Small-scale Electricity Generation from Biomass

Experience with Small-scale Technologies for Basic Energy Supply

Part I: Biomass Gasification

gtz HERA Poverty-oriented basic energy services

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Preface

Energy is essential for human development. Without an adequate basic energy supply people cannot cook their food, light their homes or keep essential medication chilled. Alongside the introduction of efficient and clean thermal use of traditional biomass for cooking, the provision of electricity from renewable energy sources can provide basic energy services for lighting and communication and promote local economic growth.

Renewable energy from photovoltaics, wind turbines and small hydro plants is highly suitable for off-grid electricity supply and has been successfully introduced in countless cases in developing countries. However, although the application of biomass as a sustainable electricity source seems promising, it is still seldom perceived as an option for providing electricity for the rural poor.

In order to generate electricity, biomass can be combusted, gasified, biologically digested or fermented, or converted to liquid fuels propelling a generator. Several research institutions and international agencies rate biomass as one of the cheapest available renewable energy sources for power generation. Furthermore, conversion from biomass to electricity is a low-carbon process as the resulting CO_2 is captured by plant regrowth. In contrast with solar PV or wind power, biomass power technology can generate electricity on demand at any time, as long as a sufficient supply of biomass stocks is assured. Many agricultural and forest product residues can provide feedstock for energy conversion without increasing land requirements. Local farmers can generate additional income by providing biomass fuels for small local power plants.

However, despite the apparent benefits, there has been little experience of implementing small electricity-generating biomass plants in off-grid areas of developing countries. In approaching this issue, the GTZ programme “Poverty-oriented Basic Energy Services” (HERA) assessed the lessons learned from GTZ and non-GTZ pilot activities and thus identified the most important potentials of and obstacles to different biomass power technologies. This assessment resulted in a **three-part series of papers on “Small-scale Electricity Generation from Biomass”** covering **biomass gasification (part I)**, **biogas (part II)**, and **plant oil (part III)** for electric power generation.

1 Introduction

It appears to be a fascinating solution: The conversion of wood or other carbon-rich dry biomass into a combustible gas and then into electricity via a generator set – a perfect solution for remote rural areas with a lack of electricity but an abundance of shrubs, straw, rice and peanut husks or other forms of biomass.

The technology has been well known for more than a hundred years. In light of rising prices of fossil fuels in 2008 and the debate about climate change, this technology has again come under consideration as a renewable energy source in rural areas. In fact, it is possible to convert dry wood or rice husks into gas and electricity. However, it is not as easy as some manufacturers would like to make us believe.

The Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) on behalf of the German Ministry for Economic Cooperation and Development (BMZ) has been searching for sustainable solutions to provide access to basic energy services in rural areas and has analysed experiences with small-scale applications of the gasification technology over the last decades. This analysis was based on publicly available documents, as well as interviews and email discussions with experts in this field. This text summarises the results, revealing several difficulties and challenges. It refers to small-scale applications of less than 100 kW only and focuses on potentials for providing basic energy services to rural households and small businesses.

2 The Technology

Biomass gasification is basically the conversion of solid fuels like wood and agricultural residues into a combustible gas mixture. In order to produce electricity the generator gas is used as a fuel in an electric generator set with a combustion motor.
The gasifier is essentially a chemical reactor that uses wood chips, charcoal, coal or similar carbonaceous materials as fuel and burns them in a process of incomplete combustion due to a limited air supply.
Products of the gasification process are

- solid ashes
- partially oxidized products like soot (which have to be removed periodically from the gasifier) and
- generator gas.

The main flammable components of the resulting generator gas are

- Carbon monoxide (CO),
- Hydrogen (H_2), and
- Methane (CH_4).

Due to its high content of nitrogen (more than 50%) and other incombustible components this producer gas has a low calorific value compared to other fuels. The calorific value of generator gas is only about 5 -6 MJ/kg versus 35-50 MJ/kg for natural gas.

There are many different gasification methods in use or in development, but the downdraft fixed-bed technology is almost exclusively used for small-scale power gasifiers. This is the only economic option on a small-scale that also produces a fairly clean gas. Models with batch or continuous feed are available.

Theoretically, electricity can be produced by various kinds of technical equipment, for example a combustion unit in combination with a steam turbine, a gas turbine, a Stirling motor, or even a fuel cell. In practice internal combustion piston engines are almost exclusively used to drive electric generators for the small-scale applications discussed here. Apart from some minor adaptations, this generator set is more or less the same as used with other fuels. Spark ignition “Otto” engines as well as compression ignition “diesel” engines can also be used. While the Otto engines can be operated on generator gas only, diesel engines generally need co-fuelling of conventional diesel fuel.
However, all internal combustion engines require a very clean gas as a fuel. Otherwise excessive engine wear and low power output will inevitably occur. Therefore a cleaning system is an essential component of a gasifier plant. Cleaning systems that use water to wash out the undesired components are quite efficient. However, they produce a high quantity of toxic and carcinogenic liquid waste. Hence, dry cleaning systems are the preferred solution in non-industrial systems today.

The gasification technology is principally well suited for small power plants ranging from 10 kW to over 100 kW. Appropriate gasifier systems with internal combustion engines can produce 1 kWh of electricity from 1.1 – 1.5 kg wood, 0.7 – 1.3 kg charcoal, or 1.8 – 3.6 kg rice husks. Assuming the wood originates from renewable production – regardless of whether planned forestation or natural regeneration - it would be a perfect, nearly CO_2 neutral, renewable energy source.

Hence, this technology seems to be a very interesting solution for many initiatives and projects in times of the climate change debate. The general features of the technology are indeed promising: In contrast to a photovoltaic system or a wind generator, electricity can be produced at any desired time given the availability of the required biomass. A generator in the range between 10 and 100 kW provides sufficient energy not only for household lighting,

but for televisions, refrigerators and the operation of small machinery as well. In addition, the provision of fuel in the form of wooden sticks or agricultural waste can be a source of income for small farmers and an incentive for reforestation.
However, the following documentation of practical experience shows that there are still many obstacles to overcome.

3 Existing Experience in Different Countries

Gasification of biomass or coal is a relatively old technology. Town gas in Western European cities was produced by the gasification of coal before natural gas became widely available. By 1850, large parts of London had gas lights powered by the gas produced from gasifiers using coal and biomass. With the increasing availability of other energy sources and electrification the technology lost its importance.
In the early years of the 20th century, gasifier systems to power stationary engines and trucks were demonstrated but did not gain general acceptance. The technology reappeared only after petroleum fuels became scarce during World War II. Almost one million gasifier-powered vehicles were in use during that time. However, with increasing availability of diesel and gasoline this rather inconvenient technology was again abandoned.
The energy crisis of the 1970s and 1980s again triggered interest in gasification technology. By the 1980s about 15 manufacturers were offering wood and charcoal power gasifiers. Amongst others, DGIS, GTZ, and SIDA began financing and running pilot gasifier power systems in several developing countries. Brazil, China, India, Indonesia, the Philippines and Thailand had gasifier programmes based on locally developed technologies. In some cases the technology was promoted by local entrepreneurs. However due to frequent technical problems and decreasing petrol prices the interest in this technology again disappeared rapidly.

Only large-scale industrial applications and plants for heat production have achieved some economic success and become fairly common. Biomass gasification is used quite successfully in Scandinavia, especially using residues of the wood, pulp and paper industry. (IEA, 2004)
However, worldwide the development and construction of new small and medium-size gasification plants has once more gained momentum during the last decade parallel to the discussions on climate change. In particular the guaranteed high feed-in tariffs in Germany have triggered the installation of about 50 gasifier power plants.

The experience with the gasifier power plants constructed in the last 30 years is the background for this appraisal summary, even if it is very hard to obtain reliable detailed data especially concerning long-term operation. Manufacturers promote their gasifiers with performance figures. However, these rarely seem to be based on practical operation. The projects that use the gasifiers publish their use as success stories, but apparently only rarely collect reliable long-term data. Tracking the operational history of a gasification plant is in many cases almost impossible. It is for that reason that the information provided may contain minor contradictions. Nevertheless, there are some important studies available that relate personal observations by experts and allow for a conclusive statement.

A comprehensive World Bank study in 1998 examined gasification plants installed in the 1980s and came to the following disillusioning results: Most gasifier plants had been taken out of operation. After just a few years only 11 of the 24 installed gasifiers in Indonesia were still in use. In the Philippines only 1-5 % of the gasifiers installed 3-6 years earlier were still operating. Results from other countries were similar. The detailed analysis of the status of 24 gasifiers in Indonesia revealed: “Almost none of the projects identified became fully commercial, and most proved unsustainable for technical, financial/economic, and institutional reasons” (Stassen, 1995). Only with significant subsidies did some of the examined gasification projects produce some benefits for the users. The reliability of many gasifier systems installed in the 1980s proved to be low compared to conventional options. The study found only very few cases where the gasifier plant operated more or less efficiently, continuously and reliably. But even in those few cases severe technical problems had occurred at the beginning. Only through the steady commitment of the gasifier company or other external experts could the plants be modified and adapted to local conditions in a way that made technically sound operation possible. However, even one of the most promising examples in the study, a gasification plant in Vanuatu, stopped its gasification-based operations eventually. Although permanent technical support had achieved stable operation, it was converted to run exclusively on coconut oil some years later (Schragl, 2007).

Even though proper documentation of operational experience is rare it can be stated that recent projects are struggling with similar difficulties, regardless of whether in developing or industrialised countries.

3.1 Germany

Driven by high prices for fossil fuels, about 50 wood gasifiers have been built and installed in Germany between 2000 and 2010. In 2008 alone, at least 25 gasifier plants with outputs ranging from 10 to 270 kW were installed (Schuessler et al., 2009). The plant operators experienced favourable conditions due to the guaranteed high energy feed-in tariffs of about EUR 0.20/kWh.

However, some of these plants never worked according to plan. Many have been taken out of operation after some months of trial. Some plants went up in flames and developers went bankrupt. The few plants that achieved more or less continuous operation were operating under special circumstances: They were part of university research programmes or were operated by the developers themselves. Moreover, in almost all cases about one to two years of adaptation were necessary.

A study by the Dresden University (Schuessler et al., 2009) with detailed analyses of five plants that all had more than 4,000 hours of operational experience concluded that theoretical economic operation of the plants seems to be possible if

- all the development and maintenance work that today has to be performed by highly qualified engineers and technicians becomes obsolete due to reliable technology, and
- at least 60-80% of the total energy input can be converted into economical, profitable use.

This positive formulation indicates clearly that

- even in Germany the technology is not yet reliable, and
- in view of the disappointing low electric output efficiency of about 20%, gasifier plants can only be profitable in settings where high demand exists for the produced heat.

3.2 India

At first glance, South Asia seems to provide more positive reports. In countries such as India and Sri Lanka gasification technology is used quite frequently and installation companies have an active communication strategy.

In fact, one of the most encouraging reports comes from India: Saran Renewable Energy Pvt Ltd received the 2009 Ashden Award for replacing diesel generators with biomass gasification systems. According to reports, a gasification plant with a dual fuel generator supplies up to 128 kW of electricity to small businesses, farms and households in Bihar through a local grid spanning about 1.5 km.

The plant costs were US$170,000, about 90% of which was spent on the gasifier and generator and about 10% on the distribution line. About 30% of the plant was subsidised by the government.

US$0.04/kg is paid to local farmers for supplying biomass, mainly stems of a locally grown tree named ‘dhaincha’, probably a Sesbania plant. In addition, 10-15% diesel fuel is co-fired to ensure proper ignition. Customers are charged about US$0.15/kWh.

With this tariff structure the plant is expected to recover the capital costs within 6 years. A crucial factor for the economically successful operation of this plant seems to be the dense cluster of small business customers (grain mills, cold stores, sawmill, welding workshop and farmers). Most of them use diesel generators to drive the machinery of their irrigation pumps and thus replace high costs for electricity. The introduction of the gasifier plant is reported to have resulted in about 40% lower costs (Wheldon, 2009). However, it should be noted that no long-term operation data is available yet.

One of the most important manufacturers is an Indian Company based in Gujarat. The company confirms having installed hundreds of gasifiers for small power plants of 3 – 500 kW all over the world, e.g. in Austria, Uganda, Madagascar, India, Bangladesh and Australia. The plants are fired with wood and agricultural residues.
However independent experts claim that these gasifiers run only with very well selected woody fuel and generally work only with diesel engines by co-firing considerable amounts of diesel. Many of the gasifiers are used in small industries for combustion and heating purposes only.
At least two of these Indian gasifier plants were installed in Germany. One 250 kW plant in Neubrandenburg was dedicated to the use of woodchips (*Holzhackschnitzel)* as biomass fuel. However, difficulties at the company designated as potential user seem to inhibit its operation.
In Bavaria a biogas plant provider and operator installed an original gasifier plant from India. The idea was to make use of the woody biomass that is not appropriate as feedstock for this biogas plants. However, the plant did not work well. Most likely the resin contained in conifer wood caused special problems. However, this was not the biggest problem. Support from the Indian manufacturer was apparently insufficient if not non-existent. Furthermore, the plant - installed in a closed hall due to the cold climate - emitted so much CO and other toxic gases that the company had to stop its operation.

On behalf of GTZ gasifiers at six locations in India were visited in 2009. All plants seemed to be constantly in use, providing an electricity output of 60 - 500 kW. Mainly rice husk and wood were used as fuel. Plants with diesel engines needed an additional input of about 20-30% diesel fuel. Plants with specially designed gas Otto engines worked exclusively with producer gas as fuel. However they needed an additional small electric generator for the start-up phase. All of these plants had a sophisticated gas cleaning system. However, the plants did not come close to fulfilling any European safety and pollution standards (Ecoplan,2009). Unfortunately no detailed data is available on the efficiency and economics of these plants.

3.3 Sri Lanka

A recent, as yet unpublished study from southern Sri Lanka reports on a gasification project that has already been working well for more than one year. The 12 kW plant provides electricity for 27 families, considerably reducing their consumption of kerosene. On average each family saves about EUR 0.80/month.
However, the installation of the machinery took a long time and required a great deal of know-how. The operation of the plant is laborious and requires a committed, permanently employed operator. Every day the filters have to be cleaned and once a month the whole plant has to be disassembled and cleaned of tar and soot.
The families pay a monthly fee of EUR 1.25 and contribute 60 kg of dry chopped wood as fuel. But this is just enough to cover the running costs. The initial investment costs were covered by the project. Although the power plant's capacity would allow more families to connect, most families are unwilling or unable to pay the initial connection fee of about EUR 30 requested as compensation for the initial contributions of the pioneering families.
All this indicates that commercial operation of such a plant would not be possible in the given environment.
Furthermore, compared to other renewable energy technologies gasification proved to be expensive. The per capita investment costs for the gasification power plant were about 30-40% higher than those for a micro-hydro power plant or solar home systems installed in the region. Obviously the running costs are considerably higher as well (Laufer, 2009).

Another project in Sri Lanka with a locally produced gasifier supported by a German emergency aid organisation had a similar experience. It took more than one year of intense modification and adaptation to get the tar and soot problem under control. Due to the wet gas cleaning system the project had a number of problems in the beginning with high quantities of condensates and liquid waste. A dry gas cleaning system solved this problem and by 2009 the gasifier had been working well for more than one year. However, the local population can hardly pay the running costs and it would be impossible to finance the investment costs by the revenues from electricity sales.
As this project was implemented in the context of the Tsunami relief, the most important benefit of this gasifier power plant is seen in its incentive for local reforestation.

3.4 Africa

While in Asia many gasifier plants are or have been in operation, there seems to be little on the ground in Africa. In the early 1990s, a gasification plant based on rice husk was operational in Molodo, Mali. It was the result of a joint cooperation between Mali, Germany, and China. However, the performance of the plant was rather mixed and a Chinese technician had to supervise it constantly to guarantee smooth performance. This technician was the only person able to fix the very specific technical problems (in particular problems with gas cleaning). Therefore, replicability and long-term sustainability were not achieved.

4 Overall Appraisal of the Potentials and Challenges

Even though availability of operation data is limited, the multitude of gasification projects allows for an appraisal of the potentials and challenges:

- Gasification technology is **principally well suited for small power plants** in the range of 10 kW to over 100 kW.
- Producer gas can be used as fuel for both Otto (gasoline) engines and diesel engines. In general these engines have to be adapted slightly to this fuel. Otto engines can run exclusively on producer gas while diesel engines need admixing with conventional diesel fuel.
- The **investment costs for a gasification plant vary significantly**. Data from Sri Lanka to European countries range from EUR 150/kW_{el} to EUR 3,000/kW_{el}. It is likely that the cheap gasifiers from local production require far more maintenance and that these costs are often not documented and calculated correctly.
- However, in contrast to the information in company brochures of gasifier producers it has to be stated that **there is not yet any reliable, affordable standard gasifier technology appropriate for rural small-scale applications readily available off the shelf**. There are still several unsolved technical problems.
- In general, the small-scale power-gasifier technology proved to be **unreliable and expensive**. Even the few cases where the gasifier plants performed quite well over a prolonged period experienced many technical problems during the first one or two years. Only extraordinarily motivated and committed management and operation were able to overcome these obstacles; furthermore, speedy and reliable expert backstopping and supplies of spare parts were available. This applies to developing countries as well as to industrialised countries.

- **Appropriate fuel is dry chopped wood, charcoal** and, with appropriate equipment, **rice husk**.
- **The use of other raw materials** for fuel like peanut shells, straw etc. **is fraught with problems** and requires co-firing of considerable amounts of other (fossil) fuel.
- Specific fuel consumption of gasifier systems with internal combustion engines depends on the type of raw fuel and ranges between 1.1 – 1.5 kg/kWh for wood and between 1.8 and 3.6 kg/kWh for rice husk gasifiers.
- Wood fuel gasification systems in combination with Otto engines show overall system efficiencies (energy in the fuel/electrical energy produced) from 16 to 19 per cent. Gasification systems fuelled by rice husk show overall efficiencies of 7 to 14 per cent. By integrating gasifiers in combined heat and power systems (CHP) their efficiencies can approach 80%.
- Clean operation of downdraft reactors can only be achieved in a small power range. Hence, steady full load operation of the plants with maximum turn down ratios of about 50% of full load is crucial for efficient operation and achieving tar-free gas production.
- The economic benefits of small-scale power gasifiers depend on the potential savings of switching from high-cost commercial fuel to locally available low-cost biomass. The potential fuel cost savings have to compensate the higher costs for the initial investment, labour, operation and maintenance. Little reliable operating data on the economy of gasification plants is available. These indicate:
  - The WB study quotes operational costs between US$0.03/kWh and US$0.25/kWh in the 1990s with **no or only marginal profitability**.
  - Many projects show that even in cases where capital costs did not have to be covered by the users, **the system's profitable operation is difficult**.
  - Recent studies in Germany also do not show more than a "theoretical" profitability due to all the costs for development and maintenance work by highly qualified en-

gineers and technicians. Within the German context, gasifier plants only make sense in settings where the produced heat can be used beneficially and increase the creditable efficiency. However, apart from a few industrial applications, there seems to be rarely any chance for this in most developing countries.

- There remains the main technical challenge of achieving a **high purity of the producer gas** to avoid the formation and accumulation of tar and soot. The internal combustion engines have strict purity requirements regarding the generator gas. Too much particular matter, tar or other residues decrease the lifetime of the combustion engine and make frequent maintenance necessary.
- The main strategy to address this challenge is to equip gasifier systems with a gas filter. This raises the costs, requires frequent cleaning of the filter system, and often produces much **carcinogenic waste**, especially in the case of wet stripping of the gas. This causes **severe environmental and health threats**.
- None of the plants that were monitored in the WB study and visited by GTZ took adequate measures to deal with the condensates; instead the pollutants were freely discharged into the environment. In addition, none of the operators dealing with these contaminated condensates used protective clothing or gloves.
- The remaining **ashes** are unproblematic and can be used as fertiliser, e.g. in fuel wood plantations.
- The **gaseous emissions** of a well-established and well-operated gasification plant are low. The gas is used as fuel for the combustion motor and its exhaust gases are similar to those of engines running on fossil fuels. If originating from renewable sources they contribute significantly to reducing the GHG burden. However, one component of the generator gas is CO, which can constitute a serious threat in the event of leakages or improper management. Cases of **CO intoxication** are not unheard of.

5 Conclusions

The biomass gasification technology is theoretically an interesting option for rural development. It promises:

- Sustainable conversion of locally available biomass into electricity for local supplies;
- Local value chain with income generation for the suppliers of the biomass as fuel;
- Incentives for reforestation.

Hence it will remain on the energy development agenda.

However, many severe challenges remain unsolved:

- There is no reliable technology readily available.
- High costs for technical development, repair and maintenance make it unprofitable.
- Dangerous threats exist to the environment and health due to carcinogenic waste.

Therefore, at present the application of the gasifier technology for small-scale electricity production in developing countries seems to be justifiable only in very few cases. Each new plant would be a unique tailor-made facility. The main **preconditions** for a successfully operating gasification plant are:

- Major obstacles (economic or environmental) for the use of other fuels (fossil or renewable) or forms of energy;
- High and constant availability of cheap appropriate biomass fuel;
- Availability of an experienced manufacturer;
- Continuous availability of specialised know-how for maintenance and operation that is not to be financed through the operational profit (for example, possible in co-operation with research projects);
- Low labour costs;
- Sufficient economic potential of the electricity users to cover at least the operational costs.

Additional **conducive conditions** would be:

- Besides electricity use, heat or other by-products of the system can be sold or used in a profitable way.
- Positive side effects such as providing an incentive for reforestation, reducing GHG emissions etc. justify considerable subsidies.
- Initial capital does not have to be repaid directly by the consumer of the electricity produced; subsidies are in place.

At the current stage, the technology may be a reasonable solution in some industrial settings where continuous qualified technical support can be guaranteed. However, at this moment it does not seem to be an appropriate technology for communal purposes and providing electricity to households and small businesses in remote areas.

Any international donor or implementation agency has to be aware of its responsibility concerning the potential environmental damage as a side effect of a gasification plant. Hence strict environmentally sound management of the plant has to be guaranteed. With the current state of development this requires expensive know-how, technology and strict supervision.

Due to the discrepancy between the promises of gasifier manufacturers and the numerous questionable or negative experiences on the ground; the discussion within GTZ resulted in the following conclusion:
If any private company (producer or developer) claims to have an appropriate solution for a particular situation (considering availability of fuel and maintenance know-how, as well as energy needs and cost limits) it should be given a chance to implement the plant. However,

the private company should **not be paid for the installation of the plant** and its development directly, but instead should **be remunerated for the electricity supplied based on output per kWh**. How to translate this into appropriate contractual terms remains a challenge. Similar to corresponding guaranteed feed-in tariffs on the national level, output-based remuneration in small mini grids could lead to more sustainable applications of the gasification technology for rural electrification purposes.

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