Small-scale Electricity Generation from Biomass

Experience with Small-scale Technologies for Basic Energy Supply

Part I: Biomass Gasification

giz HERA Poverty-oriented basic energy services

BMZ On behalf of Federal Ministry for Economic Cooperation and Development

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Part I: Biomass Gasification

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Author: Elmar Dimpl
Editors: Michael Blunck, Heike Volkmer

Cover Pictures:
- Wood gasifiyer at Muni Sewa Ashram, India (Dr. Dunja Hoffmann)
- Portable 10 kW gasification plant from the US based company “ALL Power Labs” (Elmar Dimpl)
- 300 kW gasification plant in a recycling park Usingen, Germany (Elmar Dimpl)

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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 photovoltaic's 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 (Mahapatra, Chanakya, Dasappa, 2009) and international agencies, such as the ESMAP programme administered by the World Bank (ESMAP, 2007), rate biomass as one of the cheapest available renewable energy sources for power generation. Furthermore, conversion from biomass to electricity can be a low-carbon process as the resulting CO_2 is captured by plant re-growth. 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. In addition, 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 GIZ programme "Poverty-oriented Basic Energy Services" (HERA) assessed the lessons learned from GIZ and non-GIZ 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: Wood or other dry biomass is converted 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.

This technology, known as biomass gasification, 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. However, converting biomass to electricity is not as easy as some manufacturers would like to make us believe.

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) 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 and focuses on potentials for providing basic energy services to rural households and small businesses.

2 The Technology

Biomass gasification is the conversion of solid fuels, such as wood and agricultural residues, into a combustible gas mixture. An electric generator set with a combustion motor uses this gas as a fuel to produce electricity. The gasifier is a chemical reactor that uses wood chips, rice husks, 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 small-scale power gasifiers use almost exclusively the downdraft fixed-bed technology. The air/gas stream moves downwards through a fixed (not fluidized) bed of woodchips. This is the only economic option on a small-scale that also produces a fairly clean gas.

Theoretically, electricity can be produced by various kinds of technical equipment, such as 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 be used. While the Otto engines can be operated on generator gas only, diesel engines generally need co-fuelling of conventional diesel fuel.
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 below 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, 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 nearly CO_2 neutral, renewable energy source.

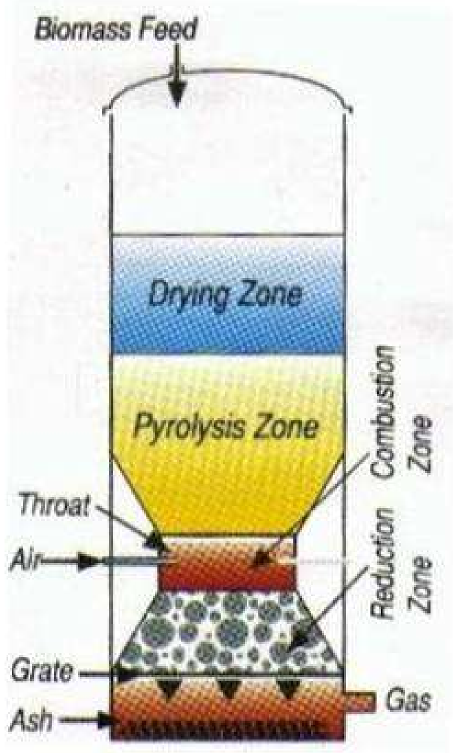

Figure 1: Biomass Gasification Process (Ankur Scientific http://www.ankurscientific.com/whatisgasification.htm)

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 also 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.
Nonetheless, despite the apparent advantages of biomass gasification, 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 but has had a rollercoaster ride of a history. In Western European cities, town gas was produced by the gasification of coal before natural gas became widely available. By 1850, large parts of London were lit by gasifier-produced gas lights. However, with the increasing availability of other energy sources and electrification, the technology soon 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. Yet, with increasing availability of diesel and gasoline, this comparatively inconvenient technology was again abandoned.

Next time gasification technology received interest was during the energy crisis of the 1970s and 1980s. By the 1980s about 15 manufacturers were offering wood and charcoal power gasifiers. Amongst others, DGIS, GIZ, 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 once again disappeared rapidly.

Only medium and 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).

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. Many plants have been installed in India and South-East Asia. In Germany, the guaranteed high feed-in tariffs triggered the installation of about 50 gasifier power plants.

The experience with gasifier power plants constructed during the last 30 years provides the background for this appraisal summary. However, it must be noted that it is difficult to obtain reliable data especially concerning long-term operation. Manufacturers promote their gasifiers with performance figures. These figures rarely seem to be based on practical operation data. Projects using gasifiers publish their gasifier 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 nearly impossible. But the conclusions of some comprehensive studies could be evaluated and checked with personal observations by experts and allow for a conclusive statement. Nevertheless, the information provided in this documentation may contain minor contradictions.

A comprehensive World Bank study carried out in 1998 (Stassen, 1995) 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 technical 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, 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, eventually stopped its gasification-based operations, as well. 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, the following sample of experiences point to the conclusion that recent projects are also struggling with similar difficulties as their predecessors, regardless of whether they are in developing or industrialised countries.

3.1 India

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

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. Approximately 30% of the plant was subsidised by the government (Wheldon, 2009).
US$0.04/kg is paid to local farmers for supplying biomass, which in this case is mainly stems of a locally grown tree named ‘dhaincha’, 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). In a short communication in August 2011, the director of Saran confirmed that the first plant is still working and that a second plant with output power of 30 kW has been installed. But no detailed long-term operation data was made available.

One of the most important manufacturers is the Indian company Ankur 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. These plants are fired with wood and agricultural residues.
Independent experts claim that these gasifiers run only with very well selected wood 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.

In Bavaria, Germany, a biogas plant provider and operator installed an original Ankur gasifier plant from India. The idea was to make use of that wood biomass that is not appropriate as feedstock for his biogas plants. However, the gasifier plant did not work well. Most likely the resin contained in conifer wood caused special problems. 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 GIZ commissioned the visit and assessment of gasifiers at six locations in India (Ecoplan, 2009). All of these medium sized 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.

Recently, two biomass gasification initiatives have caught significant attention as both claim to work with viable business models and to have hardly any major technical faults: DESI Power (http://www.desipower.com/) and Husk Power (http://www.huskpowersystems.com/). A comparative analysis was conducted by the IFMR Centre for Development Finance in 2010. It came to the conclusion that "small renewable energy plants with capacity of 25 - 40 kW can be viable if they select an ideal area of operation" (IFMR, 2010).
In this context, a 25-40 kW plant covers the demand of about 1200 households. The consumption of a 40kW plat is about 30 kg wood raw materials per hour.
Several people confirmed (personal communication by M. Blunck) that both systems seem to work quite well. However, concerning the environmental aspects of the waste disposal, it seems there are still many open questions remaining.

Village Energy Security Programme (VESP) has installed several small scale gasification plants (10-20 kW) in India since 2005. A report of the World Bank initiated technical assistance came to the following findings (WB, 2011).The "ability to pay in the remote communties" can be "adequate to cover the operation and maintenance costs". However, the performance of the VESP projects was "largely mixed" due to:

- Technology suppliers' failure to provide prompt and reliable after sales services
- Inadequate training of local operators
- Lack of organized supply of fuel wood
- Lack of capacities and interest among the village communities to manage the day-to-day affairs of the power plant

To overcome these problems the study proposes:

- To shift the management of the power plants from self organized Village Energy Committees to skilled entrepreneurs.
- To establish local service providers duly certified by the equipment manufacturers

The arrangement of every household supplying a certain quantity of biomass regularly was unsuccessful in most VESP projects. To overcome this "ineffective system for biomass supply," it seemed to be "better to monetize the biomass supplied and thereby provide an incentive" to the more active households.

3.2 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.

3.3 Cambodia

Since 2006, about 150 Cambodian enterprises have installed gasifiers to generate shaft power or electricity from wood or rice husks (Mansvelt, 2011). Nearly all of them are medium sized gasifiers in the range of 100-300 kW, hence not exactly the size discussed here. However, many of the results listed below indicate potentials and limitations also relevant for small-size gasifiers.

- Rice millers can achieve substantial savings by the substitution of diesel fuel by syngas.
- The estimated all-in cost of electricity produced varies considerably and is in the range of US$ 0,06 - 0,27.
- For a theoretically calculated small 75 kW rice mill gasifier, the study comes to the conclusion that “the systems are too expensive to compete with the EDC grid electricity so only in areas without grid availability can a small economic benefit be acheived” (p.40)
- Substantial reduction of greenhouse gasses “can be realized”.
- People were “largely unaware” of the negative impact that gasifiers can have on health and environment and hence “did not take any action to treat tar and waste water. The land around many enterprises with gasifiers was heavily polluted with black tar and waste water” (p. 47).
- In a similar way the APN study on biochar (APN, 2011) states that “in several cases” the effluent of the gasification process “was slowly draining into a local stream”.
- Consequently the Mansvelt claims “Strict gasifier waste disposal guidelines must be developed” (p.47).
- Toxic CO gas leaks threatening the labourers were frequently observed.
- Gasifiers used for electricity generation were often fuelled with wood that has high moisture content causing an even higher environmental threat and lower economic efficiency. Therefore the study proposes to assess as alternative the potentials of small steam engines that tolerate fuel with higher moisture content (Mansvelt, 2011 p. vi).

3.4. African countries

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. The performance of the plant was rather mixed and a Chinese technician had to supervise it constantly to guar-

antee 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.

In Madagascar, according to a UNIDO study, the company BIONERR has already installed four gasification units: two on power generation mode and two on thermal mode. For the two units based on power generation mode, one works with rice husks and the other one with cornstalks.
"The one working with rice husks is located in Ambatondrazaka in the region of Alaotra region. It was installed in 2006, its power capacity is 40 KW and works through the dual mode. BIONERR collects the rice husk from the rice mill of the village producing 2 tons/day on average (working an average of 10 hours/day). Although, the residue was collected for free at the beginning, farmers decided to sell it."
The cornstalk unit, is located in Boriziny (Port-Berger). It was installed in 2006. Its power capacity is 30 KW and it works through the 100% gas mode. Cornstalks are collected for free from the farmers producing corn around Port-Berger". But no information of the collection cost is available. "As for the rice husk, 1.5 kilo of cornstalk is needed to produce 1 KW." (Berguerie & Blanchard, 2009).
In a brief personal communication, Edwin Adkins, Columbia University, reports on two gasifiers manufactured by Ankur India and operational in Madagascar. One is small, ~35 kW, running on rice husks (probably the above mentioned) and the other is larger, 150-250 kW, running on wood. "At least from a brief review, it appears that both systems are operational and at least somewhat profitable." (E. Adkins, 09/ 2011). However, no detailed data could be obtained.

3.5 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.
Some of these plants never worked according to plan. Most 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 Dresden University (Schuessler et al., 2009), which includes a detailed analysis 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
- with the low electric output efficiency of about 20%, gasifier plants are only operating profitably in settings with high existing demand for the produced heat.

However, as the following examples show, there are also promising new technical approaches that have at least the potential to overcome some of the operational challenges and the waste problem by:

- a better automatic regulation of the gasification process via several pressure, temperature, and gas sensors in the whole conversion chain.

- A gas cleaning processes with combustible filter material that can be recycled into the process and burnt instead of being disposed in the environment.

A furniture company in northern Germany, planning to utilize the wooden residues in an energetic way, is currently testing a small compact portable 10 kW gasification plant from the US based company “ALL Power Labs” (see photo on cover). The company promises a significantly improved tar conversion and fuel flexibility through

- a multi-stage gasification architecture with waste heat recycling
- an onboard computer that “provides the expertise usually required from trained operators”.

In this system sawdust is used as gas filter material that can be used as feedstock for the plant after exhaustion of its filtering capacity.
A visit of a demonstration operation in August 2011 led to the impression that the plant concept offers some promising technological approaches. However, is was not yet ready for the intended final commercial operation.

In 2011, a 300 kW gasification plant was built in the recycling park Brandholz in Usingen, Germany. Interestingly, the approach uses plant oil as gas filter material that can be burnt afterward in the system itself. However, despite these promising results during the testing phase, the plant is so far still not operational.

The Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany is actually conducting a research project on “a novel biomass gasification process for the production of a tar-free synthesis gas”.
The aim of this project is to demonstrate a proprietary gasification process design that enables the production of a tar-free, hydrogen and carbon monoxide rich synthesis gas. There are no other gas-cleaning stages necessary prior to feeding it into a gas engine except a hot gas filter. This development is patented by Fraunhofer ISE (http://www.energetische-biomassenutzung.de/en/projects/projects-list/details/projects/82.html). ISE claims that “all used parts are state of the art and well proven. This will lead to low-maintenance and thus cost-effective operation, even for small plants (e.g. down to 50 kW fuel input power). The process shall have the capability to be supplied with different types of biomass.”
According to different information, the research process is coming to an end and the commercial application of the technology is in preparation. ISE expects its availability for application in 2013.

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 following potentials and challenges:

- Gasification technology is mostly used in medium sized systems with about 150 - 500 kW. But it is **principally well suited for small power plants** in the range of 10 kW to over 100 kW also.
- 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. Systems with diesel admixing seem to be more tolerant against fluctuation of the load and of the syngas quality and quantity.
- 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}. Locally manufactured gasifier technology (eg. Cambodia) is claimed to be cheaper than imported (eg. from India). However, frequently low quality is reported for gasifiers from local production. 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.
- 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.

  Even when plants are operational from the technical perspective, it turned out that communal organisations were not the ideal operators. Instead, commercial operators with more ownership have been proposed.
- **Appropriate fuel is dry chopped wood** and **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) fuels.
- 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 far more than 50%.
- Clean operation of downdraft reactors can only be achieved in a small power range. Hence, steady full load operation of the plants is crucial for efficient operation and achieving tar-free gas production. (Maximum passable turn down ratios are in the range of about 50% of full load).
- 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:

- Operational costs seem to vary considerably and are reported to be between US$0.03/kWh and US$0.27/kWh. But most of these calculations are rather based on theoretical reflections than on monitored data.
- 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**. Only in remote places with little energy alternatives and gasifiers integrated in biomass processing industry, like rice mills, did a profitable operation seem possible. In most other cases, no or only marginal profitability has been reported.
- 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 engineers 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.
- Cases from Asia demonstrate that the procurement of wood as feedstock was more difficult and costly than expected. Many community based approaches did not work well. Time and effort for collection, transport and conditioning of the wooden sticks were perceived as too high.

- 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. Nearly all reports document **severe environmental threats** by the disposal of these waste products. Nearly none of the plants that were monitored in the different studies 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 generally 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 can 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 Conclusion and Recommendations

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;
- A 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, as documented above, many severe challenges remain unsolved, especially for small applications:

- There is no reliable technology readily available.
- High costs for technical development, repair and maintenance make it unprofitable.
- Dangerous threats to the environment and to health exist due to carcinogenic waste.
- As for all biomass based electrification technologies - the appropriate management of such a complex system and the sustainable provision of appropriate feedstock is needed.

In principle, the practicability of the technology has been proven and the costs at least in some cases are not far from being competitive. Hence, more pilot applications with a certain research component are needed. The following chapter provides a checklist of the main issues to be kept in mind if committing in the small-scale gasification activities.

On a policy level

Besides the general question regarding sustainable biomass use and the legally and politically supportive environment for mini-grids, the specific questions are:

- Quality standards and guarantees for the gasifier technology
- Development and application of strict gasifier waste disposal guidelines

On a research level

- Proper monitoring of existing plants and fair-minded identification of the challenges and potentials
- Development of the technology from custom-made, individual solutions with need for high qualified know-how to standardized systems with standard components operable by trained local staff.

On a project's implementation level:

At present, the application of the gasifier technology for small-scale electricity production in the framework of international development co-operation 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:

- Existence of 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, 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 and a steady demand for energy can be guaranteed. However, at this moment, it does not seem to be an appropriate technology for mere 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.

The following criteria have to be fulfilled for a promising operation of biogas gasification plants:

- Appropriate feedstock:
    - Availability: Quantity of available biomass, sustainability of biomass supply, costs for its collection, transport, and conditioning
    - Appropriate Quality, Moisture, Composition, homogeneity purity
- System Technology
    - Experience of the manufacturer, documented references, provided guarantees
    - Appropriate size for the expected load
    - Type of gas cleaning technology
    - Guaranteed gas quality
    - Appropriate engine, gas or diesel engine, size, durability
- Waste disposal system
    - Composition of the waste, Condensates, ash, oil, water
    - How much waste is generated? How is it treated or disposed
- Operation, Ownership
    - Who will be operator of the plant, relations, contracts between biomass providers, operator, energy consumers
    - Availability of maintenance know-how and spare parts
    - Qualification of staff
    - Work safety and health protection

Due to the discrepancy between the promises of gasifier manufacturers and the numerous questionable or negative experiences on the ground; the discussion within GIZ 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, there should be found appropriate ways that the private company covers a part of the risk. It should **not be paid exclusively for the installation of the plant** and its development directly, but instead should **be remunerated at least in parts 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.

Documents and Literature

Asia-Pacific Network for Global Change Research „APN“ (2011): Biochar for Carbon Reduction, Sustainable Agriculture and Soil Management (BIOCHARM). Final Report for APN Project ARCP2009-12NSY-Karve.
Study focussing on potential impact of biochar, including the assesment of gasification as one of the possible technologies for biochar production.

BEGUERIE, V.; BLANCHARD, K. (2009): The Potential for Renewable Energies in Rural Areas of Madagascar. UNIDO, Bureau de Représentation pour l'Océan Indien à Antananarivo. 131 p.

ECOPLAN (2009): Biomassevergasung ("Gasification of biomass") und Nutzung des Gases in Verbrennungsmotoren - Eindrücke und Rückschlüsse aus der Praxis aus Besichtigungen indischer Anlagen im Juli/August 2009.
Draft of mission report on behalf of GTZ. 12/2009 unpublished. Available from Dunja Hofmann, GTZ OE 4413. Describes technical aspects of gasifier plants at 6 locations in India: All gasifiers with a power output from ~30 – ~500 kW work well and have been working more or less constantly for years. however, none of the plants meets European concepts of safety and pollution control. No economical data has been assessed.

ESMAP (2007). Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies. ESMAP Technical Paper 121/07. Energy Sector Management Assistance Program (ESMAP), World Bank Washington, DC.

IEA Bioenergy (2004): Biomass Gasification Success Stories.
http://www.ieabioenergy.com/MediaItem.aspx?id=49

IFMR Research Centre for Development Finance: Empowering Villages (2010). A comparative Analysis of DESI Power and Husk Power Systems: Small-scale biomass power generators in India. 20p.

Laufer, Dino (2009): Holzvergaseranlage für die Dorfgemeinschaft Batgugammana. 2009. 8p. *Extract of PHD thesis. Unpublished. Describes management and economics of one 12 kW gasifier plant in a village in southern Sri Lanka.*

Mahapatra, S.; Chanakya, H.N.; Dasappa, S. (2009): Evaluation of various energy devices for domestic lighting in India: Technology, economics and CO2 emissions, In: Energy for Sustainable Development 13. Pages 271-279

Mansvelt, Rogier van (2011): IFC Gasifier Study. Draft Report March 2, 2011. 68p.
Study to analyze the economic benefits and environmental impact of using gasifiers in Cambodian industry, including a field survey of 27 rice mills, electricity providers and ice plants.

Schragl, Peter (2007): Short Appraisal of Biomass Gasification for Power Generation. GTZ, Internal paper, 27p. 1/2007. *Describes technological principles, the status of gasification (most data from industrialized countries). Gives an appraisal on technological, economic problems. List of contacts of experts in and around GTZ.*

Schuessler, Braekow, Treppe, Salomo, Zschunke (2009): Schwachstellenenalyse an BHKW-Vergaseranlagen - Schlussbericht. Study of TU Dresden, Institut für Energietechnik. 128p. *Detailed operational analysis of five gasification plants in Germany. Detailed description of plants from 12 different producers.*

Stassen, Hubert E. (1995): Small-Scale Biomass Gasifiers for Heat and Power. A Global Review. = World Bank Technical Paper 296. Washington, D.C.
The results of a four-year biomass research effort (1986 – 1990) that monitored 12 power gasifier operations in Africa, Asia and Latin America. Contains detailed operation data on performance, cost effectiveness, scope of applications, potential environmental implications.

Wheldon, Anne and Jeremy Rawlings (2009): Case Study Saran Renewable Energy Pvt Ltd, http://www.ashdenawards.org/files/pdfs/finalist_2009/Saran_case_study_2009.pdf

World Bank (2011): India: Biomass for Sustainable Development. Lessons for Decentralized Energy Delivery. Village Energy Security Programme. Draft, July 2011. 100p.
Assessment of the electricity generation from biomass approaches of the Village Energy Security programme (VESP).

Additional sources of information

Homepage of Indian manufacturer Ankur:
http://www.ankurscientific.com/whatisgasification.htm

A list of Manufacturers working in collaboration with Indian National Mission on Bamboo Applications: http://gasifiers.bioenergylists.org/bamboogasifier

The Biomass Energy Resource Center (BERC) in the United States
http://www.biomasscenter.org/component/search/gasifier.html?ordering=&searchphrase=all

The European Biomass Gasification Network of researchers, developers and implementers.
http://www.gasnet.uk.net/

International Energy Agency (IEA) Task 33 / Thermal Gasification of Biomass
http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=iea/homepage.xml

Extensive database of the Biomass Energy Foundation on equipment, consulting, small and large gasifier systems, research and support
http://www.woodgas.com/gdatabase.htm

Dalili, Simon (2009): Biomass Gasification and Pyrolysis - Opportunities and Barriers for efficiency and Sustainability. In: UNDP: Bio-Carbon Opportunities in Eastern & Southern Africa. P: 233 - 266. http://www.undp.org/climatechange/carbon-finance/Docs/
Good overview of the whole range of different pyrolysis and gasification technologies from charcoal to syngas production as well as of potential processing of syngas to liquid fuels (BTL), the "2nd generation bio-fuels".

Russel, Andy (2008)l: Producer Gas for Power Generation. Practical Answers -Technical Information Online. Dez. 2008.
http://practicalaction.org/practicalanswers/product_info.php?products_id=381
Short, comprehensive overview with focus on small-scale applications in developing countries.

Steinbrecher, Nils; J. Walter (2001): Marktübersicht dezentrale Holzvergasung: Marktanalyse 2000 für Holzvergasersysteme bis 5 MW. Öko Institut, Darmstadt.
http://www.oeko.de/service/bio/dateien/de/bio-marktuebersicht-2001.pdf
Comprehensive overview of gasification projects in Germany and other European countries. Description of technology, market and producers and operation experience regarding reliability, security and readiness for marketing.

Wiese, Lars (2008): Energetische, exergetische und ökonomische Evaluierung der thermochemischen Vergasung zur Stromerzeugung aus Biomasse. Research report of TU Hamburg-Harburg. 222p
Based on measurements at existing European biomass gasification plants simulation models of these plants are set up. Afterwards the plant concepts are optimised and evaluated. It can be shown, that the power production in biomass gasification plants can be an energetic and exergetic interesting alternative to existing biomass steam power plants.
http://doku.b.tu-harburg.de/volltexte/2008/382/

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
HERA – Poverty-oriented Basic Energy Services
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn
T +49 6196 79 6322
F +49 6196 79 80 6322
E hera@giz.de
I www.giz.de/hera