Report: final recommendations

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

Introduction

The contract “Provision of services: Analysis of alternative uses for biogas in Cambodia” between UNIDO (United Nations Industrial Development Organization) and Fachverband Biogas e.V. (FvB, German Biogas Association) comprises 6 work-packages with their corresponding deliverables, as seen below.

Work-package	Name of the report	Author
Review of alternative uses of biogas and evaluation of suitability for Cambodia	Analysis of alternative uses of biogas in Cambodia and business models	Grope, Scholwin et. al
Analysis of potential business models and evaluation of suitability for Cambodia		
Field mission in Cambodia	Initial assessment report	Hofmann and Bontempo
Development of feasibility studies in three different locations	Biogas bottling (mobile biogas bottling facility and traditional biogas bottling)	Hofmann
	Biogas backpacks	Fischer
	Analysis of using biogas from tapioca starch effluent for various options	Hofmann
Recommendations for next steps	Final recommendations	Hofmann, Grope et. al
Trainings for BTIC	Training report	Hofmann

This report, final recommendations, condensates the recommendations given by FvB through all those reports.

Report: Analysis of alternative uses for biogas in Cambodia and business models

The objective of this report is to analyse alternative uses of biogas, such as upgrading to biomethane and other distribution ways for biogas as a gaseous fuel.

The evaluation of alternative uses for biogas in Cambodia have shown the following facts:

- As for many technologies, production cost decreases with larger production capacities, which is especially the case for **biogas upgrading to biomethane**. In Cambodia biogas upgrading will be seldom done in practice, since there seem to be only few locations with enough feedstock that allow biogas production on a large scale (above 100 m^3/h biogas) and the high specific cost of biogas upgrading, especially for small biogas production capacities.
- The transport of biogas by **biogas back-packs** can be a very flexible and low-cost solution, but is strongly limited to the number of consumers and the transport distance. Therefore, for industrial scale biogas plants it can only be an additional option of transporting and using the biogas. In addition, there seem to be some cultural barriers for using biogas back-packs in Cambodia due to feedback received from stakeholders.
- Transporting the biogas by **biogas pipelines** can be a suitable concept in case of transport distances of maximum 10 km. A disadvantage is the strong dependency of the producer from the client(s) connected to the pipeline. In case of few customers a financial participation of the clients in the biogas production is highly recommended.
- Transporting **biogas in high-pressure gas cylinders** gives the most flexibility (interchangeability of customers and biogas storing) and allows biogas transport at long distances (> 100 km), but is very costly, especially at low production capacities.

Because of the above-mentioned facts, it is recommended to search and identify locations, where large amounts of biomass (e.g. municipal waste from households or restaurants, waste from markets as well as from food processing industries), which allow biogas production of much more than 100 m^3/h raw biogas, can be made available.

Other requirements to make a project feasible are:

- Biogas production locations should be as close as possible to either a town or a client with a high need for energy, that can be substituted by biogas (e.g. vehicle fuels or fuels for thermal application).
- The analysis has shown that using biogas for cooking, as vehicle fuel or for thermal application can be competitive in Cambodia under certain circumstances. Nevertheless, each biogas project may have very different circumstances and its suitability needs to be evaluated from case to case.

The following table gives an overview about the evaluation of different business models:

Table 1~~12~~: Overview about the economics and challenges of the business models that have been evaluated

	Economics (under the taken assumptions)	**Social and environmental benefits**	**Challenges** (in Cambodia)
A) Biogas use for cooking			
A.1 distribution by biogas back-packs	Competitive with LPG as cooking fuel	In general: - Improving security of energy supply - Households / farmers may deliver organic waste as substrate and get organic fertilizer in return - Increase of local added value - Reduction of GHG emissions from burning conventional fuels	- low energy density - limited transport distance - limited biogas to be transported in total, therefore only add-on solution to other uses of biogas in case of industrial scale biogas production - cultural barrier (Cambodians seem to be very hesitant and sceptical; they are very "proud" people that do not want to carry heavy loads) - limited market demand in rural areas - difficult financial viability, LPG retail price is about 0.06 US$/kWh - no LPG use to substitute
A.2 distribution by biogas pipe-lines	Competitive with LPG as cooking fuel	In case of substituting fire wood: - Smoke-free and ash-free kitchen, so women and their children are no longer prone to respiratory infections - Less deforestation - reduced drudgery for women and children	- economics depend strongly on local conditions (geologic, distribution of households, etc.) - large number of households need to be connected in case of industrial scale biogas production, e.g. 1,600 households in case of 100 m^3/h biogas)
A.3 distribution by high-pressure gas cylinders	Not competitive with LPG as cooking fuel (under current circumstances)		- high specific cost for cleaning and upgrading as well as compressing the biogas in case of small biogas production capacities . The larger the installation the better are the chances for an economic feasible project. The production rate should be at least 200 m^2/h better higher. - safety risks, when operating high-pressure gas bottles

	Economics	Social and environmental benefits	**Challenges** (in Cambodia)
B) Biogas use as vehicle fuel			
B.1 distribution by high-pressure gas cylinders	Nearly competitive with diesel fuel in case of larger plant (100 m^3/h biogas production)	- Improving security of energy supply (less import of fossil fuels necessary) - Increase of local added value - Reduction of GHG emissions from burning conventional fuels - Reduction of further emissions: NO_x, fine dust, noise (cleaner cities)	- high specific cost for cleaning and upgrading as well as compressing the biogas in case of small biogas production capacities . The larger the installation the better are the chances for an economic feasible project. The production rate should be at least 200 m^2/h better higher. - no existing CNG or CBM infrastructure in Cambodia - currently very limited market; therefore, extra investment for converting vehicles necessary (here not considered) – support from government recommended
B.2 on-site filling station			- customer (private or public) of large fuel amount needed to start a pilot project, near location of biogas production
C) Biogas use for thermal application			
C.1 use nearby	Nearly competitive with conventional fuels (e.g. wood)	- Improving security of energy supply - Increase of local added value - Reduction of GHG emissions from burning conventional fuels - Less deforestation	- C.1: customer with energy demand needed nearby - C.1 and C.2: small capacities (< 100 m^3/h far away from being competitive) - C.1 and C.2: high dependency on customer, should become partner (investment into biogas production) - C.1 and C.2: balancing of production and demand difficult but LPG as backup can be an easy solution - C.1 and C.2: Combination with electricity production (co-generation) may also give more flexibility, but higher cost
C.2 distribution by biogas pipelines	Not competitive under today's circumstances, but could be in near future (increasing wood prices)		
C.2 distribution by high-pressure gas cylinders	<u>Not</u> competitive with conventional fuels		- Most flexibility in terms of biogas distribution and balancing production and need (by storing the biomethane at high pressure) - high specific cost for cleaning and upgrading as well as compressing the biogas in case of small biogas production capacities

Report: Initial assessment report

In April of 2018, a field mission took place in Cambodia and 12 locations were visited in order to determine the feasibility of alternative uses of biogas in the given locations. The 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 were given for them.

As described above one original (but amended) intention of the field mission was to investigate if the owners of the locations (pig farms, rubber industry, tapioca processing) were 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 possible motivations 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, there was **not much interest 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.
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.
3. The main income from a biogas plant and genset is achieved through own energy use. The options of selling energy to the grid are very difficult to estimate under the current circumstances in Cambodia. The traditional use of chemical energy (e.g. wood or charcoal for cooking or heat supply) is by far more economical compared to the costs for electricity. Thus, the owner is much more interested to reduce the own electricity bill instead of looking for alternative uses.
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.
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.

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.
7. The option of the biogas backpacks would need much 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 has been further investigated in an additional report.

Recommendations on biogas technology, based on observations during the field mission.

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 this technology has 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.

Many pig farmers have an cooperation agreement with a company called CP. If the pig farm has a contract with CP, it is a condition to equip the lagoon with a cover, however there is no requirement to also use the biogas or installing ~~to have~~ a biogas plant. ~~In that case i~~It is ~~to~~ recommend to talk with CP (UNIDO or BTIC) to explain the below listed issues.

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. In addition, financial institutions do not yet provide soft loans with low interest rate and interesting conditions for clean energy.

To develop 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 of the gas quality 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, 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.

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.

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[1].

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.

Flare installation: it is necessary to install a flare at each biogas plant that is missing one. The flare burns the biogas that can not be used whenever the engine is being maintained, for example. This reduces the risk of biogas (methane emissions) escaping into the atmosphere.

c) 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:

[1] https://mediathek.fnr.de/media/downloadable/files/samples/g/u/guide_biogas_engl_2012.pdf

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 has been described for each location in the Field mission report.

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 has been described in detail for each location in the Field mission report.

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: 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. 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. 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 are not fixed reliably to the ground (they are just buried about 1 m deep and 1 m wide). Given this construction, gas tightness cannot be ensured nor controlled and gas leakages can lead to explosive atmospheres. 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: work instructions, safety instruction, briefing on procedures and emergency plans, definition of requirements for lone working.

The following table offers an example of the hazards most often observed at the locations visited, which already had a biogas plant and the recommendations to prevent possible accidents[2].

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.)
Inappropriate electrical installations	
The electrical installation is not appropriate, considering the risks present on a biogas plant.	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.
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	
The foundation of the construction is not safe.	All components that are not meant to move during operation should be technically fixed to avoid uncontrolled movement or damages.
Explosive atmospheres	
There are several points where explosive atmosphere (presence of methane, oxygen and a source of fire) 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.

[2] Specific recommendations were given depending on the observations made at each individual location, therefore this table only presents some examples, as it is not the objective of this report to repeat all this information again. For more information, please refer to the report Initial Assessment of the Field Mission.

Report: Biogas bottling (mobile biogas bottling facility[3] and traditional biogas bottling[4])

The objective of this report was to evaluate biogas bottling for Cambodia regarding the use of a mobile biogas bottling facility, as suggested by UNIDO, and traditional biogas bottling.

Regarding this topic, FvB recommends:

- If UNIDO wants to identify locations in Cambodia were biogas upgrading and bottling might be interesting, the potential biogas production volume rate is the most important influence factor. Biogas upgrading and bottling is only economically interesting in locations with high biogas potential , on some locations with a biogas production rate of at least 200 m^3/h or above .
- If UNIDO is intending to support biogas projects in Cambodia, the German Biogas Association recommends to support safe and environmentally friendly projects only. Many biogas plants we assessed in these projects do not comply with this recommendation.
- German Biogas Association doesn't see options for safe and reliable mobile biogas upgrading and bottling plants.
- If biogas shall be bottled, it is of a significant importance that the whole technology chain is safe, from biogas production to its use and to the maintenance of pressurised bottles.
- There is a huge lack of information on the safe biogas production and usage in Cambodia. It is to recommend to have studies and training to BTIC on safe and environmentally friendly performance of biogas plants.

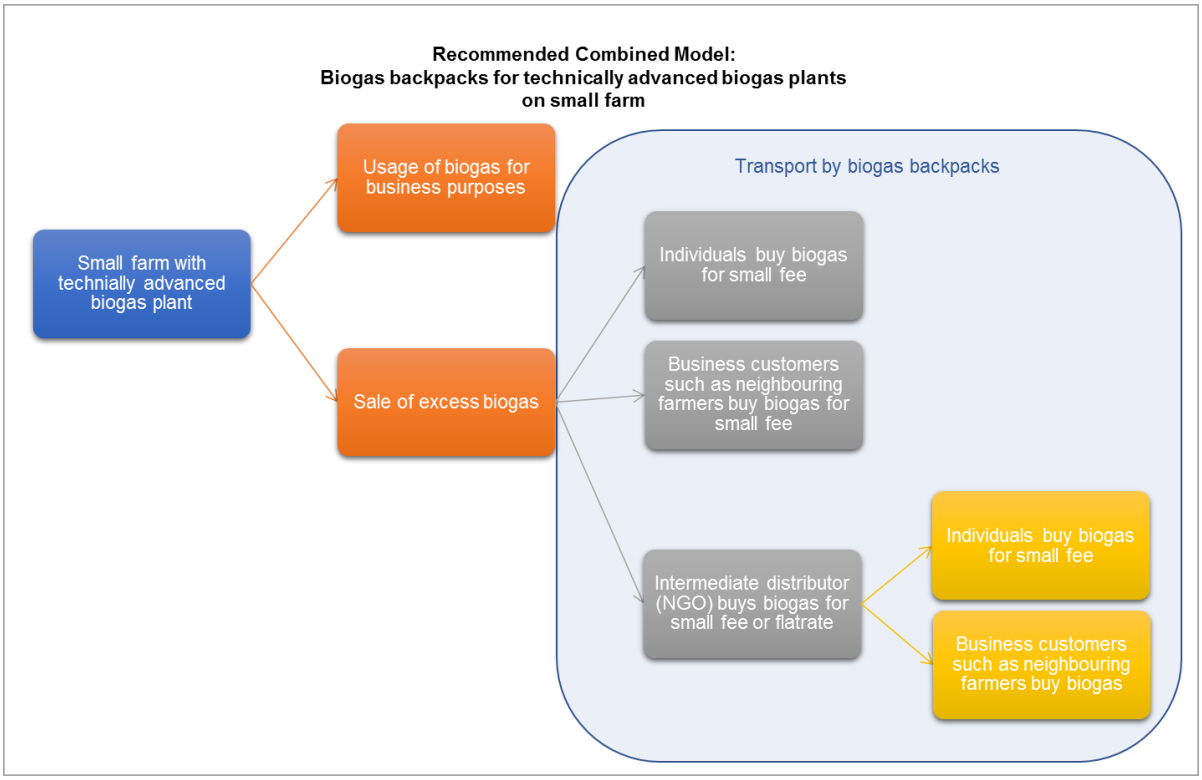
[3] Mobile biogas upgrading and compression unit. This mobile station goes from one biogas producer to the next and bottles the available biogas at the location and then continues to the following biogas producer.

[4] Traditional biogas bottling refers to biogas upgrading to biomethane and its posterior compression into bottles at 150-250 bar.

Report. Biogas backpacks

In order to implement an increased use of biogas backpacks, a very simple and easy-to-use technology, it is necessary to be aware of its advantages and disadvantages.

To benefit from the given strengths and opportunities, controlling the weaknesses and threats is substantial. The market and involved stakeholders, however, are unlikely to do that independently or, to put it differently, the challenge is considerable to do so, as this study has shown. Thus, an external influence is needed. So far, the promotion of biogas in Cambodia has been concentrated on domestic small-scale biogas plants. Considering that the market for domestic solutions is saturated, it appears logical to advocate business models revolving around the usage of biogas backpacks in combination with biogas retrieved from small farms as central locations – and thereby go beyond domestic solutions. The corresponding biogas plants should, however, be technically advanced in order to provide sufficient amounts of biogas not only for the purposes of the farm but also for the users of the biogas backpacks. This could be implemented through incentives by the government and with the help of NGOs as facilitators for logistics. Additionally, a bartering system with the users of biogas backpacks in the surrounding area such as individual households and neighbouring farmers seems helpful to ensure not only the availability of sufficient feedstock for biogas production but also to lower the costs and thus make it more feasible for the involved stakeholders. In this regard, a combination of two of the presented business models could provide the desired solution:



Report: Analysis of using biogas from tapioca starch effluent for various options

Tapioca starch is produced from the roots of the cassava plant. Processing the cassava root to produce tapioca starch produces large amounts of waste water that is rich in organic material. This waste water is often pumped into huge open lagoons for storage. In such open lagoons the organic content of the waste water will be digested by microorganisms with the consequence of high methane emissions into the atmosphere. There are several factories in Cambodia that produce tapioca starch, the report focuses on the ~~Siang Phong~~ tapioca factory visited in March 2018. The main conclusions of this report can easily be transferred to other tapioca factories in Cambodia.

The report concludes that under the actual conditions based on one example factory, there is no positive business case for investing in a biogas plant that operates safely and environmentally friendly. Only if some factors would change in the future, could this option be interesting:

- Clear regulation to feed in electricity into the public grid connected with an interesting FiT;
- Obligation to operate a biogas plant on a tapioca factory and covering the costs by the tapioca starch production.
- If the prices for fossil fuels would rise substantially or renewable energy production were supported in Cambodia a business case might arise.

When working with the Cambodian government on the topic biogas technology, FvB recommends to ensure that the following conditions are improved:

Feed in tariff for electricity: In many countries around the world renewable energy is supported by the governments as a way to become independent from the import of fossil fuels, to create business within the country instead of burning fossil fuels (and money), to create jobs and rural development and to reduce GHG emissions. One very successful way to promote renewable energies, is to ensure that these projects get priority or at least allowance to be connected to the public electricity grid and inject the produced electricity in exchange of a certain tariff (Feed-in Tariff, FiT). If there would be a FiT, for example of 16 USct/kWh for such biogas projects would become economically interesting. As a result, there would be rural development, business creation job creation and many advantages for the environment (one of them GHG reduction).

Introduce an obligation to operate a biogas plant to limit methane emissions. Tapioca factories that pump their waste water into open lagoons cause environmental damage. The negative effects are emissions from the lagoon to the ground (nitrate forms and will be in the ground and drinking water of the people) and to the air (methane, gases containing sulphur and nitrogen). If there was an obligation to operate a biogas plant for environmental reasons and the costs for CAPEX and OPEX are covered by the operation of the tapioca factory (principle: the one who causes a problem must pay to solve it) the options to use that biogas would be economical interesting.