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Renewable Energy &
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Promotion in
International
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Production Of Biogas From Pretreated Banana Waste In Costa Rica

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PRODUCTION OF BIOGAS FROM PRETREATED BANANA WASTE IN COSTA RICA - REPIC CONTRACT 2008.01

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1. Background of the Project

1.1 Production of Biogas in Costa Rica

The production of agro-industrial goods such as banana, pineapple and coffee plays a dominant role in the economy of Costa Rica. Further tropical fruits and vegetables of relevance in Costa Rica are for instance sugar cane, palm hearts, oil palm, rice, melons, and oranges. Beside the plantations, many companies have installed packaging plants for the export of the products and some have production plants for the transformation of these fruits and vegetables into products for the food industry, *e.g.* juice, puree, and cans of fruit and vegetables. Agricultural and food processing activities lead to the production of a considerable amount of biowaste, which is currently disposed on the plantations or open waste dumps (so called "trincheras"), and partly discharged in landfills. Upon formation of anoxic conditions during disposal, the green house gas methane is emitted to the atmosphere.

Although Costa Rica produces the majority of its electricity from renewable resources, the country is in a steadily increasing dependency situation concerning fossil energy for the transport and production of electrical and thermal energies due to the increasing total demand. In this situation one is astonished that so far no company from the agro-industry produces energy from biowastes today.

One analysis of the environmental politic context has shown that the legislation concerning industrial activities was not attractive enough to foster investments for existing and new installations dedicated to organic waste exploitation in this country. However, in the frame of the present governmental program the situation is changing, since the Costa Rican government fosters the development of alternative energy and the decrease of fossil energy dependency by implementing:

- The national plan of energy, which targets the decrease of the consumption and dependency of fossil energy
- The governmental program 2006-2010 initiated the introduction of an integral management of waste fosters a decrease in pollution caused by fossil energy and the production and consumption of alternative fuels. This program set the objective to Costa Rica to become the first worldwide country producing 100% of the electricity from renewable resources.
- Consultations on climate change

The present political situation should thus be very favorable to the development of renewable energy since the implementation of any technology that can support reaching the objective of a neutral CO_2 balance is expressly encouraged. In particular, biogas production in anaerobic digesters prevents the uncontrolled methane emission upon disposal in open dumps, thus the production of biogas from agro-industrial wastes can be regarded as truly *CO_2-neutral*.

1.2 Technical background of the project

Banana peels are rich in natural polyphenols, so called tannins. Tannins have been described to be inhibitory to methanogenic microorganisms, potentially due to the complexation of essential trace metals. On the other hand, tannins are valuable products for pharma- or food industries. An extraction of the tannins previous to biogas production could thus improve both technical and economical premises of the latter technology. Produced biogas could be used to substitute for fossil fuels such as bunker oil and thus contribute to CO_2 emission reduction. Consequently, the present project investigated the influence of tannin extraction on biogas production from banana wastes. If applicable, it was aimed at implementation of tannin production and biogas production in pilot-scale on Costa Rican side, involving different stakeholders from agro-industry, technical development agencies, universities, industry chambers and an electricity production company. The technical and economic feasibility was studied on case study base. Furthermore, a managerial concept taking into account aspects of technology transfer and capacity building was developed to finally implement a pilot reactor.

2. TECHNICAL FEASIBILITY OF EXTRACTION AND BIOGAS PRODUCTION FROM TANNIN RICH MATERIALS

A first phase of the project covered the development of analytical methods, the extraction of tannins and biogas production tests, which are presented here only briefly [1)]. Next to functional group based methods (i.e. prussian blue assay, rhodanine assay and butanol-HCl-assay), direct chromatographic methods (HPLC-DAD/MS^n) were developed to characterize tannin content and composition of banana peels. The studied tannin compounds included catechin and epicatechin as monomers of condensed tannins and tannic acid as model hydrolysable tannin. Gallic acid and quercitin were chosen as anaerobic / aerobic microbial degradation products of hydrolysable gallotannins and condensed tannins, whereas pyrogallol as an anaerobic degradation product of gallic acid. Methyl gallate is a plant derived medicinal product. Separation of these standards was achieved within 13.9 minutes using a Nucleodur Pyramid column (3 µm, 4 x 150mm, Macherey Nagel, Oensingen, Switzerland) (Figure 1), applying a column flow of 1 mL / min, a column temperature of 40°C and the following gradient of Acetonitril:H_2O (v/v): 5:95 (0 min); 27.5:72.5 (7 min); 60:40 (13 min); 95:5 (17 min); 5:95 (20 min).

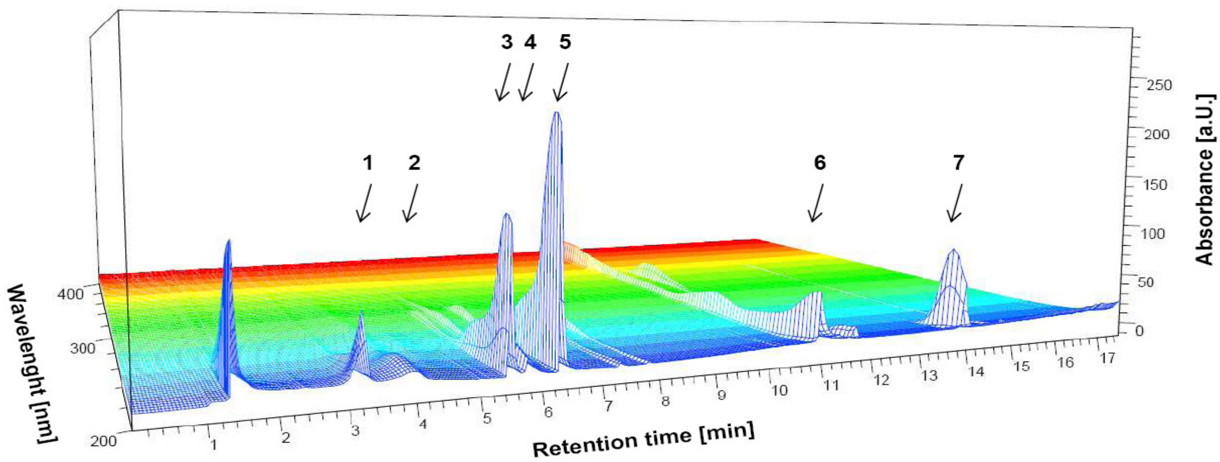
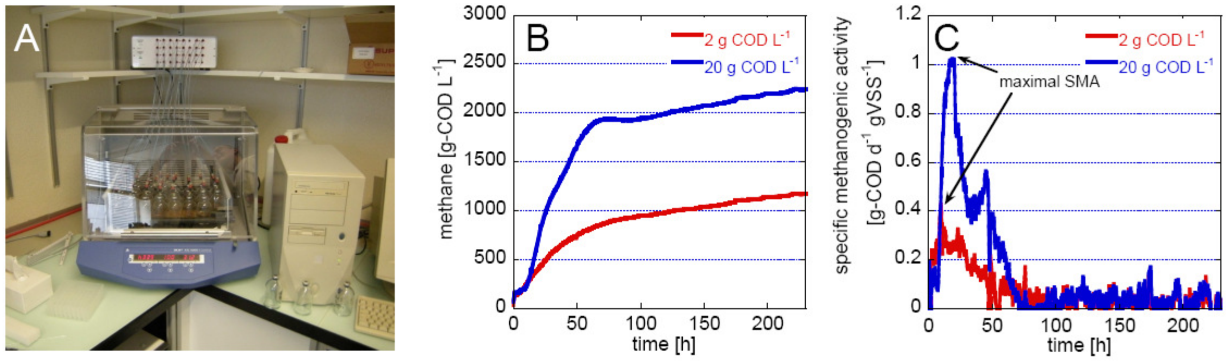


Figure 1. Chromatographic separation of tannin standards / building blocks, Pyrogallol (1), Gallic acid (2), Epicatechin (3), Methylgallate (4), Catechin (5), Quercitin (6) and Tannic acid (7) .

HPLC-DAD/MS^n analysis were used to evaluate different extraction protocols available for tannins, i.e. acetonic, methanolic, ethanolic extracts and their acid-hydrolysis products. Only the acetonic extracts contained one of the above mentioned model compounds, i.e. catechin with significant a concentration of 3 mg / g dry weight. Consequently, only small amounts of the studied tannin building blocks can be yielded when extracting banana peels, thus a commercial added value by tannin building block production is put into questions.

Biogas production tests were conducted to evaluate biogas production potential of treated and untreated banana peels. Tests were conducted as batch assays using an in-house build pressure sensing system (Figure 2). The system can record the pressure in anaerobic serum bottles in half hour intervals, storing the data on a computer. Due to the high accuracy of pressure recording and the high sampling intervals it allows a precise calculation of the specific maximal methanogenic activity (SMA, the production of methane per time unit and volatile suspended solids). The SMA is used to estimate the maximal activity that can be expected in larger scale applications. Batch activity tests contained 0.5 g (wet weight) anaerobic granular sludge (Zweifel Pomy



Chips AG, Spreitenbach, Switzerland) in 50 ml methanogenic medium.

Figure 2. (A) In house build online pressure measurement system. (B) exemplary total methane production and (C) derived specific methanogenic activity. The higher load (20 gCOD / L) leads to a higher maximal SMA.

Banana peels were extracted 1 and 3 times by acetonic (+/- acetic acid) and methanolic solutions. The solids were separated through filtration by folding filter, dried and supplied to anaerobic methanogenic granular sludge as only carbon source, using the above described activity set-ups.

Table 1. Maximal specific methanogenic activities (SMA) of banana peels extracted with different solvents.

Extraction-Method	SMA [gCOD / gVSS d]
Non extracted	0.61 ± 0.07
1 time acetone : H_2O [70 : 30; v:v]	0.34 ± 0.04
3 times acetone : H_2O [70 : 30; v:v]	0.24 ± 0.01
1 time methanol : H_2O [70 : 30; v:v]	0.33 ± 0.02
3 times methanol : H_2O [70 : 30; v:v]	0.22 ± 0.02
1 time acetone : H_2O : Acetic acid [70 : 29.5 : 0.5; v:v:v]	0.34 ± 0.01
3 times acetone : H_2O : Acetic acid [70 : 29.5 : 0.5; v:v:v]	0.45 ± 0.03

It was demonstrated that the maximal specific methanogenic activities (SMA) were highest in non extracted samples (Table 1). Among the extracted samples, banana peels treated 3 times with an acidic solution of acetone showed the highest SMA, whereas the 3 fold extraction with methanol decreased the SMA the most. Further investigations showed that extraction of tannins decreases the water soluble Chemical Oxygen Demand (COD) in banana peels, which was found to mainly determine the SMA without the addition of external substrate (i.e. hydrolysis of solid substrate is the rate limiting step in methane production). Even if water soluble, extracted COD was reunified with the extracted samples, SMA remained reduced in contrast to non extracted samples. Therefore, it was concluded that the extraction of tannins itself is unfavorable and not a prerequisite for high methane yields, like initially assumed. As a result, biogas production from banana wastes can have an outstanding economical and ecological impact for Costa Rica.

3. Economic Feasibility

A feasibility study was done in cooperation with Ernst Basler and Partner (EB+P) with considerations taking into account several aspects: location of the wastes, waste quantities, location of the bioreactor and the energy production; the addition of co-substrates or nutrients; the cost / benefit considerations for biogas production and bioreactor design. Among the different scenarios for biogas production evaluated, it was concluded that one concept, the biogas production on site of a cargo harbor (Figure 2), can be expected to be feasible (due to reasons of confidentiality no calculations are presented here). The scenarios took into account that the biogas reactor is positioned adjacent to a location with high energy consumption, i.e. the main export harbor with e.g. refrigerated containers for fruit export and cardboard factories. Biogas would then mainly function as substitute for bunker oil, or for thermal energy consumed. As substrate, rejected bananas were considered, due to the fact that no conflict with food production exists. Rejected bananas do not reach sufficient quality standards for export and are thus partly dumped. Furthermore, agricultural wastes were considered as co-substrate. Calculations included transport costs, i.e. including transport from biowastes to the harbor and later transport of the liquid / solid fermentation residues back to the farms for fertilization. As appropriate bioreactor technology, a liquid fermentation was recommended. It was demonstrated that such a scenario is economically feasible.

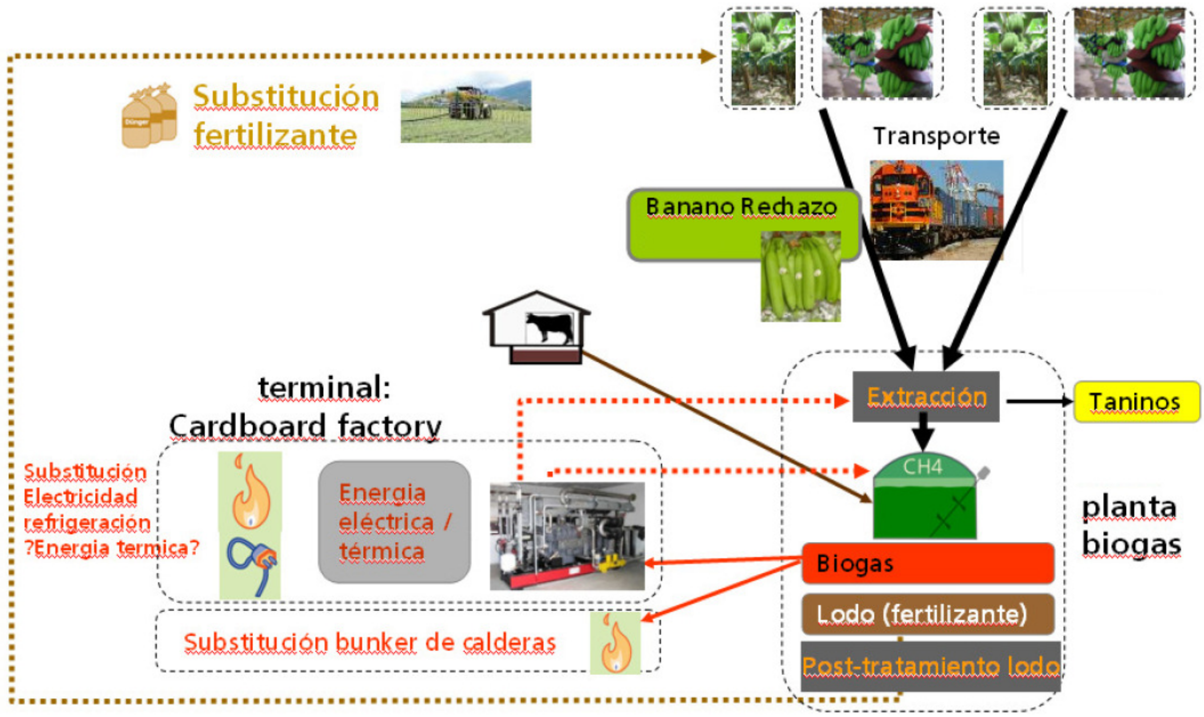


Figure 3. Conceptual scenario of biogas production adjacent to locations of high energy consumption, i.e. the export cargo terminal (source: modified from EB+P)

4. Managerial Concept

In order to promote the implementation of biogas production in Costa Rica, the REPIC project aimed at establishing a core group of experts on biogas production in Costa Rica on the one hand and at designing and constructing a pilot anaerobic reactor on the other. The construction of a pilot plant in Costa Rica was considered as an important measure for the transfer of technology, since it offers the possibility for both practical training and capacity building of local experts and is accessible as experimental testing facility to industry.

In this regards, pilot users (industrial partners) could test their substrates and substrate mixtures at cost price, with the evaluation of the reactor performance provided by the experts group. Furthermore, the experts group could provide necessary information for the design of a larger scale biogas plant and calculate the financial and economical benefit of the proposed plant as well as its environmental benefits and impacts.

Capacity building: Since the expert group needs to deal with different technical, economical, ecological and political aspects of biogas production, the group needs to be multidisciplinary and should thus be composed from:

- **Expert 1 (pilot operator) on mechanical engineering aspects supervising construction and operation of the plant**

  This person is responsible for the mechanical engineering aspects during construction and maintains the biogas plant operational, being in contact with different local and international suppliers.

- **Expert 2 (pilot operator) dealing with data collection and interpretation during reactor operation**

  This person will conduct chemical / biological analysis (methane content, volatile fatty acids, COD removal, etc) during operation and provide interpretation on the reactor performance

- **Expert 3 in charge of the economical and ecological benefits**

This person will conduct detailed analysis of the economical and ecological benefits and impacts of biogas production.

- **Expert 4 dealing with politics, ministries, etc;**

  This person will do lobbying activities and promote the concept at the political scale

- **Expert 5 in charge of coordination**

  This person will coordinate the work of all mentioned actors.

- **Expert 6 as external advisor and capacity building facility**

  This role could be taken by FHNW, yet in the initial phase only. Eventually, the expert group should be fully trained in all aspects of biogas production, thus an external expert is not required anymore.

The financing of the reactor: The industrial partners could contribute to fully cover the costs of the later reactor operation on an "*associateship*" principle. In this way, the usage / publicity rights for the operation of the reactor are given to companies based on financial contribution, i.e. requiring a lump sum cash to be paid to a fund (Figure 4). Since the construction of the pilot plant requires mechanical engineering (workshop and manpower), the first associate signing the contract can be granted for once to pay a reduced lump sum and instead contribute to the project by manpower and providing infrastructure. With the lump sums paid by associates, the expert group and the operation of the reactor should be fully financed, thus the project should achieve high sustainability.

The aims to be achieved by implantation of the pilot plant were:

- Design and construct a functional pilot plant that can be used to study different substrates (banana wastes, coffee wastes, household wastes, organic industrial wastewaters etc.)
- Investigate the feasibility of biogas technology in Costa Rica with wastes from one pilot user during a first operation
- Capacity building on (1) technical aspects and (2) all related economical, ecological, logistical, etc. aspects towards implementation of a full scale biogas plant.

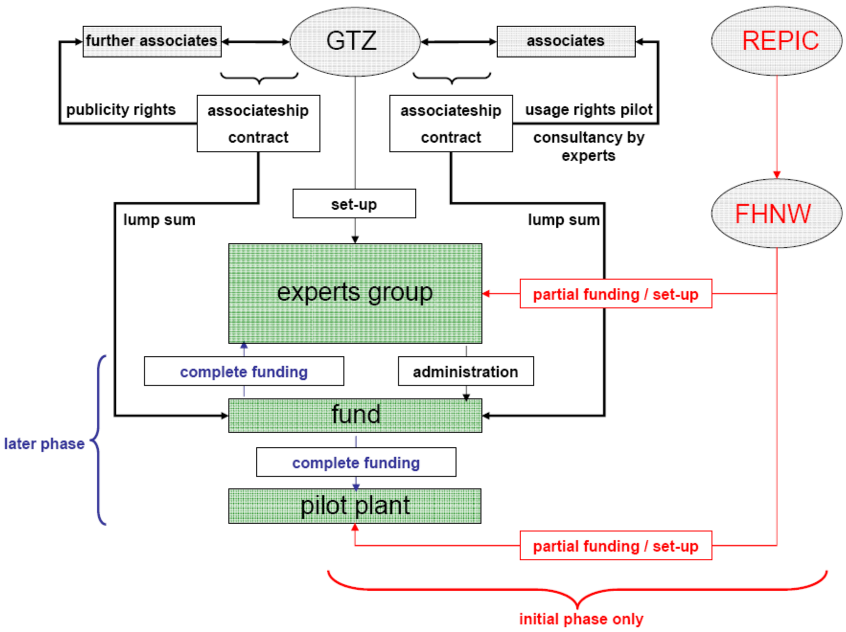


Figure 4. Organizational integration of the stakeholders

5. Implementation: Experiences and Outlook

To achieve financing and implementation of the intended pilot reactor and capacity building, extensive networking activities with different kinds of stakeholders in Costa Rica and Switzerland were conducted. Contacts were build with

- ➔ potential industrial associates: all major agro-industrial producing and processing fruits companies in Costa Rica, diverse Coffee producing cooperatives in Costa Rica, all major biogas technology suppliers in Switzerland, diverse companies active in emission trade
- ➔ technical development agencies: mainly represented by GTZ (Deutsche Gesellschaft für technische Zusammenarbeit)
- ➔ academic institutions: Earth University, Universidad National de Costa Rica - UNA, Universidad de Costa Rica -UCR, Technical University of Hamburg-Harburg
- ➔ chambers and agencies: Camera de Industria, Centro Producción mas limpia -CP+L; Instituto de fomento y asesoria municipal - IFAM;
- ➔ electricity supplier: Instituto Costarricense de Electricidad - ICE

In order to ensure the actual later usage of the pilot installation, a binding agreement regarding the contribution by financial or by man-power means was defined as a prerequisite for the continuation of the project from FHNW side. However, after more than 2 years of extensive discussion with potential industrial associates (both by GTZ and FHNW), no such binding agreement could be achieved. The lack of willingness to give binding agreements for the contribution can be potentially explained by different considerations:

- ➔ The proposal to financially contribute on basis of associate-ship was made during a period of global financial pressure (starting 2007 until the present point). This has lead to severe structural changes in the fruit producing / processing sectors, including many personnel transfers and downsizing. This lead to a "no risk" attitude towards new projects
    - o The lack of willingness to give binding agreements stands in strong contrast to the expressed interest in implementing the technology of biogas production, explicitly expressed by diverse industrial partners throughout the project. Therefore, new efforts could be fruitful upon the improvement of the global financial situation.
- ➔ No bioreactor appropriate for pilot testing in larger scale (~10m³) is commercially available. Therefore, significant resources would need to be allocated to reactor development (not only including design criteria, yet also the purchasing of parts and the mechanical construction of the reactor, i.e. welding etc.). Although rough cost estimations were presented to the industrial associates, this left uncertainties to the costs for developing the reactor, eventually.
    - o When bioreactors specifically designed for anaerobic pilot-studies become available, resources can be more focused on questions regarding the actual digestability of the wastes, logistics, training of experts, etc.
- ➔ Even if anaerobic digestion was introduced to the industrial associates with numerous practical examples and extensive data on good digestabilty of the tested substrates were presented, still some hesitation regarding the feasibility of anaerobic digestion was expressed. This might be due to the fact that so far anaerobic digestors are not installed in Costa Rica on regular base. This is in contrast to e.g. Switzerland, where anaerobic digestion is implemented on many private farms or in industry.

- The hesitation might be overcome by actual site visits of industrial decision makers in e.g. Europe, where anaerobic technology is a publically recognized and accepted green technology.

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1) Further information to the project can be found at:

Corvini, P.F.X, Mutz, D., Lenz, M. (2008). Produktion von Biogas aus vorbehandelten Bananenabfällen in Costa Rica. Forschungseinblicke FHNW. Verfügbar unter http://www.fhnw.ch/forschung-und-entwicklung/forschungsprojekte-fhnw/forschungseinblicke/

Lenz, M., Oertlé, E., Mutz, D., Corvini, P.F.X. (2008). Extraction of tannins from organic waste as a pre-treatment to biogas production. FHNW Research Report 2007-2008. Available at http://www.fhnw.ch/lifesciences/forschung-und-entwicklung/downloads/forschungsbericht-2007-2008.