OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

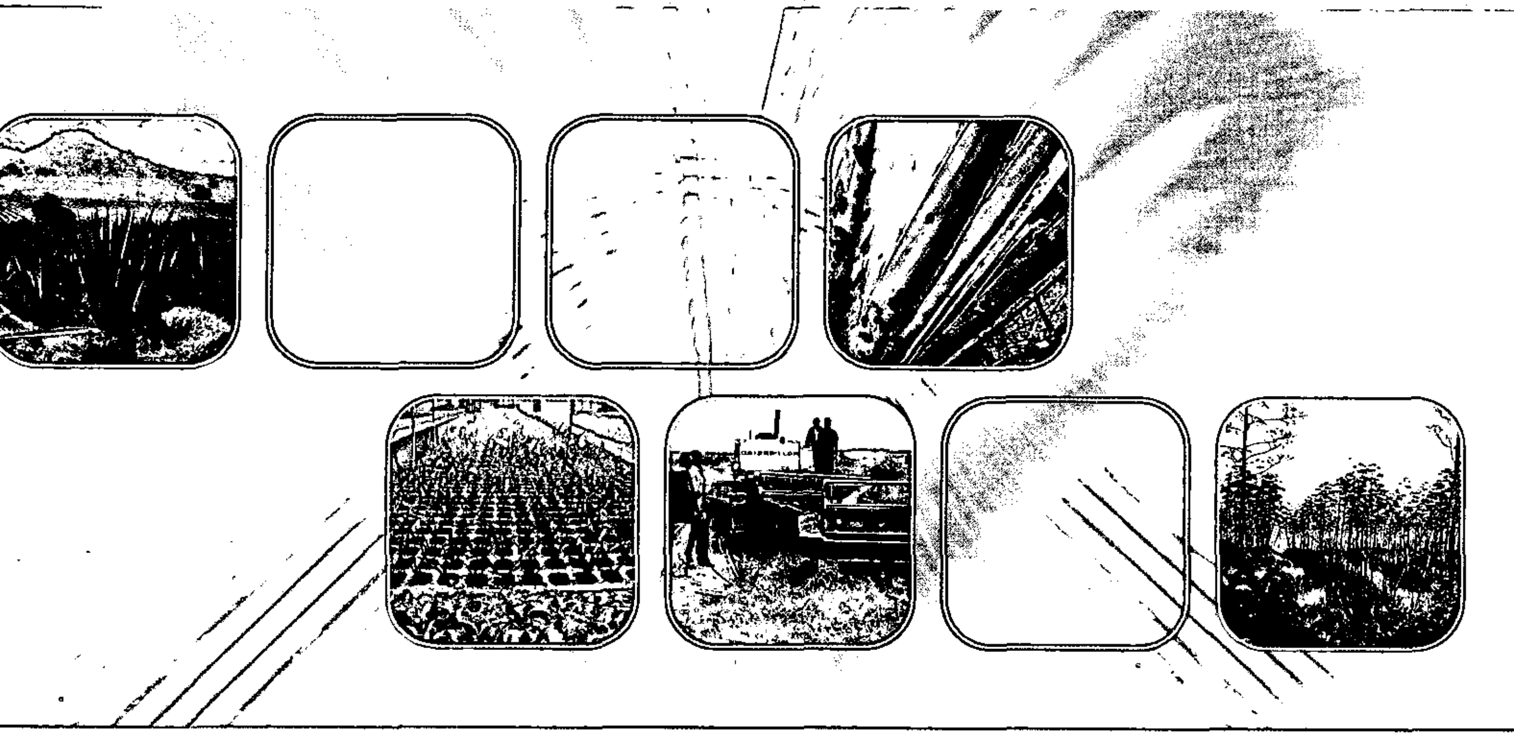
CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

COMMON FUND FOR COMMODITIES
Project CFC/FIGHF/07

Product and market development of sisal and henequen



Bio-energy from Sisal Waste

Project completion report/Addendum B.3

Tanzania, 1997–2004

COMMON FUND FOR COMMODITIES

Product and market development of sisal and henequen

Project completion report, Addendum B.3

Bio-energy from Sisal Waste

Tanzania
1997–2004

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna, 2006

Project Completion Report preparation: National and international experts and consultants involved with the project, with contributions and support from the national teams.
General guidance and consolidation: Ms. Mayra. Sanchez Osuna, Project Manager. The opinions, figures and estimates reflected in the Report and its Addenda are the responsibility of the authors and should not be necessarily be considered as reflecting the views or carrying the endorsement of the CFC or UNIDO.
The Project Completion Report and its Addenda have been reproduced without formal editing.

Common Fund for Commodities (CFC)
Stadhouderskade 55
1072 AB Amsterdam
P.O. Box 74656
1070 BR Amsterdam
The Netherlands
Telephone (++31 20) 575 4949
Fax (++31 20) 676 0231
e-mail: managing.director@common-fund.org
website: www.common-fund.org

United Nations Industrial Development Organization
Vienna International Centre
P.O. Box 300
A-1400 Vienna
Austria
Telephone (++43 1) 26026 3945
Fax (++43 1) 26026 6819
e-mail: M.Sanchez-Osuna@unido.org
website: www.unido.org

Food and Agriculture Organization of the United Nations
Commodities and Trade Division
Via delle Terme di Caracalla
00100 Rome
Italy
Telephone (++39 06) 5705 4201
Fax (++39 06) 5705 4495
e-mail: esc-registry@fao.org
website: www.fao.org

Project completion report

Sub-component B.3
"Bio-energy from Sisal Waste"

CONTENTS

Abbreviations

CFC	Common Fund for Commodities
CSTR	Continuously Stirred Tank Reactor
DTI	Danish Technology Institute
FAO	Food and Agricultural Organization of the United Nations
kg	Kilogramm
kV	Kilovolt
kW	Kilowatt
kW_{el}	Kilowatt – electrical
kW_{th}	Kilowatt – thermal
MJ	Mega joule
MWh	Megawatt hour
Nm^3	Normal cubic metre
NPV	Net present value
O&M	Operation and Maintenance
TANESCO	Tanzania Electric Supply Company
TSA	Tanzania Sisal Authority
UASB	Upflow Anaerobic Sludge Blanket
UNIDO	United Nations Industrial Development Organization

I. Project sub-component summary

1. Title: Bio-energy from Sisal Waste
2. Location: Tanzania
3. Starting date: 1997
4. Completion date: 2004
5. Sub-component financing: *The costs of preliminary activities performed for this sub-component were included under subcomponent B1*

II. Objectives of the sub-component

The original aim of this sub-component was to undertake preliminary studies on the feasibility of utilizing sisal fibre extraction waste for biogas production. The Danish Technology Institute prepared a technical study on the subject for CFC in May 2001. The study recommended the utilization of the waste for biogas production. The project continued its activities towards the design and formulation of a project proposal for a biogas production plant.

The main objectives of the project were:

- Collect and analyze the available information on sisal waste production and calculate the possible biogas production capability from available sisal waste;
- Evaluate preliminary results achieved with the small experimental biogas plant and analyze the local conditions affecting the project's facility (Facility) design and construction including the presence of the flume tow recovery system and the need for a screen to remove suspended particles from the inflow of the digester;
- Recommend a site for Facility location and propose preliminary layout for the Facility;
- Prepare a process flow sheet with a tentative mass balance and suggest the optimal solution for the Facility within available budget.

The final objective of the sub-component was to define the technical and economic viability of the production of biogas and fertilizers from sisal waste at a pilot level. The biogas should be used as fuel in a gas engine to produce electrical power and heat. The heat will be used mainly for heating the biogas reactor (digester), while the primary use of the produced electrical power will be at the Estate level. Excess electrical power might eventually be exported to the 11kV national power distribution network. Optionally, the project will assess the use of biogas for direct delivery to Estate households. The solid and liquid waste from the biogas digester will be utilized as fertilizers in the agriculture activities.

One of the main positive effects of the project will be the considerable reduction of the environmental degradation caused by the uncontrolled disposal of enormous quantities of sisal waste.

Ultimate goal of the project was to prove that currently unused sisal waste from the decortication plant process can be transformed into valuable electrical and thermal energy; the generated savings will lower the costs for fibre extraction and processing. After successful completion, this will be the first demonstration project for the utilization of sisal waste in an economically feasible and environmentally friendly way. The technologies developed and the market information that will be generated shall be disseminated widely to promote commercial adoption.

III. Implementation and results achieved

III.1 Project proposal

A project proposal including cost, design and site details was developed and a preliminary Facility and system engineering design, including technical options and alternative plans were summarized in the Technical Report and Annexes, submitted in March 2004.

III.2 Optimal digester set-up and performance

Preliminary studies recommended evaluating the application of both the Up-flow Anaerobic Sludge Blanket (UASB) and Continuously Stirred Tank Reactor (CSTR) systems that have been evaluated in the experimental work. The optimal final set-up for full-scale plant will largely depend on the applied decortication method.

The treatment of sisal solid residues in the UASB system is recommended at mesophilic (37°C) temperature and the CSTR system is suggested both at mesophilic (37°C) and thermophilic temperatures (55°C). Trials were performed in four-litre laboratory scale digesters.

The main conclusions are that both UASB and CSTR digesters are suitable for digestion of sisal solid waste and that the *thermophilic process is the most stable process for CSTR system.*

However, in order to start-up the CSTR process, co-digestion with 5% manure would be a great advantage. *The mesophilic (37°C) CSTR digester remained unstable, while operated at 100% sisal residues.*

UASB digesters were very stable during the operation at mesophilic (37°C) temperature without necessity of co-digestion with manure.

According to tests performed, calculations and estimations, waste from processing 33-34 ton of fresh sisal leaves per day is necessary for biogas production required for fuelling of the biogas engine-generator at 150-200kW base-load operations.

Since the proposed Facility will be designed for limited biogas production, the major balance of produced sisal waste (around 460 ton/day) will still be dumped.

Out of 22,315 total monthly waste, only around 5,445 tones will be utilized for biogas generation that is required for fuelling of 140-150 engine –generator (Table 1).

Long Dry Fibres		Total Waste from Sisal Processing		Total Waste required for 150 kW Engine	
ton/year	ton/month	ton/year	ton/month	ton/year	ton/month
1'980	164	267'780	22'315	65'340	5'445

Table 1

The balance, around 16,870 tons/month (or more than 202,000 tons per year) will still be wasted. The following diagram, Figure 1, shows the huge energy potential hidden in the sisal waste that is produced at Kwaraguru Estate, originally foreseen as a project site. Similar is the situation at Hale Estate (the new project site).

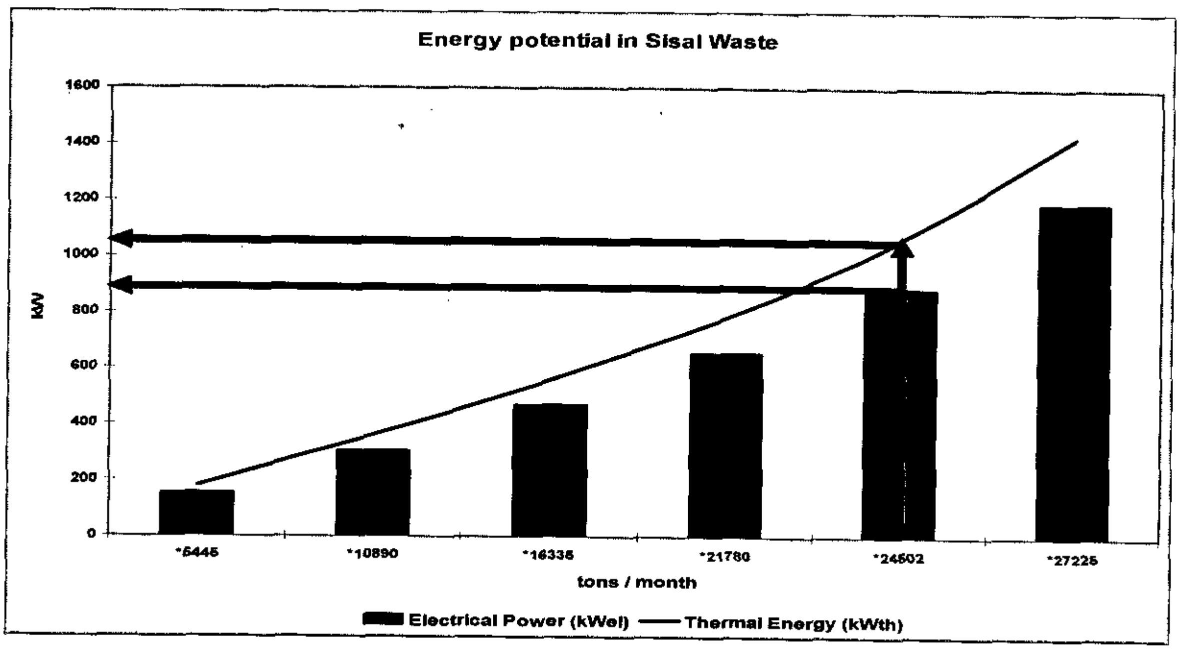


Figure 1

III.3 Proposed site

The following main criteria were considered for Facility site selection:

- Site access;
- Available infrastructure at, or near by selected site;
- Soil conditions;
- Present and future long term feedstock supply (location, availability & supply reliability, quality & quantity);

- Land availability & costs;
- Power and heat requirement for self consumption of miscellaneous consumers located in near vicinity of Facility Site;
- Access to power distribution network;
- Labour availability and skills;
- Water availability and use rights;
- Local environmental impacts;
- Necessary permits;
- Waste disposal restrictions.

The selected site satisfies all requirements as set up in the above list. The road access to the site satisfies the requirements, the site possesses the necessary infrastructure for the Facility construction and its later operation, soil is apparently stable but it will be necessary to perform further soil investigations. There are no other indications about possible underground rocks or soft spots (except present sisal waste dumping area).

The selected company will provide the land for the Facility without any cost. Before start-up of any site activities as well as before detailed layout planning, a site level plan shall be prepared. This will enable the layout planer as well as equipment designer to optimize the Facility design. In other words, this will allow to place the equipment and to size the fluid tanks and other major equipment in such way that, for example, the utilization of natural gravity flow will minimize the amount of pumps.

III.4 Facility design proposal

Biogas is distinguished from syngas (gas produced in mechanical gasifiers) because it is made through decomposition of organic waste to gaseous fuel by bacteria in the absence of molecular oxygen. The process, called anaerobic digestion, occurs in stages to successively break down the organic matter into simpler organic compounds.

The process is carried in an airtight digester. Most digestion systems produce biogas that is between 55% and 75% CH_4, about 25% - 45% CO_2, the remaining gases are usually smaller amounts of H_2S, N, H_2, methylmercaptans and O_2.

The amount of biogas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition.

To promote bacterial activity, the digester must maintain a temperature of at least 20°C (ideal 25°C - 35°C, mesophilic).

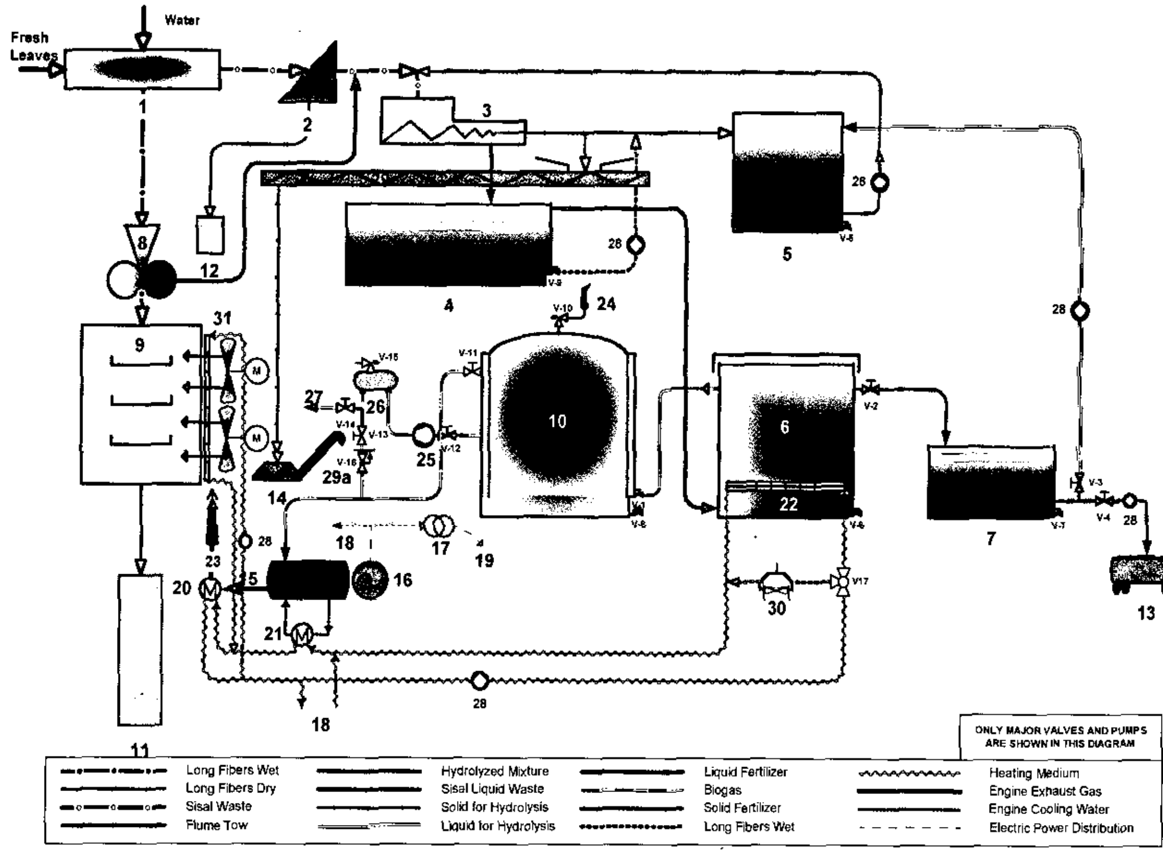
Higher digester temperatures, above 50°C-65°C (thermopilic), shorten the processing time, allowing the digester to handle a larger volume of organic waste.

The biogas energy content depends on the amount of CH_4 it contains. Typical biogas, with a CH_4 concentration of 65%, contains about 23 MJ/Nm^3 of energy that is equivalent to 0.55 kg of light diesel oil.

The process of biological anaerobic digestion occurs in a sequence of three major steps, hydrolysis, acidogenesis and methanogenesis.

The combustion of biogas can supply useful energy in the form of steam, hot water or hot air. After filtering and drying, biogas is suitable as fuel for internal combustion engines. Biogas can substitute for natural gas or propane in space heaters, refrigeration equipment, cooking stoves or other equipment.

A basic Facility's flow diagram is shown in the following picture, Figure 2.



1 Decorticator
2 Flume Tow Recovery
3 Screw Separator
4 Storage Tank Inlet
5 Hydrolysis Tank
6 Digester Tank
7 Open Storage Tank
8 Wet Fibre Squeezer
9 Fibre Drying Area
10 Biogas Tank
11 Long Fibres Storage
12 Flume Tow
13 Liquid Fertilizer
14 Solid Fertilizer
15 Gas Engine
16 Power Generator
17 0.4 / 11kV Transf.
18 Estate Power Supply
19 11kV Network Supply
20 Exh. Gas Heat Exchanger
21 Eng. Oil/W Heat Exchanger
22 Digester Heating
23 Exhaust Gas Stack
24 Flare Stack
25 Gas Compressor (Opt.)
26 Compressed Gas Tank (Opt.)
27 Estate Housing
28 Fluid Pumps
29 Conveyor
29a Bevator (Opt.)
30 Water-Air Heat
31 Air Blower

Figure 2

III.5 General description of optional design features

The main purpose of the proposed optional features is to achieve maximum utilization of produced biogas and to minimize heat loses.

The proposed biogas storage tank has 30% capacity of daily biogas production. This means that in order to consume the produced biogas without any un-economical flaring the over-produced balance, the biogas engine generator has to be operated continuously at almost base load 24 hours per day 365 days per year.

This is practically not possible. In order to improve this situation, the following two optional alternatives should be considered:

- To design larger biogas storage tank;
- To provide pressurized biogas facility.

The first alternative is not attractive enough. The volume of biogas storage tank would be several times larger, comparing to basic storage tank. The second alternative offers many following flexible features:

- Relative small storage tank;
- Possible biogas supply to the Estate and Estate housing;
- Better utilization of biogas engine generator during daily peak period;
- Using the power from biogas engine generator for gas compression during low power demand period.

How it should work? The main condition is to design the biogas engine generator to cover the daily maximum average peak load demand (plus 20% margin) during daily 8 to 10 hours shift, i.e., 210 kW. In this way the biogas engine generator would cover power demand during daily (Mo-Sat) shift operation.

During random hours, during holidays and weekends, as well as during the night, the engine would run at part load as necessary for Estate supply and biogas compressor (25) drive.

The biogas that will be produced in excess during off-peak period will be stored at appropriate pressure in compressed biogas tank (26). This tank could be designed for storage of several days' biogas production.

Another important optional system would be long fibre drying facility (9). Additionally to digester preheating the balance of gas engine waste heat can be used for sisal long fibres drying. This drying facility could be batch or continuous feeding system.
It would consist of simple building with fibres hanging or conveyor system, water air heat exchanger with air blowers (31) and an additional heat exchanger at engine side (20).
This drying facility would, especially during rainy days, considerably increase the long fibre quality and thus the income of the estate.

III.6 Staff training – facility operation

Before Facility operation, training courses at the highest level have to be conducted for plant staff. High sophistication levels of biogas technology require high levels of skills from the users. With a high training input, gaps can be bridged and proper facility operation and maintenance (O&M) can be ensured.

An operation and maintenance training program shall be developed that is consistent with the purposes of the Facility O&M practice, its intended life, safety requirements, and the criteria for its normal and abnormal operation. The training program shall include operation and maintenance requirements including but not limited to:

- Proper loading rate of the digester
- Proper operating level of the digester
- Digester temperature control
- Basics about methane production and recovery
- Safe storage of biogas
- Safe use or flaring of biogas
- Operation and maintenance of biogas engine – generator
- O&M of control and electrical systems
- Environmental considerations for handling/utilization of effluents
- O&M of other components and systems.

The training program shall emphasize the requirement of constant Facility control during its operation. The operational staff should be instructed that due to compounds in some of the feedstock, "slagging and fouling" could occur. Slagging, which is an accumulation of solid residues on parts of the combustion system and fouling, which is simply the accumulation of liquid or semi-liquid residue, can cause operational problems.

This should be highlighted as an important aspect of Facility operation and the operation and maintenance staff must understand how biomass differs from more commonly used fuels and how to prevent operational problems while using biomass for power generation.

III.7 Safety aspects

The consideration of health and safety issues has to be highlighted during the entire design, construction, commissioning and operation of the Facility.

Certain precautions should be observed in the operation of biogas systems. Biogas can be explosive when mixed with air in the proportion of one part biogas to around 10 parts air in an enclosed space. This situation can occur when the digester and or the biogas storage tank are opened for cleaning or repair. In such cases sparks and open flames must be avoided.

A biogas leak can be smelled if the hydrogen sulphide has not been removed from the biogas. No one should go inside large digesters and biogas holding vessels unless they have a companion on the outside that can get him out in case he needs help. Although the CH_4 and CO_2 of biogas are not poisonous, a person may suffocate if there is too much biogas and not enough oxygen in the air for breathing. Negative pressure in a biogas system shall not be allowed. Negative pressure occurs when the force created by the weight of the gases outside the biogas system is greater than the force inside the system. In normal operations the pressure inside the system should always be higher than ambient pressure.

A negative pressure would pull air into the biogas system and the mixture of biogas and air might explode. If that does not happen, the oxygen in the air will kill the biogas bacteria and the gas production rate will drop.

III.8 Project cost and economics

Anaerobic digester and gas engine power generation system costs vary widely. Systems can be a combination of off-the-shelf equipment with local materials. There are also several companies worldwide that build system components and provide turnkey solutions.

Factors that affect the overall cost are the Facility size and design, the local climate, and the availability and type of biomass waste material.

Partly below-ground, concrete digesters (as proposed for the Facility) have proven to be especially useful to agricultural communities in parts of the world such as Africa, South-east and East Asia and South America. The economy of proposed pilot demonstration Facility consists of large investments costs, limited operation and maintenance costs, mostly free sisal biomass waste, electricity purchase savings, and possible income from sale of electricity to TANESCO (Tanzania Electric Supply Company) and biogas to households. Additionally improved value of sludge as a fertilizer can be added to the income sources.

The preliminary studies recommended to build a pilot demonstration biogas-electricity generating installation to fix the operation and production parameters and develop the production know how. The figures presented below are estimates based on the available information and similar biogas plant experiences.

The Facility estimated price is US$ 512,020; this does not include the connection to TANESCO National network.

The estimated Facility's electricity production is about 1,050 MWh/year (150kW gas engine, capacity factor 0.85) plus the energy used for its own heating. Considering a 12 years period, the investment is therefore of US$ 0.041 per kWh. Additionally the Facility will produce added value products, i.e., around six ton/day of solid fertilizer and around 100 ton/day of liquid fertilizer that can be utilized for Estate own use or may be sold.

O&M will be normally 10-20% of annual (12 years period) investment costs, but it may vary much with later Facility organization, wages, type of Facility operation and eventual transport of sludge.

If O&M is 14% of investment costs, simple pay-back period is 12 years at zero interests, and no price can be set to value of the sludge (liquid and solid fertilizer), the resulting energy price will be around US$ 0.11/kWh, maintaining positive cash flow with IRR=0%.

However, the dynamic approach deals with a consideration of benefits and costs over several years and therefore shall be pointed out with more details.

Main investment criterion is the net present value (NPV), which is defined as follows:

$$NPV = \sum_{t=1}^{n} \frac{C_t - B_t}{(1+k)^t}$$

C_t - Costs in year t B_t - Benefits in year t k - discount rate
t - number of years from the present
n - total number of the years of the analysis period

Expected project cash flow and NPV are shown in the following Figure 4 and 5 respectively.

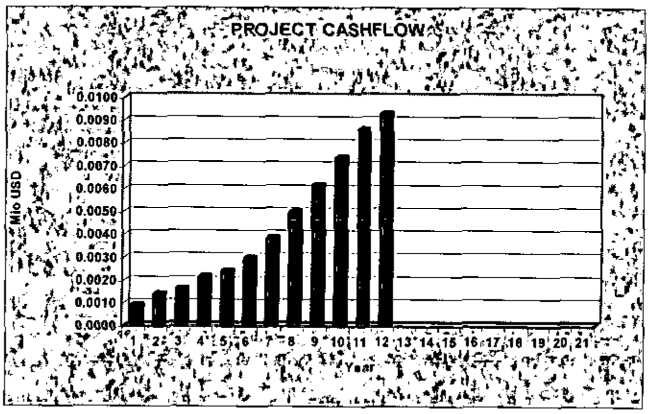


Figure 4

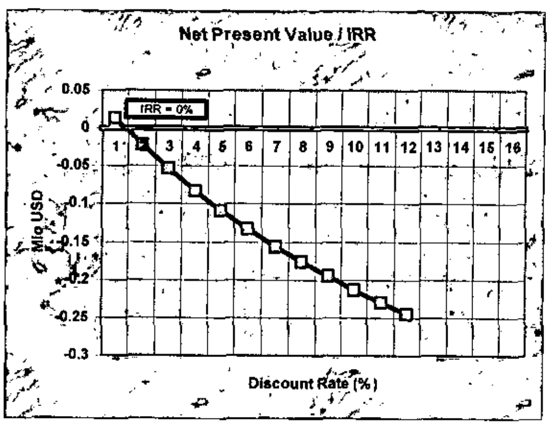


Figure 5

Final financial and economic data will be presented upon completion of the plant and availability of plant performance parameters.

IV. Conclusions and recommendations

IV.1 Conclusions

Sisal waste generated and accumulated without being properly disposed, has the potential to cause significant ground- and surface water pollution and also atmospheric pollution through methane generation. The use of sisal waste to generate renewable energy through anaerobic digestion provides a wide range of environmental benefits, in addition to the value of the biogas itself, as it is a waste treatment method that reduces environmental pollution and allows nutrients (fertilizers) to go back to the soil enhancing agriculture activities.

Evaluation of small scale biogas producing and electric power generating plants requires measuring and valuing all above mentioned aspects i.e. the biogas fuel production, the electric power output, the fertilizer output and at last but not least the environment protection. It can be said that the production and utilization of biogas have both direct and indirect economic benefits and social benefits.

The following can be concluded/highlighted:

- Sisal wet decortication process utilizes only the 2% of the sisal leaves and about the 98% of the biomass is considered waste, a mixture of short fibres, green material and the added processing water.
- The decortication process requires a lot of water and produces a huge amount of biomass waste, which eventually reaches groundwater or rivers causing water oxygen depletion and damaging the ecosystem.
- The anaerobic digestion process is an important alternative to sisal waste disposal and allows electric power generation. The anaerobic digestion is also an important measure to use sisal biomass waste resources efficiently, to improve sisal Estate profitability and long fibres production, to alleviate poverty and facilitate industrialization in rural areas.
- The biogas plants are producing energy that can replace fossil fuels, reduce CO_2 emissions, reduce smell and hygiene problems of sisal waste deposits, reduce potential CH_4 emissions from uncontrolled anaerobic degradation of the sisal waste, increase the fraction used as fertilizer and facilitate a more accurate use as fertilizer. Biogas use, replacing conventional fuels like kerosene or firewood, allows for the conservation of the environment. A critical shortage of energy, primarily of electric power, is reflected in high electric power market prices. Self-produced electricity from sisal waste can considerably improve Estate cash flow, production quality and profitability. The direct employment at biogas plants might be estimated to be 40 jobs.
- Biogas production programs, however, should not neglect the argument of improved yield, i.e. increases in Estate production as a result of the use of self-produced bio-fertilizer. Although improved yields through self-produced, biogas based, fertilizers are difficult to capture in a stringent economic calculation and for Estate-to-Estate comparison demonstration, they are very effective. Estates should be encouraged to record harvests on their plots, before and after the introduction of self-produced, biogas based, fertilizers.
- Biogas based fertilizer is a marketable product and existing Tanzanian transportation infrastructure might allow its transport at a reasonable cost.

- Savings from sisal waste controlled disposal costs will be regarded as a benefit of a biogas system as soon as stringent regulations will be issued on sisal waste.
- The production of biogas and utilization of biogas for electric power production creates national wide effects on energy balance.
- The price of supplied energy produced by biogas competes with prices on the national or regional level of the electric power market. Monopolistic practices, which enable energy supplier to sell his energy at a very high price level still dominate the energy market in Tanzania. A decentralized, economically stable and self-sufficient biogas plant therefore - under competitive conditions - provides its energy without market distortions.
- Furthermore, other benefits arise when comparing on the one hand the benefits of decentralized power generation (mainly reliable and safe power supply, lower power unit price) and the disadvantages of centralized power generation (mainly black-outs and power unit price) from Estate's economic point of view.

IV.2 Recommendations

Quality and costs are essential to make this pilot demonstration biogas production and power generation program successful and allow for a self-supporting dissemination process, and for the provision of design standards and in production efficiency.

Taking into account the calculated biogas production of anaerobic digestion and related electric power generation, the proposed biogas technology offers a very attractive and the most economic solution for Tanzanian sisal Estates and sisal long fibres production plants and it is recommended for implication. In order to disseminate efficient utilization of sisal waste for biogas production and electric power generation not only nationwide but also in other countries as well as in order to bring this Project to a successful completion, the following recommendations shall be considered:

1. Based on the findings of this report, it is evident that an anaerobic digestion system in sisal decortication plant is economic when:

- It can replace imported expensive electric power by self-generated electric power;
- It can use and/or sell self-produced solid and liquid fertilizer fraction at a reasonable price to other Estates or agricultural producers;
- Fines or levies for improper/illegal waste dumping are paid to the local authorities.
- The produced biogas should cover the base-line Estate's energy demand, while the peaks may be covered with an imported energy from TANESCO distribution network.
- The produced excess biogas or electric power can be sold and/or exported;

2. Optional systems, waste heat utilization for long fibres drying and biogas compression and pressurized biogas storage should be considered for application. If all factors for optimal integration are carefully evaluated, the running costs of an installation will automatically be as low as possible.
3. For successful and smooth Project implementation and completion it is absolutely necessary to continue and/or establish close co-operation with all responsible Tanzanian Authorities.

4. Professional technology dissemination, marketing approach, training courses for consultants and engineers, as well as introductory seminars with site visits for politicians should be organized. An international coordination would certainly speed up the process.

The following design features should be implemented:

- The Facility designer and supplier shall aim at carrying out the design and construction of the Facility without any imported materials in the long run. The lower the import content of the total plant costs, the less the external diseconomies which may arise in consequence of sliding exchange rates.
- Whenever possible, sunken digesters should be built. They do not need pumping, either from the inlet tank into the digester, or from the digester into the storage tank. The investment cost for pumps is low, but their lifetime is very short, and replacement costs are high.
- Heating systems are preferably built of plastic materials, in order to prevent corrosion by differences in galvanic potential.
- Before any design concept is initiated, it should be ensured that this concept is satisfactory from a purely technical point of view (which has to be proven in practice) and that the system is optimally integrated into the existing Estate infrastructure.

Printed in Austria
V.06-51510—June 2006—200

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Telephone: (+43-1) 26026-0, Fax: (+43-1) 26926-69
E-mail: unido@unido.org, Internet: http://www.unido.org