 1 $MW_e$ from GE Jenbacher, however, according to the employee, no electricity has been produced. Instead the biogas was used in a boiler to dry the product.

The person on the location said that energy costs are about 10,000 US$ per month or 80,000 US$ per year, if the factory is in operation. The main costs are LPG for drying the product.

### b) Estimation of biogas production

The starting point for the estimation of the biogas production is the CDM documentation for this project. There, it was stated that if the factory would process tapioca as designed, about 624,000 t/a process water would be produced. The calculated thermal energy in the expected biogas is 2.093 MW.

According to own calculations, 2.093 MW gas power corresponds to 450 $m^3/h$ of biogas production, assuming a methane content of 55%. Regarding the size and quality of the genset, an electrical efficiency of 38% can be expected which results in an average of 795 $kW_e$ electricity production only when all the biogas is used in the genset. If the biogas is used in a boiler the annual energy is about 18 GWh. Assuming a retail price of 0.045 US$ per kWh in Cambodia the produced energy in the biogas has a value of about 825,000 US$ per year what is much more compared to the real costs for energy of 80,000 US$ per year described above.

It is uncertain which amount of biogas was used in the genset to produce electricity and which share was used in the boiler but the calculation above shows that the designed biogas calculation would have been sufficient to generate all electricity needed for the factory and also all heat needed for drying the produced tapioca starch.

*Picture 16: Lagoon biogas plant at the tapioca factory, not in operation anymore*

### c) Recommendations for the existing biogas plant

Neither the tapioca factory nor the biogas plant is in operation anymore thus it is not necessary to develop technical recommendations for biogas production. Indeed, the original design of the biogas plant was made on professional basis and no obvious malfunctions are shown. If the biogas plant will not be used anymore, an appropriate dismantling of the construction is necessary.

### d) Recommendations on safety on the biogas plant

Although the biogas plant is no longer in operation, some general comments on safety can be mentioned in case the operation will be resumed sometime in the future:

| Potential hazards | Recommendations |
|---|---|
| **Fixation of the membrane** | |
| Picture 16 shows that the HDPE membrane sunk to the level of the liquid in the la-goon. The issue with this situation is that the filling of the gas storage cannot be controlled. For example, after rain, the zones of the membrane filled with water will push the membrane downwards while some other zones are full with gas. The result will be that some gas will be already generated but it | The water over the membrane should be extracted, before the biogas accumulated can be used. |

| | |
|---|---|
| might not be possible to use it (e.g. if the stored gas is not connected with the gas outlet).<br><br>Furthermore, due to the displacement of water, changes in gas pressure might occur and it is not ensured that all connection devises can operate reliable under those conditions. | |
| **Installations** | |
| In Picture 17 it can be seen that the gas pipeline is not technically fixed to the ground. | It is not clear how the growing plants shall be taken care of, since there is at least no visible gas pipe protection against machinery mowing the growing plants.<br><br>Before resuming operation, it must be ensured that no trees are close to the flare (see Picture 18). |
| **Signalization** | |
| The area where the biogas plant is located should be protected against trespassing from unauthorized persons. | |

*Picture 17: Gas pipeline installation at the lagoon biogas plant (tapioca factory, farm No 6)*

*Picture 18: Gas flare at the lagoon biogas plant (tapioca factory, farm No 6)*

## Location 7: Rubber production factory, Farm No 7

Date of the visit: Friday, 30th of March 2018

### a) Description

The rubber factory, No 7, was established in 2010. The rubber is partly produced in the rubber plantation near the factory and transported to it in liquid form. More rubber is imported. Up to 80 tons of rubber are processed per day with 20 working days per month. The incoming rubber is processed in several steps (screening, washing, chilling, pressing and drying). During the process, waste water with organic content is accruing. The wash water flows (driven by gravity) into an open lagoon. In principle, this lagoon could be covered to generate biogas.

Electricity for water pumps, mixing machines, cleaning and cutting machines and press is taken from the grid. Cost of electricity is assumed to be 12,000 US$ per year. The main energy demand is thermal energy: 700 $m^3$ wood per year for drying. The smoke from the wood is needed for the final rubber process. There is some diesel for genset in case of black-out, which is not happening often. Several employees have technical know-how.

Picture 19: Produced smoked rubber

*Picture 20: Channel in which the waste water is flowing from the factory into the lagoon*

### b) Estimation of biogas potential

To estimate the biogas potential, it is imperative to know the amount of organic material that is flowing into the lagoon and the biogas yield of that material. Both figures are currently unknown for this location.

A very rough theoretical analysis can be done using figures from the literature, however, this approach has its limitations and the conclusions reached based on it are to be considered cautiously. For example, is not possible to say if the process at RUBBER FACTORY is similar to those referred to in the literature. The main source for this estimation is the publication „Treatment of wastewater from the rubber industry in Malaysia", from Mitra Mohammadi (et. al). It is available online here.

The steps for the calculation are shown as follows:

1. *Annual rubber production:*

   80 t/d rubber * 5 d/w * 50 w/a = 20,000 t rubber per year

2. *Amount of annual waste water:*

   20 t waste water/t rubber production = 400,000 t waste water produced per year.
   The density is about 1 which results in about 400,000 $m^3$ waste water per year

3. *Chemical oxygen demand of the waste water:*

   3500 – 14,000 mg/l
   for this estimation 10,000 mg/l equals 10 kg/$m^3$

4. *Annual COD* = 400,000 $m^3$ * 0.01 t/$m^3$ = 4,000 t/a COD
5. *Biogas yield per COD:* 1 t COD = 0.25 t methane
6. *Annual biogas yield:*

   4,000 t/a COD * 0.25 t methane per t COD = 1,000 t/a = 1,524,000 $m^3$/a methane;
   equals 174 $m^3$/h methane

7. Chemical energy in the biogas: 15 million kWh

According to the estimation above, the biogas potential might be in a range of 15 million $m^3$/a methane, +/- factor 10. This estimation shows that there might be a substantial biogas potential in the waste water.

The calculation showed above is based on very vague estimations, which should <u>under no circumstance be considered as final</u>. It is of upmost importance that the real data (amount and biogas yield) is analyzed and the calculations are repeated using this data.

### c) Recommendations

For this location, the recommendations are focused on the steps to determine the real biogas potential and considerations regarding the biogas technology:

- A representative analysis of the waste water is required to develop a reliable estimation that can be used for further decisions. It is recommended to take at least 3 representative samples[6], bring them fast to a laboratory (or freeze the sample for transport) and do gas yield tests. If there is no possibility to conduct gas yield tests, measuring COD and BOD values can be enough for a prefeasibility estimation.
- Once the biogas yield is measured a prefeasibility study is recommended to analyze the potential, the technical options and financial aspects.
- The technical assessment should consider that the biogas plant could either be economically designed, by simply covering the lagoon, or more sophisticated, thus safer from an environmental point of view, by installing a HDPE layer on the ground to protect the soil from filtrations or by installing a gas flare. An even safer and better controllable biogas plant would be a complete stirred reactor tank or a high-rate reactor like an USAB reactor. A high-rate reactor will be better adapted on the waste water which contains only little DM but might be more expensive compared to a CSTR.
- The feasibility study depends on many factors that should be defined before the financial analysis can be done, like the technical standard of the biogas plant and sources of income:
    - Saving costs for electricity, in the case of this location about 12,000 US$ per year. This figure should be verified before a feasibility study is done.
    - Saving costs for wood. The owner says that the wood is needed to smoke the rubber. But in principle there are two rubber qualities that can be sold, smoked and not-smoked rubber. The owner did not have exact figures for wood that is needed for the drying but a rough estimation shows that it will be in the range of 60,000 US$ per year[7]
    - Digestate production. At this time the storage of process water is done in an unsealed lagoon causing uncontrolled emissions of nutrients, e.g. nitrogen, into the soil and groundwater. After a typical biogas process the effluent of a biogas plant is used as fertilizer in the fields around the plant. The value of the digestate could be estimated. Basis of that calculation would be a chemical analysis of the organic material in the waste water.

The most important argument against a biogas plant was mentioned by the owner: As long as they want to produce smoked rubber, they need the smoke from the wood and the energy in the biogas cannot be converted into revenues. If at some point the market changes and

[6] The number of samples depends on the effort to do and the reliability that shall be achieved. The first sample could give an estimation in which height the biogas yield might be. The more samples are taken at different times in the year the more representative the results will be.

[7] Based on 700 m³ wood per year. Each m³ contains about 2 MWh energy which results in 1.4 million kWh energy needed for drying. Retail price for heat (e.g. from cole or LPG) are estimates as 0.045 US$ per kWh.

smoked rubber can no longer be sold at better prices than non-smoked rubber, substitution of wood by biogas might be interesting.

It is also worth mentioning, that currently the process water flows into a lagoon. This water is charged with organic material and represents some risks for the environment:

- Emissions to the soil and groundwater because the lagoon is not sealed,
- Emissions to the atmosphere from the open-air storage of organic material,

Also, the lagoon is an uncontrolled waste dump site (see Picture 21). This situation should be corrected to avoid further damage to the environment.

*Picture 21: Lagoon to store the waste water*

## Location 8: Rubber production factory, Farm No 8

Date of the visit: Friday, 30th of March 2018

### a) Description

In the rubber factory, farm No 8, about 20 to 40 tons per day of “solid” rubber and about 20 tons per day of “liquid” rubber during the low season are produced. Total production is about 10,000 t/a. Process steps are similar as described for the previous factory (screening, washing, chilling, pressing and drying) but two different product qualities are produced. During the process, waste water with organic content is accrued. All processed input material is transported (up to 100 km distance).

The wash water flows (driven by gravity) into an open lagoon of 35 m x 50 m x 4 m size. As well as in the previous case, this lagoon could be covered to generate biogas.

Cost of electricity is about 25,000 US$ per year (128,289 kWh in one year) taken from the grid. Additionally, 150,000 kg of LPG per year are consumed for product drying which results in about 102,000 US$ costs for thermal energy per year.

During the high season, up to 100 workers are on the factory, in low season about 50 workers. Some of them have technical know-how.

*Picture 22: Lagoon in which the waste water (among others) is stored*

### b) Estimation of biogas potential

As explained for the other rubber production factory, only rough estimations can be done for this location as well. Therefore, and until the real data about the location is not known, <u>these estimations should not be considered as final</u>.

1. *Annual rubber production:*

   10,000 t rubber per year
2. *Amount of annual waste water:*

   20 t waste water / t rubber production = 200,000 t waste water produced per year.
   The density is about 1 which results in about 200,000 m³ waste water per year
3. *Chemical oxygen demand of the waste water:*

   3500 – 14,000 mg/l,
   for this estimation we use 10,000 mg/l which equals 10 kg/m³
4. *Annual COD* = 200,000 m³ * 0.01 t/m³ = 2,000 t/a COD
5. *Biogas yield per COD*: 1 t COD = 0.25 t methane
6. *Annual biogas yield:*

2,000 t/a COD * 0.25 t methane per t COD => 500 t/a = 762,000 $m^3$/a methane; equals 87 $m^3$/h methane

7. *Chemical energy in the biogas:* 7.5 million kWh

According to the rough estimation above, the biogas potential might be in a range of 7.5 million $m^3$/a methane, +/- factor 10. This estimation shows that there could be a substantial biogas potential in the waste water.

### c) Recommendations

For this location, the recommendations regarding an analysis of the waste water to calculate the biogas potential are also relevant.

Additionally, an energy balance calculation is recommended, in order to calculate the relationship between biogas potential and energy consumption. Although the owner had no accurate information, one can assume electricity costs of 0.2 US$/kWh, thus 25,000 US$/a for electricity correspond to 125,000 kWh/a. Assuming a price for LPG of 0.045 US$/kWh, 100,000 US$ for LPG correspond to 2.2 million kWh/a.

Comparing these results with the estimation of biogas potential of 7.5 million kWh, the biogas might cover the whole energy demand of that factory. It is necessary to get reliable data not only about the biogas potential but also about the energy consumption on-site.

## Location 9: Farm No 9

Date of the visit: Friday, 30th of March 2018

### a) Description

The farm No 9 is a pig fattening farm with 2,000 heads in 4 open stables. The farmer faced problems with diseases and pigs dying this year. The farm has a very low electricity consumption of about 1,200 US$/a (750 KHR per $kWh_{el}$).

The farm has 4 workers, none of which has technical qualifications. The farmer indicated that he has not much money and will probably not be able to invest in a biogas plant.

*Picture 23: Fattening pigs in the farm No 9*

### b) Estimation of the biogas potential[8]

The 2,000 pigs at this farm could produce about 45,000 m³ biogas per year (5 m³ of biogas per hour). This is equivalent to 297,000 kWh per year or 34 kW of gas power, which results in about 74,250 $kWh_e$/a energy or 8.4 $kW_e$ power. An engine of about 17 $kW_e$ is recommended for this farm.

A safe and environmentally friendly biogas plant of that size would cost about 140,000 US$ (10.000 US$ per installed kW x 17 $kW_e$ minus 20%). Assuming a weighted average of capital costs (WACC) of 10%, only the annual capital costs would already be 14,000 US$.

[8] For simplification purposes, the detailed calculations for this location and the following locations are not shown here. These are the same, as for the first location.

Additional costs would be operation costs. If the income of the biogas plant is about 1,200 US$ per year it is obvious that such an investment is not economically feasible.

### c) Recommendations

The actual costs for electricity are about 1,200 US$ per year. The potential electricity production with biogas is by far higher than the own consumption (about factor 10) but the electricity surplus can probably not be sold to the grid, at least not at interesting income rates.

Given these facts, i.e. low energy requirements of the farm, low costs for electricity and a farmer with limited resources to invest, it cannot be recommended to invest into a biogas plant at this location.

## Location 10: Farm No 10

Date of the visit: Friday, 30th of March 2018

### a) Description

The farm No 10 is a pig fattening farm with 2,000 heads in four open stables. The first stable was constructed 9 years ago, the second 8 years ago, followed by a third stable 7 years ago. The fourth stable was established 2 years ago. The farmer is interested in expanding. The electricity consumption is very low, about 2,600 US$/a. Lamps and personal electrical consumption is met through rechargeable batteries. Costs for battery recharge are about 500 US$/a. The farm is not connected to the electrical grid.

### b) Estimation of biogas potential[9]

The 2,000 pigs will produce about 45,000 m³ of biogas per year (5 m³ of biogas per hour). The annual energy production is about 297,000 kWh per year (33 kW of gas power), resulting in 74250 $kWh_e$/a of energy or 8.5 $kW_e$ power. An engine of 17 $kW_e$ installed capacity is recommended for this farm.

A safe and environmentally friendly biogas plant of that size would cost about 140,000 US$ (10.000 US$ per installed kW x 17 $kW_e$ minus 20%). Assuming a weighted average of capital costs (WACC) of 10%, only the annual capital costs would already be 14,000 US$. Additional costs would be operation costs. If the income of the biogas plant is about 3,100 US$ per year it is obvious that such an investment is not economically feasible.

Currently, the biogas potential and electricity consumption are very low, thus investing into a biogas plant will probably not be profitable. If the farm continues growing, a biogas plant might be interesting in the future.

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[9] For simplification purposes, the detailed calculations for this location and the following locations are not shown here. These are the same, as for the first location.

### c) Recommendations

The actual costs for electricity are about 2,600 US$ plus 500 US$ for recharging the battery per year. The potential electricity production with biogas is by far higher than the own consumption (about factor 10) but the electricity surplus cannot be sold to the grid, because the farm is not connected to the electricity grid.

Given these facts, i.e. low energy requirements of the farm, low costs for electricity and a farmer with limited resources to invest, it cannot be recommended to invest into a biogas plant at this location.

## Location 11: Farm No 11

Date of the visit: Saturday, 31st of March 2018 in Battambang

### a) Description

Farm No 11 was established by an NGO. The support from the NGO is essential for the project. In 2009, a compost production site was established using biomass from the Battambang markets. The treatment capacity is about 8 tons of biomass per day, 6 days per week. The estimated annual process is about 2,400 t/a. The produced compost is sold as fertilizer for 6.25 US$ per bag (40 kg per bag). The amount of compost produced per year or the number of bags sold per year is unknown.

*Picture 24: Compost production at Farm No 11*

The energy consumption on-site is quite low. Electricity costs are about 500 US$/a. Diesel consumption for machinery is around 100 liters per month, about 900 US$/a. Some gas is used for cooking, meals are prepared for the staff and about 10 – 20 children (that live on the dump site nearby).

### b) Biogas potential

Currently, the organic material is converted into compost and this is sold. In principle the same organic material could be converted into biogas but it is not the aim of this project to develop competition for the biomass streams within Farm No 11. Nevertheless, the calculations are shown here anyway, for interested reader:

Assuming a biogas yield from the waste of 120 $m^3$ biogas per ton of waste and 55% methane content the annual biogas production is 288,000 $m^3$ (158,400 $m^3$ of methane). The annual energy production can be estimated as 1.58 million kWh, that is 500,000 $kWh_e$. The average power would be 60 $kW_e$ and the required installed capacity of the engine would be 100 $kW_e$.

Some time ago there was a small domestic digester on that location but it is no longer in operation. The staff of Farm No 11 had no further information about the digester. Thus, no further assessment can be made concerning this domestic biogas plant. Even though no information on the biogas plant was given, it is obvious that technical work would be needed before it could start operation again, see Picture 25 and Picture 26 below.

*Picture 25: Small domestic biogas plant at Farm 11*

*Picture 26: Tube of the domestic biogas plant (not connected)*

### c) Lessons learned from this visit

The Farm No 11 project is only possible with the financial support of the NGO. The main challenge is to collect the waste, especially if there are problems with the trucks. Project shows that in principle it is possible to collect biomass (for compost or for anaerobic digestion) on markets. But establishing a collecting system is not commercially viable without support, in this case that of the NGO.

## Location 12: The Farm No 12

Date of the visit: Sunday, 1st of April 2018

### a) Description

The Farm No 12 is located close to the Farm No 11, compost production site. The waste input is about 135 tons per day and 50,000 tons per year. The current waste composition is unknown, although there is a study from 2004 in which the composition was investigated.

### b) Estimation of the biogas potential

This location was not visited and there is no information about the operating conditions of it. To establish a reliable calculation several parameters should be known, like annual amount of waste, composition of waste, degree of compaction, if the dump site is covered, characterization of the material used, climate conditions. Thus, no reliable calculation of the landfill gas potential can be developed.

However, the author was asked to do a very rough estimation even if it is obvious that no reliable figures can be created. A very rough estimation of landfill gas potential might be 480 $m^3/h$ landfill gas which equals about 860 $kW_e$. These figures are very vague, based on a landfill calculation model from Thailand and calculated with vague assumptions about the conditions of the dump site.

To install a gas collecting system would be expensive, since the gas production is low compared to the cost of collecting the waste (waste is not compacted, not covered, gas collection rate will be limited, high gas leakages). Investing in a collecting system and biogas utilization will not be commercially feasible.

If the dump site would have to get a gas collecting system for environmental reasons, and the landfill gas is available at no costs at the end of the tube, investing in a genset or CHP might be financially viable if there is an agreement with the electricity provider to sell the electricity to the grid.

### c) Recommendations

Given the current conditions in which the dump site is operating, uncontrolled amounts of methane are being released to the atmosphere. For environmental reasons it is highly recommendable to install a gas collecting system. Installing gas collecting and gas usage systems is normally not a commercially feasible investment. The costs for gas collection must be covered from other parties, like municipality, government or other organizations. If a gas collection system would be installed it should be assessed how the gas can be used best, e.g. in a gas engine or upgrading the gas to biomethane quality and use as compressed biomethane in vehicles or households.

# Additional remarks

## Environmental aspects of biogas plants

Biogas can have several positive effects for the environment like production of renewable energy thus avoiding the use of fossil fuels, production of organic fertilizer thus recycling nutrients and avoiding the use of mineral fertilizers, but also odour reduction and avoidance of GHG emissions occurring through the open storage of organic waste. However, if done wrong, biogas utilization can also have severe negative effects.

The avoidance of greenhouse gas emissions through open storage of organic waste is a very important argument for the use of biogas worldwide, since the decomposition of organic material generates methane, a gas with a very high climate change potential (25 times higher than carbon dioxide). For biogas to have this positive effect, it is necessary that methane emissions into the atmosphere are as low as possible. This was not the case in the biogas plants visited in Cambodia during this field mission.

Usually, it is standard for biogas plants to have a gas combustion unit, e.g. a gas flare to burn the biogas that is produced and cannot be stored during for example CHP or motor downtimes. Alternatively, two gas engines can be installed, each at a size that all produced biogas can be burned and one engine is always available if the other stands still (e.g. for maintenance); in this way it can be assured that no methane is released unburned so no additional flare is necessary.

None of the biogas plants visited in Cambodia had a gas flare or can ensure that all produced biogas is always burned, which means, biogas is just emitted into the atmosphere and probably generating more environmental damage than avoiding greenhouse gas emissions.

Another situation that was observed in the biogas plants visited was the absence of a HDPE membrane at the bottom of the lagoons, which would prevent leakages of liquid material into the ground, thus emissions to the groundwater. These lagoons are a common agricultural practice in Cambodia, however, this practise has very negative environmental effects - this should be considered in future biogas plants designs.

Most of the time, these situations occur as the result of disinformation. FvB recommends UNIDO and BTIC to create awareness among the owners of these biogas plants, so they can understand the importance of avoiding emissions into the atmosphere, soil and water sources from the biogas plant.

## Investment costs for safe and environmentally friendly biogas plants

As described above and in more detail below, the typical biogas plants on pig fattening farms in Cambodia are not constructed in a way that allows safe operation. The main reason for this is the financial aspects associated to a biogas plant investment. In Cambodia there is no incentive system in place to promote biogas, the conditions to sell surplus of electricity to the grid are challenging, and therefore the possible revenues for biogas production are very limited. Often the energy in biogas can only be used to reduce the own costs for electricity from the grid. In consequence the revenues of biogas production are very low and because pig fattening farmers usually don't have much money available, nearly all biogas plants in Cambodia are constructed in a very simple and economical way. Obviously, safety aspects do not play any role in biogas plant construction.

UNIDO aims to support biogas technology dissemination in Cambodia, but the supported biogas plants must be safe and should not harm humans or the environment. Each accident in a biogas plant affects the acceptance of the technology among interested stakeholders (plant operators, politicians, the general public).

There are many other countries in the world were accidents on biogas plants slowed down or hindered the development of the sector. In Thailand many low-tech lagoon biogas plants were once constructed, followed by serious accidents with many hurt and dead people. Many biogas stakeholders, one of them the Thai Biogas Trade Association, supported activities to improve safety of biogas plants. In consequence newly, constructed biogas plants are constructed considering higher technical standards, from lagoon biogas plants towards better controllable and safer completely stirred tank reactors, close to European safety standards.

Some safety aspects on biogas plants can be achieved at relatively low costs, e.g. organizational measures like training the staff but many technical measures are connected with higher investment costs. If European safety standards were not to be implemented, biogas plant investment could be just a bit lower, but each saving made, would have negative consequences not only on the technical performance but also on the environmental performance of the plant. It is imperative, that biogas plants are controllable, have low GHG-emissions and operate safely.

Typical investment costs according to European quality standards are shown in the table below.

| Installed electrical capacity | Range of specific costs (US$/$kW_{el}$) | Average specific costs (US$/$kW_{el}$) | Total investment costs (US$) |
|---|---|---|---|
| 75 $kW_{el}$ | 6,500 – 14,000 | 9,400 | 700,000 |
| 150 $kW_{el}$ | 6,000 – 9,000 | 7,600 | 1,140,000 |
| 250 $kW_{el}$ | | 7,000 | 1,750,000 |
| 500 $kW_{el}$ | | 5,400 | 2,700,000 |
| 750 $kW_{el}$ | | 4,700 | 3,525,000 |
| 1000 per $kW_{el}$ | 3,500 – 5,500 | 4,200 | 4,200,000 |

Given the costs in the table above, 100 $kW_e$ biogas plant will cost at least 800,000 US$. This cost includes planning, construction, all components including gas engine, control equipment, gas measurement and all needed safety equipment.

In the report “Feasibility Studies – Final Report”, Bart Fredriks documented several calculations for biogas plants in Cambodia. Initially, lagoons with inner liner (membrane at the bottom) were considered, but the costs were almost twice as high, thus the projects reported lower returns and the investments would be unlikely. Under this premise, it was decided to consider the simpler system.

One example shall clarify the difference in calculating biogas plants based on current Cambodian practice and European technical standards. For the location Farm No 13 with 4,800 pigs, Fredriks estimated the investment costs for a lagoon biogas plant with a genset of 100 $kW_e$ as 101,184 US$. In comparison, the investment in a 100 $kW_e$ biogas plant under European technical standards would cost about 800,000 US$, maybe 720,000 US$ in Cambodia.

According to the feasibility studies of Fredriks, considering very low investment costs in Cambodian practice, some but not all of the investigated biogas plants could expect a profitable biogas plant operation and a short return of investment. Under the condition to invest in safe and environmentally friendly biogas plants, none of the biogas plants of the locations visited would offer economical attractive biogas plant operation. The main reasons are:

1. the very low income of only reducing the already low electricity bill,
2. not acceptable conditions for electricity feed into the public grid and
3. no financial support from the government of Cambodia.