# A floating dome biogas digester: perceptions of energising a rural school in Maphephetheni, KwaZulu-Natal

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***Abstract***
*The purpose of this study was to investigate whether biogas technology could provide a school with an acceptable, affordable, efficient and sustainable alternative energy resource, thereby providing opportunities for cost savings, income generation and greater opportunities for education. The school selected for this study was Myeka High School, situated in rural Maphephetheni village, KwaZulu-Natal. The school was not connected to grid electricity and was using solar PV energy and LP gas to support its energy needs. A floating dome biogas system, which operated on human excreta and cow dung, was donated to the school to supplement the school's energy needs. Data was collected using both qualitative and quantitative techniques.*

*Results revealed that the biogas was an acceptable source of energy because the school used the biogas for cooking and refrigeration. However, it was not affordable as savings on energy expenditure of the school could not offset the original cost of the biogas system unless a capital subsidy is applied. The long-term benefits on the educational environment cannot be underestimated. Biogas energy was found to be both efficient and sustainable, provided proper management was in place. In spite of this, findings indicated a lack of appreciation of how the system functioned by teachers and students; the need for more thorough and ongoing education of users before and after installation; the need for robust toilets and washbasins; and on the difficulties in getting the system fully operational in the limited time span for evaluation. Although income generation opportunities through biogas were not utilised at the school, there was an opportunity for income generation through biogas generation, provided there was encouragement, support and markets available.*

*Keywords: biogas, Myeka High School, rural electrification, school energisation*

## 1. Introduction

The availability of sufficient energy is important for improving people's living standards, and also for developing the local economy (Sokona 2002). Large businesses, hospitals, households, schools and other institutions are dependent on energy, which could be traditional or conventional energy, to run their daily activities, both for profit and for the well being and development of communities (Foley 1990). The problem with conventional energies such as LP gas, paraffin and grid electricity is that they are expensive for low-income communities. Grid electrification is by far the most common method of providing energy for rural and urban people because it is envisaged that by providing communities with electricity, economic development and an improved standard of living for people is achieved (Seeling-Hochmuth 2002). This means that rural grid electrification could be the answer to rural energy needs.

However, electricity is mostly provided to urban areas, leaving the rural people with no option but to rely on more expensive, less available or less convenient energy sources such as wood, paraffin or LP gas (Theron 1992). One of the reasons for the non-electrification of rural areas is that of the high investment required for installation from the service provider. Rural areas are sparsely populated and far from main roads where electricity power lines are often situated, therefore making it expensive for the service provider to connect a low number of consumers along a particular length of line (Mapako 1997). In addition, the amounts of energy consumed are generally low, providing an insufficient return on investment. This lack of availability of grid electricity leaves rural communities with few options, one of them being renewable energy.

Renewable energy is an ideal alternative because it could be a less expensive option for low income communities and an ideal renewable energy source is one which is locally available, affordable and can be easily used and managed by local communities. One of the renewable energy sources that can provide an alternative for conventional energy sources is biogas that uses cow dung, human waste and agricultural residues to produce energy (Keyun 2001).

The South African government has realised that renewable energies could play a very important role in supplementing other existing energy sources (DME 2002). Their realisation is reflected in the Department of Minerals and Energy (DME) White Paper on Promotion of Renewable Energy and Clean Energy Development released in 2002. The objectives of the government outlined in the document are twofold: making renewable energy accessible and affordable to the people and ensuring that it contributes to sustainable development in a manner that conserves the environment. Although this is still a draft policy document, it reflects the commitment of government towards renewable energy. The White Paper sets the principles, goals and objectives that government proposes towards achieving an enabling environment for renewable energy. In the document, biogas is mentioned as one type of renewable energy to be focused on (DME 2002).

With the support of the DME and other institutions, the objectives of the government was put to the test by implementing a biogas pilot project in a rural high school to assess the benefits that biogas energy could bring to such an institution. Biogas technology is rare in South Africa, with few projects in evidence but not properly monitored and evaluated (Solar Engineering Services 2001). Therefore, this study is unique in that it envisages doing what other projects have not done, that is to monitor and evaluate a biogas project from the beginning. However, it does not include quantitative measures of the gas produced per input or the energy balance within the digester.

## 2. Biogas / methane gas

Biogas technology produces methane, a clear combustible gas produced when organic matter contained in animal and human excrements and agricultural residues such as cassava, sugar cane are mixed with water and anaerobically fermented in airtight containers called biogas digesters (Hislop 1992; TERI 1994). The anaerobic fermentation process, also called methanogenesis, involves three stages (Lawbury 2001; Santag 2001). The first stage is hydrolosis, whereby organic waste is broken down into simple soluble compounds by fermentative bacteria. The second stage, acidification, acid-producing bacteria convert the end products of stage one into acetic acid, hydrogen and carbon dioxide. Acetic acid is most important as it accounts for approximately 70% of methane produced. The last stage whereby hydrogen, carbon dioxide and acetic acid are decomposed by methanogenic bacteria produces mainly methane and carbon dioxide. Approximately 60% methane ($CH_4$) and 40% carbon dioxide is produced with traces of other gases such as hydrogen, nitrogen and hydrogen sulphide. All these stages take place in the biogas digester when it has been fed with organic matter and water at a ratio of 1:2. The produced gas could be used for cooking, lighting, refrigeration or to generate electricity.

Temperature affects the production of biogas. The temperature at which the stages of biogas formation take place is very important and needs to be kept constant. The methanogenic bacteria, which facilitate the formation of biogas, are very sensitive to temperature changes and the optimum temperature for the bacteria to operate is between 33-38° Celsius (Lawbury 2001). Temperatures below this slow down the biogas production process, while a higher temperature than necessary kills the biogas-producing bacteria. This is why the structure for biogas production is generally built underground, to keep the temperature as constant as possible (Lawbury 2001).

Generally cow dung is used to generate biogas, but human excreta has the potential to produce biogas as it contains similar matter to cow dung (Srivastava 2002). Additional water and cow dung is not normally required when the biogas digester is connected to a flush toilet that provides excreta, urine and flush water. Although human excreta can be used to produce biogas energy, which is of benefit to people, negative connotations are attached to it. Some people may view the biogas produced from human excreta as dirty and not fit to be used, especially for cooking. Despite the negative connotations, countries like China have been using biogas produced from human excreta wherever possible. In India, about 4 600 public flush toilets have been connected to biogas digesters by a local NGO working to improve the social conditions of the people (Srivastava 2002). Nepal also has taken to using human excreta for biogas generation whereby in a village called Jantemod, public toilets have been connected to biogas digesters and the gas generated has been used for lighting inside and outside the toilets for safer public use (Karki & Gautam 2000). This reflects a growing trend towards using human excreta for biogas generation.

## 3. Description of the study area and Myeka School

Maphephetheni is a rural village situated approximately 60 kilometres west of Durban in the Valley of a Thousand Hills. The village has two sections, the more remote uplands and a lowlands, with an estimated population of around 8 000 people. It is sparsely populated with dirt roads that are poorly maintained. There are three high schools that go up to grade 12 and Myeka High School is one of them (Green & Erskine 1998).

Myeka High School offered classes from Grade 8 to Grade 12 with 24 teachers, 850 students and 16 classrooms. It was the only high school in the area that boasted renewable energy technology. The other two high schools had no power supply at the start of the project, although the school closest to Durban was later connected to grid electricity. Myeka High School had 14 Photovoltaic (PV) solar panels that provided energy for the school's teaching aids and lighting. LP gas was used to power a generator, which supplemented the solar energy, and also to run the Home Economics room appliances (Dube 2002). The biogas was intended to replace this LP gas provision.

## 4. Aim of the study

The aim of this study was to investigate the acceptability and feasibility of a large size floating dome biogas system at Myeka High School. The PV solar system did not provide sufficient power to the school and the school regularly experienced problems of energy shortages. This forced them to use LP gas extensively, which was very expensive for the school and often could not be purchased because of financial constraints. Therefore, the biogas was seen as having the potential to provide the school with supplementary thermal and electrical energy and, at the same time, to provide opportunities for income generation for the school.

The plan was to keep a few cows at the school, which would provide cow dung for the biogas digesters for weekends and school vacation time, and also to be part of the taught subject of agriculture. A vegetable garden and grass cultivation were part of the planned project and were going to require the fertiliser, an end product of the biogas generation process. The vegetables and fertiliser were to be sold to the community to generate income for the school. The grass was to be fed to the cows.

## 5. Methodology

Myeka High School was selected as an opportunity to study biogas technology in action because it was the only school in the area already using some other forms of renewable energy technology, and also the principal was receptive and supportive of renewable energy for his school. The school was equipped with pit toilets and one potable water tap.

A pre-installation survey was carried out at the school to determine the required capacity of the biogas digesters through identifying eating patterns and toilet usage of students at the school. Functioning of the biogas system was much dependent on how often and how much human excreta the students passed during school days. Structured interviews using questionnaires were carried out with an original sample of randomly selected 207 students from a population of 850, but only 194 students provided useable questionnaires. Students from the school were selected and trained to conduct the interviews in isiZulu.

To accompany the biogas technology, the school was to be equipped with 16 flush toilets, two floating dome biogas digesters and water harvesting equipment. The biogas system was built using local labour. The two floating dome biogas digesters had a constant gas pressure, which ensured a steady gas supply dependent on correct feeding of the biogas digesters. Each biogas digester had an inlet hole, an underground storage tank with a steel gasholder dome placed on top and an outlet hole (see Figure 1). The inlet hole was used for mixing and feeding in cow dung and water during school holidays and weekends to compensate for the absence of human excreta. The storage tank built underground was where the anaerobic processes of methane production took place. When the biogas had been produced, it was stored in the top steel gasholder, which was connected by pipes to where it was needed. Round water seals were built on top of the underground structure so that the gasholder domes could float in the water and trap the gas until the pressure became too great. The water then allowed excess gas to escape. The outlet allowed the fertiliser residue to escape.

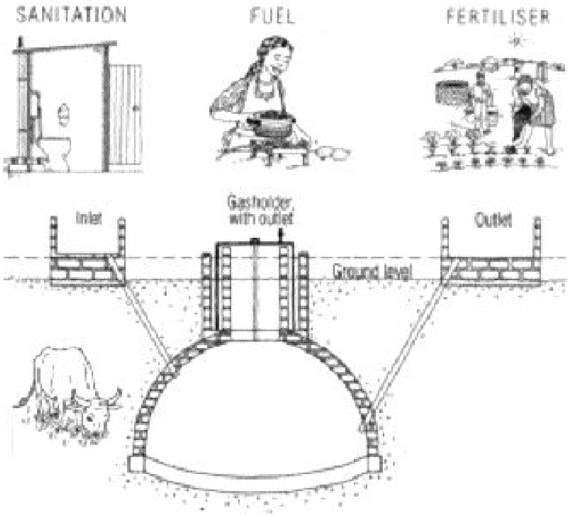

**Figure 1: How the biogas system works and its benefits**

Flushing water to the toilets came from the school's existing water system, but rainwater harvesting was incorporated into the biogas system so as to compensate for the expected increased water requirements by the school. After the priming period with cow dung and water, the biogas digesters started producing gas, which was piped to a gas cooker and used to cook food for the staff working on the project. A fridge and stoves in the school's

Home Economics Room were also connected to the biogas and for a period of two months while the researcher was monitoring the appliances, they functioned well. Staff and students were very happy because the appliances had not been working for some time due to the lack of finances for purchasing LP gas. For electrical energy to be supplied, a converted diesel generator was connected to the biogas supply towards the end of this study.

A post-installation survey was also carried out after the commissioning of the biogas system to evaluate the use of the new toilets, student knowledge of the biogas system and management system. Two hundred and twenty randomly selected students were interviewed in IsiZulu but only 175 useable questionnaires resulted. Trained student interviewers were again used for this survey. Input from the school principal, the secretary and teachers involved in biogas system management was also sought.

## 6. Results and discussion of the pre-installation survey

In the pre-installation survey, it was found that 124 (63.9%) of the students always ate breakfast, 40 (20.6%) never ate breakfast while 30 (15.5%) sometimes ate breakfast. Breakfast was separated into heavy and light meals and results showed that 157 (80.9%) of students consumed breakfast that was regarded as a heavy meal, while during lunch break at school, 161 (83%) of the students ate a heavy meal. These results reveal that more than three quarters of the students consumed heavy meals and, therefore, could be expected to use the school toilets substantially and often.

Students were also asked whether they used school toilets during school hours. Out of the 194 students, 171 said they used the school toilets and 23 (11.9%) said they did not. A number of the students (33%) urinated twice during school hours while most students (54%) defecated once a day in the school toilets (see Table 1). A chi-square analysis was carried out to see whether there was relationship between the type of meal a student ate and toilet use for defecation. This revealed an insignificant relationship between eating a light or heavy meal for breakfast and defecation (p=0.42 for light breakfast, p=0.40 for a heavy breakfast). Therefore, it meant that the type of meal that a student ate did not influence the frequency of using of school toilets in this study.

**Table 1: Students urinating and defecating at school**

| *Urinating per day* | *Number of responses* | *Percentage* |
|---|---|---|
| Once | 39 | 20.1 |
| Twice | 65 | 33.5 |
| Three times and more | 40 | 20.6 |

| *Defecation per day* | *Number of responses* | *Percentage* |
|---|---|---|
| Once | 105 | 54.1 |
| Twice | 34 | 17.5 |
| Three times and more | 7 | 3.6 |

The students who did not use the toilets and those who did not like the school toilets often were asked why. Students had a choice of giving more than one reason. Eighty-eight (45.4%) students mentioned reasons of hygiene (toilets not clean, no basins to wash hands), 69 (35.6%) mentioned personal reasons (not being able to relieve oneself when there were people waiting outside and only using home toilets), 48 (24.7%) mentioned toilets built badly (no lights, no doors, uncomfortable seats) while 11 (5.7%) mentioned constipation. Students were asked to give suggestions as to what they thought should change for the toilets to be user friendly. They also had an option of giving more than one suggestion. One hundred and fifty nine (82%) students mentioned building of good toilets (proper lighting, comfortable seats and lockable doors) as something they would like to see happen, while 130 (67%) mentioned cleanliness. The need for toilet paper in the toilets was mentioned by 51 (26.3%) students. These results showed that well built and clean toilets were thought to be the most important incentives for toilet use.

## 7. Discussion on capacity required

The capacities of the biogas digesters were based upon the results of the pre- installation survey. A human being could be expected to pass about 33kg to 110kg of faeces and 365 to 550kg of urine in a year (Anon 2003). If 365kg of urine was used for this study, then a person would pass 1 litre of urine per day (24 hours at 1ml = 1gram). In this case students spent, at the most, six hours at school, which translates into 0.25 litres. On average a person would pass 72kg faeces per year, which could translate into 200 grams per day.

Assuming that faeces have 50% greater density than water, then it would be 0.3 litres per day plus 1 litre flushing of the toilets which equals 1.55 litres. Eight hundred and fifty students would pass about 1125 litres a day, using the results that more students use the toilets once a day and assuming that better built toilets would encourage all students to use the toilets at least once a day. Retention time in the biogas digesters was 40 days (Solar Engineering Services) so then 1125 litres = 45 000 litres storage was required. This capacity was divided amongst two large floating dome biogas digesters that were installed at the school. The 16 flush toilets were built around each, and were connected to the two biogas digesters (see Figure 2). The toilets system provided eight for girls and eight for boys.

Figure 2: The biogas digester connected to flushing toilets at Myeka High School

## 8. Results and discussion of the post-installation survey

In the post installation survey, conducted after commissioning of the biogas system, students were asked questions relating to their toilet use, their knowledge and management of biogas. Out of a sample of 175 students, 143 (81.7%) were using the new school toilets while 32 (18.3) students were not. This survey was carried out before the old pit toilets were demolished, so some students were still using the old toilets to relieve themselves. From both the pre-installation and post-installation surveys, when looking at old and new toilet use, there was not much change. Students who used the new toilets were asked what they liked about the new toilets and they had a choice of giving more than one response. About half the students (47.4%) mentioned the fact that the toilets were flushable followed by cleanliness of the toilets mentioned by 44 (25.1%) students. Other reasons given were that the toilets were built nicely and there was toilet paper provided. The students really liked the idea of flushable toilets.

Students were asked what they did not like about the toilets. Again they had a choice of giving more than one response. Toilets being difficult to flush (no water coming out and the waste is left lying visible was mentioned by 94 (53.7%), while ten (5.7%) mentioned safety (biogas exploding if in contact with fire) as their dislike. One student said he had no place to smoke as smoking was prohibited in the new toilets. The rest of the students had no dislikes about the toilets. These results revealed that dirtiness of the toilets was the main reason for non-usage due to too little water or pressure being too low per flush. Students who did not use the toilets explained why. Fifteen (8.6%) students mentioned dirtiness of toilets, 12 (6.9%) said it was because of personal reasons. Nine (5.1%) mentioned that the toilets were difficult to flush while three (1.7%) said they did not use the toilets because they were not safe as the biogas system, including the toilets, might explode if in contact with fire (see Table 2).

**Table 2: Reasons for not using the toilets (n=32)**

| *Reasons given* | *No. of responses* | *Percentage* |
|---|---|---|
| Dirty | 15 | 8.6 |
| Personal | 12 | 6.9 |
| Difficult to flush | 9 | 5.1 |
| Not safe | 3 | 1.7 |

In both surveys, students had mentioned personal reasons and hygiene / dirtiness as the reasons why they did not use the toilets. This might mean that the changes that took place with the toilets were not adequate. Most of the toilets were not working due to problems with the flushing mechanism. Water pressure in the toilets was too low and they had to be changed from a 1 litre to a 4 litre flush, which still did not work very well.

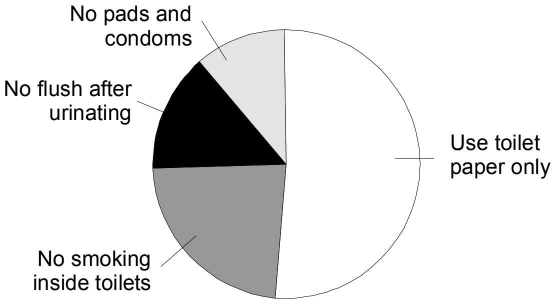

Figure 3: The topics remembered from talks on biogas

Students were asked whether they were given any information on how to use the toilets. More than ¾ (86.3%) said yes. Teachers reported that each class was given a talk and demonstration on the working of the biogas system and toilet use in isiZulu during the term before it became operational. The kind of information reported by the students included using only toilet paper in the toilets (58%) (see Figure 3). Knowledge about how the biogas worked was assessed. More than half of the students (66.3%) did not understand how the biogas system worked, despite explanatory talks given in isiZulu by teachers. Some of the science students had built a biogas digester model to be shown at the World Summit on Sustainable Development, which was on display at the school. This had obviously not really helped the majority of the students to understand the functioning of the biogas system. They were also asked where they got the information. Almost three quarters (74.9%) of the students received information from the teachers who were the major source of information.

Few students were involved in biogas/ toilet management, (2.9%) and were probably members of biogas management committee, which was formed with students and teachers. The initial plan was to involve classes by rotation in biogas maintenance and toilet monitoring, but this apparently did not happen. Eighty-three (47.4%) students mentioned that there was a hired person to manage the toilets, 56 (32%) said they did not know, while 18 (10.3%) said they thought the teachers did. Others (engineers and other people not from the area) were mentioned by 13 (7.4%) while only five (2.9%) mentioned other students as managing the biogas / toilets.

In reality, two people were employed. One lady was hired to clean the toilets and issue toilet paper to the students, while one man was hired to feed the biogas digester with cow dung and water when needed and to repair the biogas system and toilets. The question on what students perceived as the benefits of biogas provided for a choice of more than one response, as it was an open question. Responses revealed that almost three quarters (84%) of the students viewed the biogas as producing gas and generating electricity to run appliances (see Table 3). This shows that the main outcome of the biogas system was well known to the students but the functioning was less well understood.

**Table 3: Perceived benefits of biogas**

| *Benefit* | *No. of responses* | *Percentage* |
|---|---|---|
| Gas and electricity | 147 | 84.0 |
| Do not know | 24 | 13.7 |
| Fertiliser | 8 | 4.6 |
| School saves energy spending | 4 | 2.3 |

### *8.1 General comments given by students*

Students were also asked to give general comments on the whole biogas system. Some examples of these were that tourists would be attracted to the area because of the biogas system and their school would be popular around South Africa as the first one to use biogas. The educational standard at the school would be better because teaching aids would be available for use most of the time.

Other comments were that they would like the toilet doors to have internal locks, hand washing basins and taps to be replaced as they were already broken and although much emphasis was placed on how to use the toilets to students, some still did the wrong things such as smoking in or behind the toilets. There was general enthusiasm for the idea of biogas digesters, but for some a lack of motivation to change behaviour was apparent.

### *8.2 Perceptions from the principal, secretary and the management committee*

The school secretary was interviewed to collect information on energy expenditure by the school. She reported that the school had been using LP gas to run the fridges and stoves in the Home Economics room. It was a 20kg cylinder, which they refilled twice monthly at a local shop. It cost the school R224 every month for the Home Economics room alone. Spending on LP gas to supplement the solar PV energy supply when there were problems was about R896 per month. The potential savings for the school, by using biogas instead of LP gas was therefore R12 440 per year. However, the payment of the cleaner and biogas maintenance officer would need to be subtracted from this amount. They each earned R200 a month.

The school principal reported that solar PV panels, donated by Eskom and Shell, had problems in that when the sun was not shining, energy produced by the solar panels was very low and sometimes did not function at all. The principal also said it was impossible for the school to use all its electrical equipment at the same time as the system would trip. Criminals also targeted the solar panels and about nine panels were stolen and not replaced, reducing the amount of electricity available to the school. Therefore, he saw biogas as having the potential to supplement the power supply of the solar system, and the increasing energy needs of the school. However, he also felt that the extra management required by the biogas system placed an additional load on him and the teachers. This was outside their conventional roles as principal of the school and as teachers, as they were already very busy with their educational duties. The principal was not very happy about the attention that the biogas system demanded. In addition, the generator was not yet functioning, which was very disappointing.

There were other problems experienced with the biogas technology. The cleaner had used cleaning fluid to clean the toilets and consequently the methanogenic micro-organisms had died and it took almost three months for them to reactivate.

## 9. Income generation from biogas technology

Volunteer community members managed the vegetable garden, which was planted before the biogas digesters were commissioned. The vegetable garden disappeared after three months due to lack of proper management, as community members seemed to have lost interest in it. A very low yield of crops was produced and the Home Economics class used this for practicals.

The biogas digesters had not yet started producing fertiliser, therefore, none were used on the crops. Although no income was generated through the sale of fertiliser and crops, the school had saved slightly on expenditure for vegetables for Home Economics practical classes.

## 10. Discussion and conclusions

Because the school did not have flushing toilets and biogas before the project, it was important to teach the students how the system worked so they learned to appreciate what it could do for them. From the results of the survey, not even half of the students knew how biogas worked. On toilet use, there were fewer than half of the students who remembered information on how to use the toilets. It could be concluded that either the information given was not clear and sufficient or the students just did not follow the rules on toilet use. Involvement of the students is essential as they are the main users of the toilets and benefit from biogas. Lack of involvement translated into lack of support in the project. Few students viewed biogas as something that would economically benefit the school but they knew that the biogas would provide the school with gas to run appliances and also to generate electricity.

Because of problems experienced with the biogas digester, such as poor design of the toilet flushing mechanism, the water pressure being too low for the bowl, and the use of cleaning fluid, commissioning of the system was delayed. Although the biogas had been connected to provide energy to a fridge and a stove in the Home Economics room for two months, the gas generator was not yet operating in a trouble free manner. The methane from the biogas system had been connected to an adapted diesel generator and there were a number of hiccups that still needed to be sorted out. An adequate regulator was needed to control surges and the generator did not function properly.

Some concrete results were available to draw a solid conclusion on the sub problem ‘does a large capacity floating dome biogas digester have the potential to provide a school with energy that will provide acceptable, affordable, efficient and sustainable alternative to existing forms of energy and also increase opportunities for income generation?’ What can be concluded was that the biogas was found to be acceptable to the school as most students and teachers were happy with the new innovation because it would upgrade the standard of teaching and learning at the school through the provision of gas. The Home Economics class was happy to use the gas for cooking and refrigeration. The principal accepted biogas but felt that its management was going to be an extra burden to him and the teachers. The biogas system was efficient as it provided gas to the Home Economics room for the two months of the monitoring with no expenditure. The converted diesel generator was never commissioned because of a fluctuating power supply. It was to be connected at a later phase of the project. It is essential that a maintenance engineer be available to sort out problems and misunderstandings on the biogas system. No income generating activities took place at the school during this time period. The sale of fertiliser and vegetables never took place, because there was no proper management of the vegetable garden and the fertiliser was never collected in containers for sale. However, during a subsequent visit, the vegetable gardens were extensive and impressive.

As a general solution for rural schools’ energy needs, the biogas energy holds great promise. However, policy must allow for major subsidy of the capital cost (which because it uses mostly local labour and materials, contributes to the local economy). There should also be adequate engineering management support, which should become less demanding as time goes on. Toilet mechanisms and water taps need to be of excellent quality and water supplied at adequate pressure. Students and teachers and maintenance staff should also all receive satisfactory training to understand biogas and toilet systems. Technology for using biogas for the generation of electricity still needs to be refined.

## Acknowledgements

Funding for this study was provided by the National Research Foundation (NRF).

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*Received 15 December 2003; revised 28 February 2005*