SMALL SCALE GASIFICATION SYSTEMS

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1. INTRODUCTION

The production of a combustible gas from carbon containing materials is already an old technology. Dry distillation was first practiced on a commercial scale in 1812, when a towngas company in London started production.

The first commercial updraught gasifier for continuous gasification of solid fuels with air was installed in 1839. Updraught gasifiers were subsequently further developed for different fuels and were in widespread use in specific industrial power and heat applications up to the 1920's, when their function was gradually taken over by oil fuelled engines and furnaces.

In anticipation of unreliable petroleum supply, between 1920 and 1940 compact tar-free down draught gasifier systems for automotive application, were developed in Europe. During the 2" World War tens of thousands of those gasifiers were used in Europe and elsewhere. Shortly after the War most gasifiers were decommissioned because of widespread availability of inexpensive liquid fuels.

The energy crisis of the 1970's brought a renewed interest in biomass gasification. The technology was perceived as a relatively cheap indigenous alternative for small-scale industrial and utility power generation in those developing countries that suffered from high world market petroleum prices and had sufficient sustainable biomass resources. In the beginning of the 1980's at least 10 (mainly European) manufacturer's were offering small-scale wood and charcoal fired power plants (upto approximately 250 kW_{el}). At least four developing countries (Philippines, Indonesia, Brazil and India) started gasifier implementation programmes based on locally developed technologies. Several biomass gasification systems were installed through donor financed projects and local entrepreneurs in a large number of developing countries. Almost none of these projects have been successful. Most of the demonstration projects have been abandoned due to technical, financial/economic and institutional problems.

Since the 2nd World War there has been hardly any small scale biomass gasifier implementation programme in the developed countries. A short introduction to gasification technology is presented in this paper including the most important characteristics related to gasification. Chapter 3 gives an overview of the feedstock preparation requirements. The technical, financial/economic and institutional problems with the above mentioned initiatives are outlined in Chapter 4. Only recently there is a substantial growing interest in this technology. The motivation for this interest and consequently for several initiatives will also be discussed in this paper.

Economic, social and technical benefits of gasification technology are listed in Chapter 5. To overcome similar failures in future research and development work is necessary to solve the technical and financial/economic problems. These research and development needs are discussed in Chapter 6. An overview of (semi-)commercial status of small scale biomass gasification systems will be presented in Chapter 7 which includes a list of current small scale fixed bed gasifier systems. Future perspectives of the gasification technology will be evaluated in Chapter 8. As an example, a 2 MW_{el} CHP fixed bed gasification system is financially analysed. Final concluding remarks are given in Chapter 9.

2. THEORY

The substance of a solid fuel is usually composed of the elements carbon, hydrogen and oxygen. In addition there may be nitrogen and sulphur, but since these are present only in small quantities they will be disregarded in the following discussion [I].

In the gasifiers considered, the biomass is heated by combustion. Being passed through a bed of fuel at high temperature then reduces the combustion gasses.

In complete combustion, carbon dioxide is obtained from the carbon and water from the hydrogen. Oxygen from the fuel will be of course incorporated in the combustion products, thereby decreasing the amount of combustion air needed.

Combustion, occurring in the oxidation zone, is described by the following chemical formulae:

C + 02 = C02 + 401.9 kJ/mol (1)

H + ½02 = H20 + 241.1 kJ/mol (2)

Thus, burning 1 mol of carbon to dioxide releases a heat quantity of 401.9 kJ.

The most important reactions that take place in the reduction zone of a gasifier between the different gaseous and solid reactants are:

C + C02 + 164.9 kJ/mol = 2C0 (3)

C + H20 + 122.6 kJ/mol = CO + H2 (4)

C02 + H2 + 42.3 kJ/mol = CO + H20 (5)

C + 2H2 = CH4 (6)

CO + 3H2 = CH4 + H20 + 205.9 kJ/mol (7)

Equation (3) and (4) are the main reactions of the reduction stage and require heat. As a result the temperature will decrease during the reduction. Equation (5) describes the so- called water-gas equilibrium. For each temperature, in theory, the ratio between the product of the concentration of carbon monoxide (CO) and water vapor (H20) and the product of the concentrations of carbon dioxide (CO,) and hydrogen (H,) is fixed by the value of the water gas equilibrium constant (Kw).
Kw is given in the next formula:

Kw = ([CO] * [H20]) / ([C02] * [H2]) (8)

In practice, the equilibrium composition of the gas will only be reached in cases where the reaction rate and the time for reaction are sufficient.

The reaction rate decreases with failing temperature. In the case of the water-gas equilibrium, the reaction rate becomes so low below 700 'C that the equilibrium is said to be 'frozen'. The gas composition then remains unchanged.

Introduction of the water-gas equilibrium concept provides the opportunity to calculate the gas composition theoretically from a gasifier, which has reached equilibrium at a given temperature. The next table presents typical gas composition data as obtained from commercial wood and charcoal co-current gasifiers operated on low to medium moisture content fuels (wood 20%, charcoal 7%), {FAO 1986}.

Component	Wood gas (vol%)	Charcoal gas (vol%)
Nitrogen	50 – 54	55 – 65
Carbon monoxide	17 – 22	28 – 32
Carbon dioxide	9 – 15	1 – 3
Hydrogen	12 – 20	4 – 10
Methane	2 - 3	0 – 2
Heating value (MJ/m3)	5 – 5.9	4.5 – 5.6

3. GASIFICATION TECHNOLOGY

Biomass gasification is a process in which solid biomass fuels are broken down by the use of heat in an oxygen-starved environment, to produce a combustible gas. Biomass fuels that can be gasified include wood, charcoal, rice husks, coconut shells and a variety of other dry biomass materials. A biomass gasification system consists primarily of a reactor into which fuel is fed along with a limited (less than stoichiometric or that required for complete combustion) supply of air. Heat for gasification is generated through partial combustion of the feed material. The resulting chemical breakdown of the fuel and internal reactions result in a combustible gas usually called "producer gas". The heating value of this gas varies between 4.0 and 6.0 MJ/Nm^3.

Small-scale gasifiers are all of the "fixed-bed" bed type. The different fixed-bed reactor types are often characterised by the direction of the gasflow through the reactor (upward, downward or horizontal) or by the direction of respectively the solid flow and the gas stream (co-current, counter-current or cross-current) see Figure 1-3. Looking to the applications, a further distinction can be made between power gasifiers and heat gasifiers, see Figure 4. Power gasifiers require a more or less tar- and dust-free gas while heat gasifiers are not very sensitive to these types of impurities.

Updraft or counter current gasifier

The simplest type of gasifier is the fixed bed counter current gasifier. The biomass is fed at the top of the reactor and moves downwards as a result of the conversion of the biomass and the removal of ashes. The air intake is at the bottom and the gas leaves at the top. The biomass moves in counter current to the gas flow, and passes through the drying zone, the distillation zone, reduction zone and the oxidation zone.

The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high gasification efficiency. In this way also fuels with an high moisture content (up to 50 % wb) can be used.

Major drawbacks are the high amounts of tar and pyrolysis products, because the pyrolysis gas is not lead through the oxidation zone. This is of minor importance if the gas is used for direct heat applications, in which the tars are simply burnt. In case the gas is used for engines, gas cleaning is required, resulting in problems of tar-containing condensates.

Downdraft or co-current gasifier

By the conventional downdraft gasifier biomass is fed at the top of the reactor and air intake is at the top or from the sides. The gas leaves at the bottom of the reactor, so the fuel and the gas move in the same direction. The pyrolysis gasses are lead through the oxidation zone (with high temperatures) and or more or less burnt or cracked. Therefore the producer gas has a low tar content and is suitable for engine applications. In practice however, a tar-free gas is seldom if ever achieved over the whole operating range of the equipment. Because of the lower level of organic components in the condensate, downdraft gasifiers suffer less from environmental objections than updraft gasifiers.

Drawbacks of the downdraft gasifier are:
- the high amounts of ash and dust particles in the gas;
- the inability to operate on a number of unprocessed fuels, often pelletisation or briquetting of the biomass is necessary;
- the outlet gas has a high temperature leading to a lower gasification efficiency;
- the moisture content of the biomass must be less than 25 %.

The gasifiers are used in a power range from 80 to 500 kW_{el}.

Open core gasifier

A more recent development is the 'open core' gasifier design for gasification of small sized biomass with high ash content (see). The producer gas is not tar-free; it contains approx. 0.05 kg tar per kg gas.
In the open core gasifier the air is sucked over the whole cross section from the top of the bed. This

facilitates better oxygen distribution since the oxygen will be consumed over the whole cross section, so that the solid bed temperature will not reach the local extremes (hot spots) observed in the oxidation zone of conventional gasifiers due to poor heat transfer. More over, the air nozzles in conventional gasifiers generate caves and create obstacles that may obstruct solid flow specially for solids of low bulk like rice husk.

On the other hand, the entry of air through the top of the bed vreates a downward flow of the pyrolysis gases, and transports the tars products to the combustion zone. Thus, flow problems due to the caking of rice husk caused by back mixing of tar are avoided. [3]

Crossdraft gasifier

Crossdraft gasifiers are adapted for the use of charcoal. Charcoal gasification results in very high temperatures (> 1500 ^{o}C) in the oxidation zone which can lead to material problems. Advantages of the system lie in the very small scale at which it can be operated. In developing countries installations for shaft power under 10 kW are used. This is a.o. due to the very simple gas cleaning section (cyclone and baghouse filter). A drawback is the minimal tar cracking performance, resulting in the need for high quality charcoal. Because of the limited capacity of crossdraft gasifiers and the limited scope for large scale of implementation the crossdraft gasifier types are not further handled in this paper.

Comparison of updraft and downdraft gasifiers

For the updraft and downdraft gasifier the main technical and operational parameters values are listed in the next table. Because of the variety of gasifier designs which have been developed for each type of gasifier, the mentioned data are only rough indications. But least they give an indication of typical differences between the two basic fixed bed gasifier designs.

Gasifier type	down draught	up draught	'open core'	cross draught	cross draught heat
max. proven commercial capacity (kW_{el})	350	4,000	appr. 200	appr. 150	20,000*
start up time (min)	10 - 20	15 - 60	15 - 60	10 - 20	15 - 60
sensitivity to fuel characteristics	sensitive	not sensitive	very sensitiveE	sensitive	not sensitive
tar production full load (g/NM^3 gas)	< 0.5	1 - 15	10 - 15	< 0.1†	n.a.
size & volume gas cleaning section	small	big	big	small	n.a.
quantity residual tars	small	big	big	very small†	none
sensitivity to load fluctuations	sensitive	not sensitive	not sensitive	sensitive	not sensitive
turn down ratio	3 - 4	5 - 10	5 - 10	2 - 3	8 - 10
HG_{eff} full load (%)	85 - 90	90 - 95	70 - 80	80 - 90	90 - 95
CG_{eff} full load (%)	65 - 75	40 - 60	35 - 50	60 - 70	n.a.
cold gas heating value full load (MJ/Nm^3)	4.5 - 5.0	5.0 - 6.0	5.5 - 6.0	4.0 - 4.5	n.a.

* kW_{th}
E only rice husk
† low volatile content (< 10 %wgt) charcoal
n.a. not applicable

Only wood, with uniform dimensions, has proven to be a suitable final gasifier fuel. Several experiments with gasifying other types of biomass have been conducted but most of them failed due to the specific biomass characteristics. Biomass comes available in different forms, for example chips or loggings from forest activities, bales from verge grass or straw, loose from construction activities (demolition wood) and thinnings from landscape conservation activities. This material has to be received, handled, stored and processed prior to gasification. In order to identify the necessary pretreatment steps it is important to have a thorough understanding of the biomass characteristics related to gasification.

Biomass characteristics related to gasification

Each type of biomass has its own specific properties which determines its performance as a fuel in gasification plants. The most important properties relating to gasification are:
- moisture content;
- ash content;
- elemental composition;
- bulk density and morphology;
- volatile matter content.

Moisture content

The moisture content of biomass is defined as the quantity of water in the material expressed as a percentage of the material's weight. For thermal conversion processes like gasification, preference is given to relative dry biomass feedstocks because a higher quality gas is produced, i.e. higher heating value, higher efficiency and lower tar levels.

Natural drying (f.i. on field) is cheap but requires long drying times. Artificial drying is more expensive but also more effective. In practice, artificial drying is often integrated with the gasification plant to ensure a feedstock of constant moisture content. Waste heat from the engine or exhaust can be used to dry the feedstock.

Ash content and ash composition

Ash is the inorganic or mineral content of the biomass which remains after complete combustion of the feedstock. The amount of ash between different type of feedstocks differs widely (0.1% for wood up to 15% for some agricultural products) and influences the design of the reactor, particularly the ash removal system. The chemical composition of the ash is also important because it affects the melting behaviour of the ash. Ash melting can cause slagging and channel formation in the reactor. Slags can ultimately block the entire reactor.

Elemental composition

The elemental composition of the fuel is important with regard to the heating value of the gas and to the emission levels. The production of nitrogen and sulphur compounds is generally small in biomass gasification because of the low nitrogen and sulphur content in biomass.

Bulk density and morphology

Bulk density refers to the weight of material per unit of volume and differs widely between different type of biomass. Together with the heating value, it determines the energy density of the gasifier feedstock, i.e. the potential energy available per unit volume of the feedstock.
Biomass of low bulk density is expensive to handle, transport and store. Apart from handling and storing behaviour, the bulk density is important for the performance of the biomass as a fuel inside the reactor: a high voidage tends to result in channeling,

bridging, incomplete conversion and a decrease in the capacity of the gasifier.
The bulk density varies widely (100 - 1000 kg/m^3) between different biomass feedstocks, a.o. as a result in the way the biomass comes available (chips, loose, baled, etc.).

Volatile matter content

The amount of volatiles has a major impact on the tar production levels in gasifiers. Dependend on the gasifier design, the volatiles leave the reactor at low temperatures (updraft gasifiers) or pass through a hot incandescent oxidation zone (downdraft gasifiers) were they are thermally cracked. For biomass materials the volatile matter content varies between 50 and 80%.

Typical values on moisture content, ash content and net heating values for different feedstocks are listed below.

Type	LHV_w (kJ/kg)	MC_w (%)	AC_d (%)
Bagasse	7,700 - 8,000	40 - 60	1.7 - 3.8
Cocoa husks	13,000 - 16,000	7 - 9	7 - 14
Coconut shells	18,000	8	4
Coffee husks	16,000	10	0.6
Cotton residues:			
- stalks	16,000	10 - 20	0.1
- gin trash	14,000	9	12
Maize:			
- cobs	13,000 - 15,000	10 - 20	2
- stalks			3 - 7
Palm-oil residues:			
- fruit stems	5,000	63	5
- fibres	11,000	40	
- shells	15,000	15	
- debris	15,000	15	
Peat	9,000 - 15,000	13 - 15	1 - 20
Rice husks	14,000	9	19
Straw	12,000	10	4.4
Wood	8,400 - 17,000	10 - 60	0.25 - 1.7
Charcoal	25,000 - 32,000	1 - 10	0.5 - 6

4. TECHNICAL/SOCIO-ECONOMIC BENEFITS OF GASIFICATION

Particularly in western countries, a growing interest has been noticed in relatively small-scale fixed bed gasification installations, which reliably convert biomass and/or waste in electricity and/or heat. The motivation for this interest are manifold:

- Under current Common Agricultural Policy (CAP) legislation, large amounts of the most productive arable land in Europe are to be taken out of food crop production. Gasification technology will encourage the use of set-aside land for the production of energy crops. Fertilizer, pesticide and herbicide inputs are much lower than for conventional food crops. While there may be some disadvantages in some cases, (such as increased water demand), it is generally accepted that they are preferable from an environmental point of view than uncultivated land.
- Due to surpluses of agricultural production in the EU countries and rising EC subsidies there is an urgent need for new markets for agricultural products.

Biomass fuel production (energy crops) for use in small and medium scale gasification systems may provide a new market of a size that is commensurate with the size of the problem, and therefore have an important positive effect on the solution of the present agricultural problems.

- Important positive effects of the utilization of biomass for efficient energy production with gasifiers are the positive environmental effects. Especially the carbon neutral character (global warming) when fuelled with biomass and the low sulphur oxide emissions (acid rain), may be important factors in stimulating biomass energy production through gasification.
- Equipment for small scale reliable and efficient biomass based electricity production may find a ready export market in decentralized energy systems in rural European areas and countries in development (Eastern Europe included).
- In industrial and demolition activities biomass residues are produced. Often these residues must be removed and dumped at considerable costs. Utilization of these biomass waste streams in nearby small-scale fixed bed gasification systems may be the more economic solution.
- The production and use of gasifiers will create jobs in manufacturing, agriculture, services, etc. Those jobs will be especially created in small and medium scale industries and rural areas. Additional jobs may be created by producing for export markets.
- The use of biomass fuels and agricultural biomass materials will stimulate the realization of small/medium sized energy production by gasification in rural regions and agricultural industries in the European community and elsewhere. In order to achieve this it is necessary to have a better understanding of the gasification technology with respect to reactor design, gas cleaning, automation and control, and plant design (matching of all plant components).

5. FEEDSTOCK PREPARATION REQUIREMENTS

From the previous chapter it becomes clear that the different biomass characteristics results in the necessity to pretreat/process different types of biomass feedstocks when they are going to be used as a gasifier fuel. The need for a suitable feed preparation system is well known but unfortunately poorly understood.

Feedstock preparation is required for almost all types of biomass materials because of large variety in physical, chemical and morphological characteristics. The degree to which any specific pretreatment is desirable will depend on the details of the gasifier plant, i.e. capacity, type of reactor (downdraft gasifiers are more strict to uniform fuel specifications than updraft gasifiers), etc. Fuel requirements for different gasifier types are presented in

Gasifier type	downdraft	updraft	open-core	cross-draft
Size (mm)	20-100	5-100	1 - 3 (rice husk)	40 - 80 (charcoal)
Moisture content (% w.b.)	< 15-20	< 50	< 12 (rice husk)	< 7 (charcoal)
Ash content (% d.b.)	< 5	< 15	approx. 20	< 6
Morphology	uniform	reasonable uniform	uniform	uniform
Bulk density (kg/m^3)	> 500	> 400	> 100	> 400
Ash melting point (^{o}C)	> 1250	> 1250	> 1000	> 1250

All listed fuel characteristics can be influenced by pretreatment process, e.g. mineral additives can influence the ash melting behaviour. However, the most important pretreatment technologies are drying, sizing and densification. Other pretreatment technologies like screening and zifting are only of importance to very specific materials like heavy contaminated (sand, paper, plastic, non-ferro and ferro metals, etc.) demolition wood. Harvesting is necessary when energy crops is the fuel.

Sizing
Sizing of the feedstock may be necessary as different sizes are specified for different types of gasifiers. For small scale fixed bed gasifiers, cutting and/or sawing of wood blocks is the preferred form of fuel preparation. Chipped wood is preferred for larger scale applications. The size range of chips can be chosen by screening such that the fuel is acceptable for a specific gasifier type.

For medium- and large-scale fixed bed gasifiers wood chips from forestry or wood processing industries are produced by crushers, hammermills, shredders and/or mobile chippers (particularly for thinnings from landscape conservation activities). Most of these sizing apparatus are provided with a screen. Dependend on the feedstock morphology and characteristics (hardness) the throughput or capacity of theses techniques vary widely.

Drying
Drying of the fuel is advisable if fresh wet materials (moisture content 50-60% on wet basis) are to be gasified. As outlined previous under § 1.2.3 lowering the moisture content of the feedstock is associated with a better performance of the gasifier. Utilizing the exhaust gases from an internal combustion engine is a very efficient way to do so. The sensible heat in engine exhaust is sufficient to dry biomass from 70% down to 10%. Rotary kilns are the most applied dryers. The energy costs of drying are high, but these can be outweighed by the lower downstream gas cleaning requirements for dried feed.

Densification
Briquetting or pelletization are important techniques to densify biomass materials for increasing the particle size and bulk density. The reasons for densification are:
- densified biomass is less expensive to transport;
- densified products are easier to store and handle;
- densification enables certain biomass feedstocks to be gasified in a specific gasifier.

Sequence of pretreatment
The sequence of pretreatment technologies depends on the type and characteristics of the biomass material and the requirements of the gasifier fuel. The following aspects are important in the biomass pretreatment sequence:
- coarse materials like window-frames need to be sized in two or more steps;
- wet materials like waste from public gardens requires more drying energy compared to dry materials like demolition wood;
- artificial drying of coarse materials requires more time compared to fine materials like sawdust;
- wet materials like thinnings, waste from public gardens, green waste (vegetable, fruit and garden) have a generally small particles size;
- screening of wet materials is a less efficient process compared to screening of dry materials; and
- hammermills can only be applied for relatively dry materials; for sizing of wet materials, chippers provided with a knife must be applied.

6. LESSONS FROM THE EXPERIENCE

Over the years a considerable number of gasification systems for demonstration purposes have been financed worldwide. A large diversity of fuels and equipment was experimented with, however, positive results were seldom achieved and small/medium scale gasifiers have not succeeded in penetrating the market in significant numbers. Several gasification plants were evaluated in detail in the context of the "UNDP/World Bank Small Scale Biomass Gasifier Monitoring Programme".

Based on this extensive monitoring, analysis and evaluation of existing gasifier/engine generator units, it can be concluded that two major reasons are responsible for the fact that small scale biomass gasifiers are presently not generally utilized and accepted. One of those reasons is technical while the other is of a financial/economic nature.

Technical Problems
In the last fifteen years, many small scale gasifier systems have suffered from technical problems like:
(i) extreme engine wear due to strong tar contamination of the gas,
(ii) unreliable and unstable operation due to slagging conditions in the reactor,
(iii) undefined gas composition and unreliable operation due to variations in pressure drop over the reactor.

The main reason for those problems is the occurrence of large variations in the key parameters determining the quality of the biomass fuel, i.e. fuel moisture content, fuel ash content and chemical composition, fuel reactivity, fuel size and size distribution, fuel bulk density, fuel volatile matter content, etc.

Financial and Economic Problems
Small scale gasification systems at present are characterized by minimal automatic measuring and control systems. This is caused by the high costs (in comparison to the low capacity) of adequate instrumentation. As a result the systems often show variable engine power outputs and engine efficiencies at varying loads, variable peak power outputs and call for the continuous presence of expert, experienced and motivated personnel. The cost of the latter is as a general rule (again compared to the relatively small electricity production) not acceptable.

Further analysis reveals a number of underlying failure reasons of technical, financial and organizational nature. Those can be found in the final report of the UNDP/WB monitoring programme (Stassen, 1993).

7. COMMERCIAL STATUS

Power Gasifiers
At present there are only a small number of commercial small-scale biomass power gasifiers operating globally. The short term commercial prospects of small-scale biomass power gasifiers in developing countries at present appear to be very limited, due to three major factors:

(i) unfavourable economics compared to fossil fuel alternatives;
(ii) low quality and reliability of equipment resulting in operational difficulties; and
(iii) inherent difficulties in training sufficiently qualified and/or experienced personnel resulting in sub-standard operation of units.

Longer term prospects depend on the long term price developments in world oil markets as well as on the progress that can be made in improving equipment and fuel quality and simplifying operating procedures. Relative to combustion the number of gasification units is still limited but the interest is rapidly increasing. Most commercially operated power gasifiers are fuelled by wood and/or charcoal.

Heat Gasifiers
The commercial potential for heat gasifiers is significant. The technical performance is generally proven and reliable. The economic competitiveness of heat gasifiers when compared to conventional alternatives is very attractive. In addition to the excellent prospects in the agro-industrial sector, heat gasifiers can be applied in non-biomass producing industries requiring process heat, if acceptable and affordable biomass fuels are available. Potential heat gasifier markets include retrofits for oil fired boilers, ovens, kilns and driers used in industries as varied as food processing to manufacturing.

Power Gasifier Economics
The economics of biomass gasification is highly sensitive to the diesel price. Charcoal gasifier plants require at least a hundred percent increase in diesel fuel cost, in order to be even considered as an alternative to diesel power. Low priced wood gasifiers of local manufacture and relatively large capacity can be economically attractive under certain conditions (high load levels and operating hours). Economical data suggest that rice husk power gasifiers may be closest to commercialization. However, these gasifiers are still associated with unacceptable environmental pollution.

Equipment Performance
A number of performance aspects of gasifier power plants were much below manufacturers' specifications. Specifically maximum engine power output and diesel fuel savings (in dual-fuel systems) of some plants were much lower then could be expected from the manufacturer's information.

Equipment Reliability
A comparison of relatively successful and unsuccessful projects reveals that successful projects, like the unsuccessful ones, had considerable problems during the initial period after start-up. Successful projects are characterized by great willingness and commitment of the gasifier manufacturer for a prolonged period to back-stop and help the local operators immediately with any type of technical, material or spare part supply problem, as well as by a strong (financial) motivation of management and operator alike to keep the gasifier working.

Equipment Quality
Because of the prototypical character of the plants, technical and operational problems were to be expected, especially because the performance of power gasifiers appears to be sensitive to relatively small changes in fuel and energy demand related parameters.

Operating Personnel
Properly operating a biomass gasification system requires training and experience. The labour required for operating a gasification plant is quite different from such required for running of an equivalent Diesel engine. Motivation and discipline are necessary, but the operator must also be able to react adequately on two or three input parameters as well as have some basic technical skills. Achieving this appears to require not only an

adequate initial training programme but also continuous technical back-up for a prolonged period of at least one year.

Environmental Pollution
Biomass gasification systems produce solid, liquid and gaseous wastes, which, if not adequately controlled, could lead to detrimental impacts for the environment. Solid wastes are primarily residue ash. In most cases disposal of this ash is not a problem, and gaseous emissions from biomass gasifiers are also not a significant factor (possible CO leakage, no SO_2 and particulates).

Liquid effluents can be highly toxic and untreated disposal of such effluent can lead to contamination of drinking water, fish kills and other potentially negative impacts. At present additional research and development work is needed to find solutions to this problem. Fortunately most down draft and cross draft power gasifiers can be equipped with dry gas clean-up systems, which drastically reduce the quantity of liquid effluent produced. As a result disposal can be accomplished in a controlled and acceptable manner. The problem does not arise in heat gasifiers, because such systems usually completely combust the dirty hot producer gas inclusive the tarry components which are gaseous at higher temperatures.

Health and Safety
Operation of biomass gasifiers may result in exposure to: (a) toxic gaseous emissions (i.e. carbon monoxide); (b) fire and explosion hazards; and (c) toxic liquid effluent. With proper operator training, equipment and procedures, health and safety hazards can be minimized to acceptable levels or even eliminated.

Technology transfer: a long term approach
From the extensive monitoring and evaluation of biomass gasifier units it becomes clear that those gasifier programmes which have adopted strategies for sustainability and long term development, have showed best results. Donor agencies should concentrate on building up of local capability through training and transfer of technology, rather than simply providing expertise and equipment. This is a slow process but it is the only one which (in the long run) will lead to successful projects that benefit rural communities. Simply setting up a project and then leaving is a waste of time and money.

Any activity not carried out with a motivated local partner is destined to have no local impact. The most effective gasification programmes have resulted from the formation of strong and experienced local organisations. This enables local personnel to be trained in different aspects of the technology and adapt it to suit local circumstances. Therefore an in country group of competent and dedicated professionals with experience in technology development and implementation, seems an essential starting point for any sustained and long term expansion in the use of biomass gasification. It seems that any long term programme should start with setting up a national centre of expertise.

Technology Status World-wide

More or less conventional fixed bed gasifiers has been applied by several companies to gasify biomass materials. The status of some commercial small scale biomass gasification systems are outlined below:

Up-draught gasifiers
Only a few commercial up-draught power gasifiers are in operation today. All systems are located in South America. The situation was completely different in the 1940's and 1950's when both in Europe a considerable number of systems were functioning on a diversity of fuels like wood residues and agricultural wastes. The last European up-draught power gasifier (in Germany) was closed down recently for environmental reasons (water pollution due to tarry residues).

Down-draught gasifiers
The only commercial down-draught wood gasifier presently in operation in a developing country is located in Loma Plata, Paraguay. This full-gas unit was installed in 1983. After initial technical problems and after extensive modifications of the gas cleaning section, the system now functions to the satisfaction of the user. The plant consists of 2 down-draught systems of approximately 300 kW_{el} each. A third unit is

under construction. The plant is owned and paid for by an immigrant community, is fuelled by local available firewood and serves to provide power to the town and surroundings of Loma Plata. So far an evaluation of the technical and economic viability of this plant (as compared to a wood fuelled steam power station) is lacking due to a refusal of the plant manufacturer.

At least one manufacturer (Martezo) can point to a small number of continuing commercial projects in a developed country (i.e. France). Systems are situated at isolated sawmill sites and operate to the satisfaction of the user. Operational and financial details with respect to those plants are scanty.

Cross-draught gasifiers
In Brazil and other South-American countries, a number of commercial cross-draught charcoal gasifiers (both full gas and "dual fuel") of local design and manufacture have been installed since approximately 1982. Most projects seem to have had considerable initial technical problems, due to sensitivity of the equipment for fuel quality. Quite a number of installations were decommissioned or are functioning irregularly because a fuel gas of acceptable quality could not be produced on a sustained basis. Some projects have overcome the difficulties and are functioning technically adequate and to the satisfaction of the user.

Open-core gasifiers
A number (at least twenty) commercial open core rice husk gasification plants have been in operation in China decades. Since 1967 identical units were installed in Mali. Recently (1986) it was decided to install an additional new unit. Since approximately five years a number of locally designed and manufactured open core gasifiers haven been commercially installed at rice mills in Thailand. The Mali plants were evaluated in the context of the "UNDP/WB monitoring programme". It was concluded that plants operate technically satisfactory and, at given locations are able to produce electricity at marginally lower financial cost than equivalent diesel engines. However, it should be borne in mind that units produce considerable amounts of potentially harmful tars.

Manufacturers
The varying interest in biomass gasification technology over the last century is reflected in the total number of manufacturers. Most manufacturers in the 1970's are not active in this field anymore and/or they have not sold any gasifier. However, the recent interest in the technology has been a great stimulation to manufacturing companies. Currently, there are some tens of companies offering small scale biomass gasifier systems world-wide. A list of currently active manufacturers is given below with some characteristics of their gasifier system.
The list shows that manufacturers can be found at almost every continent. Most manufacturers specify wood and wood residues at the biomass feedstock although still some claim to be able to gasify various types of biomass. Electricity generation is the main application. However, the gasifiers can also be used for shaft power (e.g. irrigation) and heat generation.

8. FINANCIAL COSTS OF A 2 MW_{el} FIXED BED GASIFIER

INTRODUCTION

In this chapter the financial feasibility of a 2 MW_{el} biomass/waste fired combined heat and power (CHP) updraft and downdraft gasification system is investigated. Although no such units can be found in Europe or elsewhere, the concept is investigated in order to determine the most optimal capacity for small scale gasification CHP-plants.

The updraft gasifier unit consists of the following unit operations:
- fuel pretreatment (drying, sizing, densification);
- gasifier + ash container;
- (multi)cyclone;
- tar cracker;
- scrubber + demister;
- gas/air mixing device;
- compressor; and
- gasengine/generator set.

Regarding the tar production and the system's energy efficiency, the following remarks can be made.

The high tar production of updraft gasifiers (approx. 25 wt% of the fuel is converted to tar compounds) leads to a considerable loss of energy output since tar has a high heating value (approx. 30 MJ/kg). Furthermore, when tar is condensed and removed from the system, for instance by means of a scrubber, treatment of the tar/water is necessary before the water can be disposed of. This is a very costly process. Moreover, an application for the tar must be found.

On the other hand, when a tar cracker is used, the energy in the tar compounds is not lost, but the tar cracking process itself consumes energy (according to Garcia (1990) the heat requirement for naphthalene varies from 1.4-9.1 MJ/kg naphthalene dependend on the overall reaction). This energy demand can be delivered by partial combustion of the gas.

Downdraft gasifiers produce a sufficient clean gas at high load levels (which is the case in this concept) when they are operated correctly by dedicated operators. Therefore, no tar cracking reactor is necessary for the CHP downdraft gasifier concept.

The scrubber is incorporated to remove final impurities in the gas (tar, soot/dust particles, ammonia, H_2S, chlorides, etc) while the demister will remove disperged water droplets. To increase the volumetric efficiency of the engine a compressor is provided.
The gas cleaning/cooling section should perform such that the producer gas quality meets the gas quality requirements for gas engines, i.e. the tar and dust content should preferably be below 100 mg/Nm^3 and 50 mg/Nm^3 respectively, while the gas temperature should be as close as possible to ambient conditions.

FUEL PRETREATMENT COSTS

The cost for drying, storage, sizing and densification is described below.

Drying

The cost of drying is the product of the amount of moisture removed, the energy required to evaporate the moisture and the cost of that required energy. For example, when wood chips are to be dried from 55% to 30% w.b., 556 kg water per ton of dried material at 30% w.b. must be evaporated. With a specific energy consumption of 3 GJ/tonne water or 2.1 GJ/tonne wet material, the energy consumption per tonne dried material will be 1.67 GJ or 463 kWh. With a purchase price of heat equal to 4 ECU/GJ the drying costs becomes 6.7 ECU/tonne. According to Strehler biomass feedstock drying may vary between 5 and 20 ECU/tonne.

The drying costs depends largely on the dryer efficiency. Assuming a dryer efficiency of 85% and a purchase price of heat equal to 4 ECU/GJ_{th} the drying costs becomes 4.7 ECU/GJ_{th}.

Storage

Because several biomass materials are produced irregularly, in particularly agricultural residues and/or energy crops, storage is needed when they are to be utilized as a gasifier fuel. The costs of storage depends on the storage method and the bulk density of the material. Literature data show large variations in the storage costs. For uncovered, outdoor storage the costs are low and vary between 0.1 and 2 ECU/m^3. However, the quality of the biomass material can not be assured in the case of chipped material. Outdoor, roofed storage costs are higher and vary between 0.3 and 3.7 ECU/m^3.

Sizing

From the investment costs, the energy consumption and the throughput/capacity the sizing costs can be determined per tonne material. However, the throughput/capacity depends largely on the fuel characteristics while the energy consumption increases with increasing fineness of the sizing. This results in large variations in sizing costs figures. They vary between 10 to 50 ECU/tonne fresh material for sizing biomass material into chips.

Densification

Like sizing, the costs of densification can be calculated from the investment costs, the energy consumption and the throughput/capacity of the briquetting/pelletizing machine. These costs are of the same order as the sizing costs.

CALCULATION OF THE TOTAL GASIFIER INVESTMENT COSTS

Technical performance data for a 2 MW_{el} downdraft or updraft gasification unit are presented in the next table.

Power output	MW_{el}	P	P
Efficiences		downdraft	updraft
Hot gas efficiency gasifier (full load)	A	90	95
Cold gas efficiency gasifier (full load)	B	75	60
Electric efficiency engine (on producergas)	C	35	35
Thermal efficiency engine	D	45	45
Generator efficiency	E	97	97
Bruto electric efficiency	F=B*C*E	25	20
Efficiency heat recovery gas cooling	G	80	80
Bruto thermal efficiency	H=B*D+G*(A-B)	46	55
Total bruto efficiency (thermal + electric)	I=F+H	71	75
Output and input parameters			
Annual operating hours (full load)	hrs/yr		J
Actual heating value of the fuel ($LHV_{w.b.}$)	MJ/kg w.b.		K
Bruto electricity production	MWh_e/yr		L = (P * J)
Bruto heat production	MWh_{th}/yr		P * J * H / F
Own electricity consumption	% of bruto power output		10%
Efficiency heat recovery at user	% of bruto heat output		95%
Ash production	kg/tonne throughput		10
Specific fuel consumption	tonne/MWh_e		L / (F * K) * 3.6

Prices of process equipment have been estimated on basis of existing equipment of a smaller capacity, for which a scale-up factor of 0.72 has been used (as derived in Van Swaaij et al., 1994). The investments of this case have been compared to a recent cost overview (Van Swaaij et al., 1994) and fits well within the range. Direct process equipment costs are presented in the next table.

Components	Downdraft	Updraft
Direct investments	Costs (ECU)	
-Process equipment (installed)		
Gasifier[1]	470,000	470,000
Multi cyclone[2]	25,000	25,000
Tar cracker[3]	0	129,000
Heat exchanger[4]	64,000	64,000
Scrubber + demister[4]	64,000	64,000
Compressor[4]	17,000	17,000
Gas engine and generator (2 @ 1 MW_{el}-units)[5]	1,240,000	1,240,000
Total	1,880,000	2,009,000

1. Stassen et al. (BTG); UNDP/WB Small-scale biomass gasifier monitoring report, p. 40, 1994. Based on the price of a high cost heat gasifier system (capacity 4 MW_{th}, used scale factor 0.72). Low cost dual fuel system (up-scaled from 100 kW_{el} with scale-factor 0.72: ECU 120,000; High cost dual fuel wood/steel system (up-scaled from 100 kW_{el} with scale-factor 0.72: ECU 550,000; these system costs exclude engine, generator, control and electrical equipment.
2. Siemons et al. (BTG); Emission requirements for the combustion of wood waste residues, p. 12, 1994.
3. BTG; assessment of the R&D-group, 1995.
4. BTG; based on an assessment for a 1 MW_{el} gasification unit. Scale-up factor 0.72.
5. Knoef et al. (BTG); based on information from the Dutch electricity distribution company EDON: real costs of two complete 1 MW_{el} installated gas engine and generator sets in the Netherlands, 1995.

Operational costs are personnel costs, fuel costs, maintenance costs and utilities (process water, electricity). Since fuel will be transported to the site and has to be stored, handling capacity (manpower) is needed. To run the plant continuously, two operators on a 24 hours shift basis (5 shifts) are needed. Other personnel costs concern staff personnel and financial administration. Operational costs for both concepts are assumed to be similar.

Products of the plant are electricity and heat. Ash residues are taken into account as waste, that in the worst case has to be disposed. Eluability tests should prove for which applications the ash can be utilized (f.i. in construction materials or as fertilizer).

An overview of the needed manpower and other operational costs are given below.

Parameter	Specification
Personnel	5 shifts @ 2 operators 1 chief 0.5 marketing staff 1 staff 1 financial administration
Utilities -process water -electricity	 7 m^3/tonne biofuel 10% of the bruto electricity production
Revenues -electricity -heat	 to be calculated to be calculated
Maintenance	5% of direct equipment investment
Residues -ash	 10 kg/tonne throughput

9. CONCLUDING REMARKS

In the aftermath of the world oil price rises of the middle and late 1970s, several donor financed projects were implemented in a number of countries. The majority was for power applications and little attention was given to research & development, technology transfer and support capability. As a result, many pilot and demonstration projects in the rural areas failed. Despite this, gasification technology is recognized as a promising technology for power and heat generation in many areas. If this potential is to be fulfilled, however, it will be necessary to learn the appropriate lessons from the experience to date. Future donor activities should focus on:

Support for wider commercialization of small scale heat gasifiers
Heat gasifiers are relatively simple and this technology is mature and has a wide scope for application. Standardization, quality control and marketing are the main points of the manufacturing firms.

Support for research and development work on small scale power gasifiers
The technology for power gasifiers is not yet ready for widespread commercialization and it is strongly recommended that donor agencies support research and development work instead of promoting demonstration projects. The main priority is the development of a manufacturing method for a standard gasifier fuel composed of a mixture of low-cost biomass feedstocks and automation of the gasification system in order to increase the reliability and reduce the operational costs.

Identifying the conditions for commercialization
Before efforts are made to commercialize small scale power gasifiers, it is essential that the following conditions are fulfilled:

- The technology should be mature and proven in demonstration and prototype models.
- A local capacity for manufacturing the gasifier system must exist. Manufacturers must provide an adequate after-sales service, guarantees and training of operators.
- Labour, with the skills and motivation required for operation of gasifiers, should be available.
- Accurate and objective information on the technology, the gasification system and its capabilities, its limitations, and how it compares with competing systems should be available to potential customers.
- Loan finance should be available for purchasers of approved systems.
- Regulations covering the safety, quality of gas produced, permitted level of noxious emissions and discharges, and other aspects of gasifier operation should be in force.
- Any legal obstacles to the sale of surplus electricity should be removed.

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