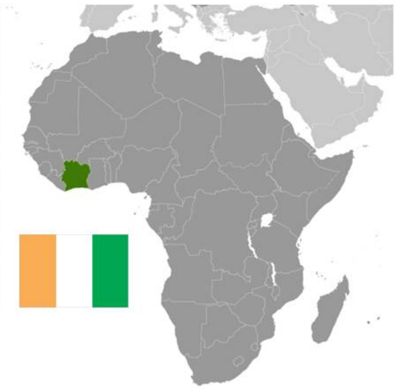
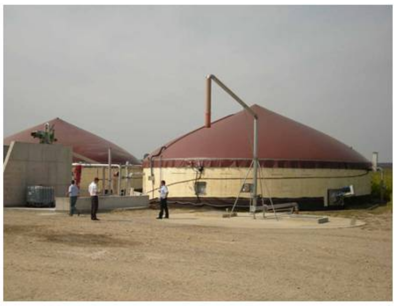
# Using cocoa bean shells for biogas: a case study of a cocoa factory in Cote d'Ivoire, West Africa





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## Project Summary

Cocoa beans are the key product for the manufacturing of chocolate and are produced in equatorial regions of the world. Cocoa bean shells are the main by-product of cocoa bean production and in some cases are already used for generating heat energy through combustion. However, the potential of this by-product as a main substrate for biogas to offset fossil fuel energy has yet to be investigated and is of great interest given the vast quantities available. This study looked at the energy situation at a cocoa bean factory in Cote d'Ivoire where the construction of an biogas plant is being considered based on its own by-product, cocoa bean shell as the main digestion substrate. Chocolate production involves costly and highly energetic processes and so the prospect of making use of its main by-product has energetic, economic and environmental benefits. In this study, several energetic scenarios involving cocoa bean shell utilization for biogas were modelled to compare with the current situation at the cocoa factory. The focus was on the extent biogas from cocoa bean shell could replace or offset the factory's demands for grid electricity and LPG (butane) for thermal energy. The simulations showed that the best short term scenario (up to 7 years) from a financial perspective would be to invest in a small biogas plant (ca. 300 kW) to offset the thermal energy currently provided by the butane. This would however provide only a minimal ca. 16% reduction in carbon emissions. The scenario of investing in a larger biogas plant (ca. 1.4 MW) to offset as much grid electricity as possible provided the best long term (7 years onward) financial result. This latter scenario also reduced carbon emissions by 49%. For the small biogas plant scenario, an initial investment was calculated at €881,729 and a payback period of 3.3 years. For the larger biogas plant scenario, an initial investment of €3,131,647 was calculated, with a payback period of 5.5 years

which is because it offers a great savings per annum due to a reduction of electricity costs. In seeking to increase environmental accountability and streamline operational activities, these recommendations should assist the international company in the decision making of how to reach these goals. The company's end decision will no doubt depend on economic, environmental and logistical reasons, and the importance it places on securing a reliable and storable energy source for its cocoa bean production. Furthermore, given that an expansion production is likely, investing in biogas technology represents a quite feasible option to offset the cocoa factory's increased energy demands. This particular cocoa bean factory represents one of many in Cote d'Ivoire which contributes about a third of the global cocoa bean production.  If this energy concept is realized and proven successful, many other cocoa bean processors could invest in biogas plants based on cocoa bean shell and thereby assist in reducing carbon emissions and benefit financially. This concept is relevant to the place of cocoa bean grinding which can be in either the place production or importation. The Netherlands, Cote d'Ivoire, Germany and the United States are major processing countries and thus possess great potential in utilizing this concept. This could of course be applied to other food industries where adequate amounts of residue or by-products are available and prove suitable as biogas substrate.

## 1. Case study outline

In this case study of a cocoa bean factory in San Pedro, Cote d'Ivoire, the feasibility was assessed of installing a biogas plant based on cocoa bean shell as the main digestion substrate. Generally, the international company would like to increase its environmental accountability and improve its production process. The utilization of its own by-products for energetic purposes provides an ideal opportunity to reach these goals and thereby achieve better environmental and economic outcomes. The focus of this study was on the extent biogas from cocoa bean shell could replace or offset the factory's demands for grid electricity and LPG (butane) for process (thermal) energy. Currently at the San Pedro factory, some of the cocoa shells are combusted in a boiler which generates 60-70% of the factory's steam requirements for its processes and machinery. The remaining amounts of cocoa bean shells are discarded or incinerated with no energetic use. This study assessed this current use of cocoa bean shells and looked at the possibility of utilizing some or all of this material as substrate for biogas production through anaerobic fermentation. The biogas would then be used to replace or offset current butane and grid electricity requirements. Several energetic scenarios involving cocoa bean shell as substrate for biogas were modelled to compare with the current situation of energy use and cocoa bean production at the cocoa factory.

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## 2. Research Objectives

In being able to provide the cocoa bean company with an understanding of the potential of biogas production to improve its situation and to justify the investment into this renewable technology, the following research objectives were set.

i) Build a model to assess the feasibility of using biogas generated from cocoa bean shell at a real cocoa factory in Cote d'Ivoire. Base the model on biogas generated from the anaerobic fermentation of cocoa bean shell, the main by-product of cocoa bean production. The model should:

- Be able to predict the best scenario for replacing or off-setting the fossil fuels LPG (butane) and grid electricity.
- Flexible to allow the user to modify variables and parameters and carry out sensitivity analyses.
- Allow the end user a good overview of the steps in the various processes.

ii) Simulate various realistic scenarios for the cocoa factory as options for the company to improve the current energy mix situation

iii) Determine the best energetic solution for both electricity and process (thermal) energy using the available waste product cocoa bean shell as raw material

iv) Provide a basic economic analysis using the simulated scenarios

v) Provide a basic environmental assessment by estimating and comparing green house gas (GHG) emissions for the simulated scenarios based on emissions factors

## 3. Biogas as a renewable energy

Biogas technology is well established in many parts of the world, particularly where government subsidies have allowed for its expansion and promoted its potential to help reduce global warming. However, much potential still exists in developing regions where reliance for heating energy is often on wood based fuel, electrical energy may be lacking and large amounts of biomass (agricultural, industrial and domestic) may be available. Biogas is a proven, reliable and promising technology, providing a clean source of renewable energy when proper management programs are followed. Successful use of biogas technology can also provide other benefits including the production of bio-fertilizer, social and ecological benefits including sanitation, reforestation and reducing the reliance on fossil fuels. The energetic output, both quantity and purity which correlates to the methane content of the biogas varies depending on a range of factors including the feedstock used, the biogas system used and its level of optimization (Arthur, Baidoo, & Antwi, 2011).

In developing countries with agriculture based economies, this technology can help decrease the reliance on wood fuel and thus reduce deforestation, improve electricity infrastructure and make better use of agricultural and organic domestic waste. This is because a range of organic feedstocks can be anaerobically fermented to generate biogas. Biogas feedstocks used have included cereals, grains, livestock manure (fluid and solid), urban effluent, domestic waste, green matter and algae (Arthur, Baidoo, & Antwi, 2011). Normally this material would breakdown in landfill or rot in the open, thereby emitting carbon dioxide and methane into the atmosphere. Methane is considered to be about a thirty times stronger greenhouse gas as carbon dioxide. Therefore, by utilizing this material to promote and capture released biogas, a reduction in greenhouse gas is achieved.

Biogas is primarily composed of methane and carbon dioxide, contains smaller amounts of hydrogen sulphide and ammonia, and is saturated with water vapour. Therefore it must be desulphurized and dried before utilization to prevent damage of the gas motors. Biogas is mainly utilized in engine-based combined heat and power (CHP) plants. Biogas purification and utilization as renewable natural gas for vehicle fuel or injection into the gas grid is of great interest. The digestate from anaerobic fermentation is a valuable fertilizer due to the increased availability of nitrogen which improves short-term fertilization for crops and can replace mineral fertilizer (Weiland, 2010).

Germany is currently the largest biogas producing country in the world with an end of 2011 forecast of 7100 plants totalling 2780 MW electrical power (Fachverband Biogas e.V., 2011).

## 4. Conclusions

Based on the analyses scenarios compared to the current situation at the cocoa factory, several recommendations could be given to the cocoa processing factory at San Pedro, Cote d’Ivoire.

### *4.1 Long term financial gain and partial independence from grid electricity*

Giving the best financial result from around 7 years onwards after investment was Scenario 3 where all the cocoa bean shell by-product is fermented to generate as much biogas as possible to then offset as much electricity as possible. After 7 years this scenario would save the company more than all other scenarios. This had a relatively high investment cost of €3,131,647 for a 1.4 MW (electric) biogas plant but an annual saving of €574,311 meaning that its payback time would be only 5.5 years. After 20 years, negating increased costs for electricity, butane and biogas plant maintenance, this scenario has the potential to save the company €12,454,660. This scenario entails a high level of independence from grid electricity, where biogas combined with a high capacity CHP machine(s) would supply 58% of the factory's electricity. Butane would still need to be purchased for process energy needs which means if costs rise to €740, the Scenario 2 of butane replacement with biogas and a small CHP (0.6 MW electric) to offset grid electricity by 22% would provide a better long term financial gain. This scenario however is much more sensitive to fluctuations in electricity, with increasing costs creating a larger difference in annual repayments compared to Scenario 3 (high grid electricity offset). Given that costs may possibly rise for both electricity and butane, the preferred choice between scenario 2 or 3 would vary. However, because of the potential savings for a larger CHP machine, the annual repayments between scenarios 2 and 3 are very similar. Therefore, one solution could be to invest in several CHP machines rather than one large unit so that if electricity price rose dramatically the energy could be managed so that more electricity would be produced by both units. Alternatively, if butane prices rose dramatically, the biogas could be directed to the burner(s) to generate process energy instead and one of the CHP machines could be shut down.

### *4.2 Short term financial gain, minimal investment and independence from butane*

From a short term financial perspective, Scenario 1 would provide the best result where biogas would be produced by a much smaller biogas plant (266 kW electric) in quantities enough to replace butane. This would give the best financial result until around 7 years, being able to pay back the investment in just 3.3 years. It would only require an investment for the biogas plant of €881,729 and offer a saving of €269,174 per annum. It would be still highly dependent on grid electricity meaning if there were any disturbances to supply or dramatic price increase, the feasibility of this choice would suffer. After 20 years, negating increased costs for electricity, butane and biogas plant maintenance, this scenario has the potential to save the company €5,828,919. On the understanding that this would be the first biogas plant established using cocoa bean shells as the main feedstock, this may be the best option. Also, if other investment capital could be used elsewhere for improvements in other areas of production, this option doesn't bind the capital to just one venture.

### *4.3. Environmental outcomes*

There is potential to improve environmental impact conditions for the factory from an energetic perspective. Both the fossil fuels grid electricity and butane for electrical and thermal energy can be offset to some extent by implementing biogas technology. The factory's current combustion of organic material (cocoa bean shell) has a good greenhouse gas emissions balance and so here there is only little room for improvement. In reality, the efficiency of the boiler combustion system and its maintenance condition could improve actual factory emissions but this would require on site consultation. Similarly for the consumption of butane and even electricity, efficiency and maintenance of machinery and the implementation energy saving protocols may provide reductions of amounts required and actual environmental emissions.

Based on the energy use alone and using emissions factors for each of the energy categories and emissions sources, Scenario 3 (high grid electricity offset) provided the best result with a reduction of 48.7% to 5534 tonnes $CO_2e$ per annum by offsetting 58% of the factory's electricity. Following this was Scenario 2 (butane replacement with small CHP) which would provide a reduction of 36.4% to 6852 tonnes per annum by completely offsetting butane and 22% of the factory's electricity. Scenario 1 (butane replacement with a small biogas plant) would provide a reduction of only 16.5% to 9003 tonnes, having offset butane alone. For both Scenario 1 and Scenario 4 (biogas used to offset butane and boiler energy from cocoa bean shell), grid electricity requirements actually increase slightly because of the electrical requirements of the biogas plants. This would significantly affect the end $CO_2e$ emissions balance.

### *4.4 Process energy mix*

Given the high energy intensity of grinding cocoa beans into cocoa products such as cocoa liquor, butter and powder, the process energy demands are very high. Currently, the cocoa bean factory covers around three quarters of its process or thermal energy with the combustion of cocoa bean shells which leaves little theoretical room for improvement. The different scenarios offer a range of process energy mixes, ranging from increasing boiler combustion loads with cocoa shell digestate to complementing or offsetting butane with biogas and thermal energy from the CHP machine. Both the current situation and Scenario 3 (offsetting electricity only) are dependent on butane and therefore its price and availability. Scenario 3 would provide significant amounts of process energy from the CHP machine via a heat exchanger.