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Small-Scale Biomass Gasifiers for Heat and Power

A Global Review

Hubert E. Stassen

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Hubert E. Stassen

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Contents

Foreword

This contribution to the World Bank Technical Papers, Energy Series, is the result of an ESMAP project to assess status of biomass gasification technologies and their applicability in developing countries. ESMAP, the joint United Nations Development Programme/World Bank Energy Sector Management Assistance Programme, was established in 1983 to provide advice and technical assistance on sustainable energy to developing countries and is administered by the Industry and Energy Department of the World Bank. The four-year biomass research effort (1986–90) monitored gasifier operations in Africa, Asia, and Latin America and compiled uniform data on the gasifiers' performance, economics, safety, and public acceptability. The report reviews the cost-effectiveness of gasifier systems, scope of applications, conditions for implementation, and potential environmental implications.

Biomass gasifiers have a long history and substantial future potential. First used commercially in the 19th century, the technology has seen service only sporadically in the 20th—chiefly to compensate for wartime shortages of petroleum-based fuels. The energy crises of the last 20 to 25 years, however, have rekindled interest in biomass gasification, particularly in developing countries seeking the potential savings from generating energy from plentiful, domestic waste products—such as forest- and wood-industry residues, rice hulls, senescent rubber trees, and coconut husks—instead of from expensive, imported diesel and fuel oil. Self-contained biomass gasification units have been seen as appropriate for areas remote from traditional energy supplies and have generally aimed at process-heat generation and small-scale power generation.

Whether the specific technologies for biomass gasification—many of them conceived and manufactured in the industrial countries—could function efficiently and economically using the natural and human resources available in developing countries was largely untested when this monitoring program began, and few countries had the information they needed to select the appropriate and reliable technologies.

The field data collected and analyzed by the program indicate that the commercial potential for heat gasifiers is significant but that for power gasifiers is presently more limited. Like many studies in the Energy Series, the report reveals that local capacity to operate, repair, and maintain the systems is essential. Expanded use of gasifiers will also depend on the availability of more flexible equipment and better comparative fuel-price economics. In the meantime, this report provides objective on-site performance data—as against manufacturers' claims—that can serve as a guide for those interested in advancing the efficient technical use of local energy sources in developing countries.

Richard Stern
Director
Industry and Energy Department

Abstract

This document is the final report of the Biomass Gasification Monitoring Program (BGMP) sponsored by ESMAP (the joint United Nations Development Programme/World Bank Energy Sector Management Assistance Programme) and administered by the World Bank Industry and Energy Department. The four-year biomass monitoring program (1986–90) compiled uniform data on the performance, economics, safety, and public acceptability of biomass gasifiers in Africa, Asia, and Latin America. The present report summarizes data obtained from field reports submitted during the life of the monitoring program and synthesizes the insights gained from the program as a whole. As the first comprehensive review of the state of the art of biomass gasification in developing countries, the report is intended as a reference manual and guide for policymakers, planners, investors, and entrepreneurs.

The report begins by explaining the revival of worldwide interest in biomass gasification for developing countries during the 1970s and 1980s as well as the rationale for the monitoring program. It continues, in chapter 2, by discussing the technical, commercial, economic, pollution, health, and safety aspects of biomass gasification technology. The methods used by the BGMP, the gasifiers monitored, and the results of the monitoring are described in chapter 3. The performance aspects of the technology, as revealed by the BGMP data, are discussed and analyzed in chapter 4; the BGMP data are also compared with the equipment manufacturers' specifications. Insights on the costs and economics of the use of biomass gasifiers in developing countries are provided in the following chapter.

The report summaries the project's conclusions about the value added by biomass gasifiers, costs and economics of gasification, and availability and reliability of gasification equipment in chapter 6. That chapter also includes suggestions for research and development work that may improve the competitiveness of the technology versus the use of prime movers fueled by petroleum derivatives and on the type of technology most likely to result in successful projects. A final chapter contains a "checklist," including background information, that could serve as a quick evaluation instrument for assessing the viability and applicability of proposed biomass gasifier projects.

Acknowledgments

With the completion of field monitoring activities in 1990, the ESMAP-sponsored UNDP/World Bank Small-Scale Biomass Gasifier Monitoring Programme (BGMP) effectively finished. The program produced about 20 technical reports on individual gasifiers and an interim technical overview. The reports contain a wealth of new data on the technical and operational aspects of biomass gasifier technology, as well as detailed and hitherto unavailable information on the feasibility and costs of using biomass gasification plants in developing countries.

This report was developed in cooperation with Matthew Mendis, first ESMAP task manager; Willem Floor, second and last task manager; Prof. Ruben A. Garcia, manager of the Philippines program; Dr. Pompilio Furtado, manager of the Brazil program; Dr. Sasjomo Saswinadi, manager of the Indonesia program; and Mr. Ton Zijp, manager of the Africa and Pacific program. I would like to thank Robert van der Plas of the Power Development Division, Industry and Energy Department, for reviewing the paper.

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Abbreviations and Symbols

AFME	Agence Française pour la Maîtrise de l'Energie (France)
AIT	Asian Institute of Technology
BEDP	break-even diesel fuel price
BGMP	UNDP/World Bank Biomass Gasifier Monitoring Programme
BOD	biological oxygen demand
CO	carbon monoxide
CO_2	carbon dioxide
CH_4	methane
CRE	Center for Research on Energy of the Institute of Technology in Bandung
DG	Directorate General
DGIS	Directoraat-Generaal voor Internationale Samenwerking (Netherlands)
EC	European Community
ESMAP	Joint UNDP/World Bank Energy Sector Management Assistance Programme
GTZ	Gesellschaft für Technische Zusammenarbeit (Germany)
H_2	hydrogen
ITB	Institute of Technology in Bandung
ITB/TK	Department of Chemical Engineering of ITB
IC	Internal combustion engine
J	joule
kcal	kilocalorie
kg	kilogram
kJ	kilojoule
kWh	kilowatt-hour
kW_{el}	kilowatt electric
kW_{me}	kilowatt mechanic
kW_{th}	kilowatt thermal
kWh_{el}	kilowatt-hour electric
kWh_{me}	kilowatt-hour mechanic
kWh_{th}	kilowatt-hour thermal
l	liter
MJ	megajoule
MW_{el}	megawatt electric
MW_{th}	megawatt thermal

mg	milligram
Nm^3	normal cubic meter
N_2	nitrogen
n.a.	not applicable
n.m.	not measurable
n.s.	not stated
ppm	parts per million
PAH	polycyclic aromatic hydrocarbons
PREP	Pacific Regional Energy Programme
SIDA	Swedish International Development Authority
SPEC	South Pacific Bureau for Eccnomic Cooperation
UNDP	United Nations Development Programme
U.S.AID	United States Agency for International Development
US$	U.S. dollar
Vatu	Vanuatu currency (1 Vatu equals 0.01 US$).

1

Biomass Gasifiers: An Old and New Technology

The basic principles of biomass gasification have been known since the late 18th century. Commercial applications were first recorded in 1830. By 1850, large parts of London had gas lights, and an established industry had grown up using "heat gasifiers" to make "producer gas," mainly from coal and biomass fuels, to supply the lights. In about 1881, producer gas was used for the first time to power an internal combustion engine; thus, the "power gasifier" was introduced. By the 1920s, producer gas systems for operating stationary engines as well as trucks, tractors, and automobiles were demonstrated in Europe and elsewhere. However, because they were relatively inconvenient and unreliable, they failed to gain widespread acceptance and soon fell out of use.

During World War II, biomass power gasifiers reappeared in force in Europe, Asia, Latin America, and Australia. The cause was the general scarcity of petroleum fuels. In Europe alone, almost a million gasifier-powered vehicles helped to keep basic transport systems running. In most cases, the gasifiers were fueled by charcoal or wood. Again, however, most of the systems mobilized by the exigencies of war were readily abandoned with the return of peace and the renewed availability of relatively inexpensive petroleum fuels.

The energy crises of the 1970s and 1980s appear to have rekindled interest in biomass gasification. Again, a primary attraction has been the potential of biomass gasification to substitute for petroleum products. Another factor in the renewed interest in biomass gasification has been the increased energy demand of developing countries. Because of its long track record, biomass gasification is considered a mature and workable technology. Hence, as the high costs of gasoline and diesel oil have come to be seen as important constraints on modernization and development in many developing countries, biomass gasification has come to be perceived as an viable alternative to decentralized small-scale industrial and utility energy generation wherever a sustainable and affordable supply of fuelwood and agricultural residues is available.

Typical developing-country applications might include using producer gas from power gasifiers as a substitute for petroleum fuels in the standard gasoline or diesel engines that are commonly used in developing countries for electric power production and water pumping or in local industries (e.g., sawmills, maize mills, and workshops). In addition, the gas from heat gasifiers can be used in standard heat appliances such as agricultural dryers and cement, lime, or brick kilns.

Initiatives to Promote Use of Biomass Gasification

The renewed possibilities for biomass gasification seen in the 1970s and early 1980s led to a number of initiatives to demonstrate the potential benefits of introducing biomass gasifiers in developing countries. It was seen that dissemination of the gasifiers in developing countries could reduce fuel costs for small-scale power or heat generation in remote areas and that it could improve the reliability of fuel supply by making isolated rural industries or communities more self-reliant. By the early 1980s, more than 15 manufacturers (mainly in Europe and North America) were offering wood and charcoal power gasifiers in capacities up to about 250 kW_{el}. In addition, agencies such as DGIS (Directoraat Generaal voor Internationale Samenwerking) of the Netherlands, GTZ (Gesellschaft für Technische Zusammenarbeit) of Germany, AFME (Agence Française pour la Maîtrise de l'Energie), SIDA (Swedish International Development Authority), and DGI of the European Community were financing the installation of test and demonstration biomass power systems in many developing countries. In addition, at least six developing countries (Brazil, China, India, Indonesia, Philippines, and Thailand) had started power gasifier implementation programs of their own, based on locally developed technologies. In Brazil, India, Paraguay, and Thailand, the technology was promoted largely by local entrepreneurs and manufacturers.

Heat gasifiers were investigated and demonstrated to a much lesser extent. None of the above-mentioned donor agencies sponsored research, and only in Latin America (Brazil and Uruguay) and to a much lesser extent in Southeast Asia (Thailand, Malaysia and Indonesia) were a number of industrial-scale heat gasifiers fueled by wood and charcoal designed, built, and operated commercially.

The Biomass Gasifier Monitoring Programme

With the revival of biomass gasification technologies and their promotion for use in developing countries already under way, the UNDP and the World Bank decided to assess the technology thoroughly before endorsing or initiating further dissemination in developing countries. The two organizations were well aware of the pitfalls of previous attempts to diffuse decentralized energy technologies. Hence, in July 1983, the UNDP/World Bank Small-Scale Biomass Gasifier Monitoring Programme (BGMP) was initiated to "collect uniform data on the actual field performance, economics, safety and public acceptability of biomass gasifiers currently operating in developing countries."

No reliable or uniform standards or methods then existed for accurate evaluation of the technical and economic feasibility of biomass gasifiers. Data used in feasibility studies were usually based on hearsay or on unsubstantiated claims by manufacturers. Such feasibility studies as did exist were conducted on weakly supported assumptions, and technical evaluations were often based on theory rather than on hard data.

The main objectives of the BGMP thus were to remedy the lack of basic information and standards with regard to biomass gasification. The specific goals were as follows:

a. Determine whether gasifiers currently in use are meeting the technical, economic, and operational expectations of the users

b. Identify the specific gasifier technologies most likely to ensure successful projects

c. Identify aspects of the technology needing additional research and development

d. Establish standards for evaluation of proposed gasifier projects

e. Define more clearly the scope for the application of biomass gasifiers in developing countries.

This volume attempts to provide answers to all of the above questions.

2

Biomass 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 conducive to gasification include dry materials such as wood, charcoal, rice husks, and coconut shells. Biomass gasification, in the sense used here, should be distinguished from *biogas production*, which uses wet organic feedstocks such as animal dung or stillage and works by means of microbiological action to generate methane gas.

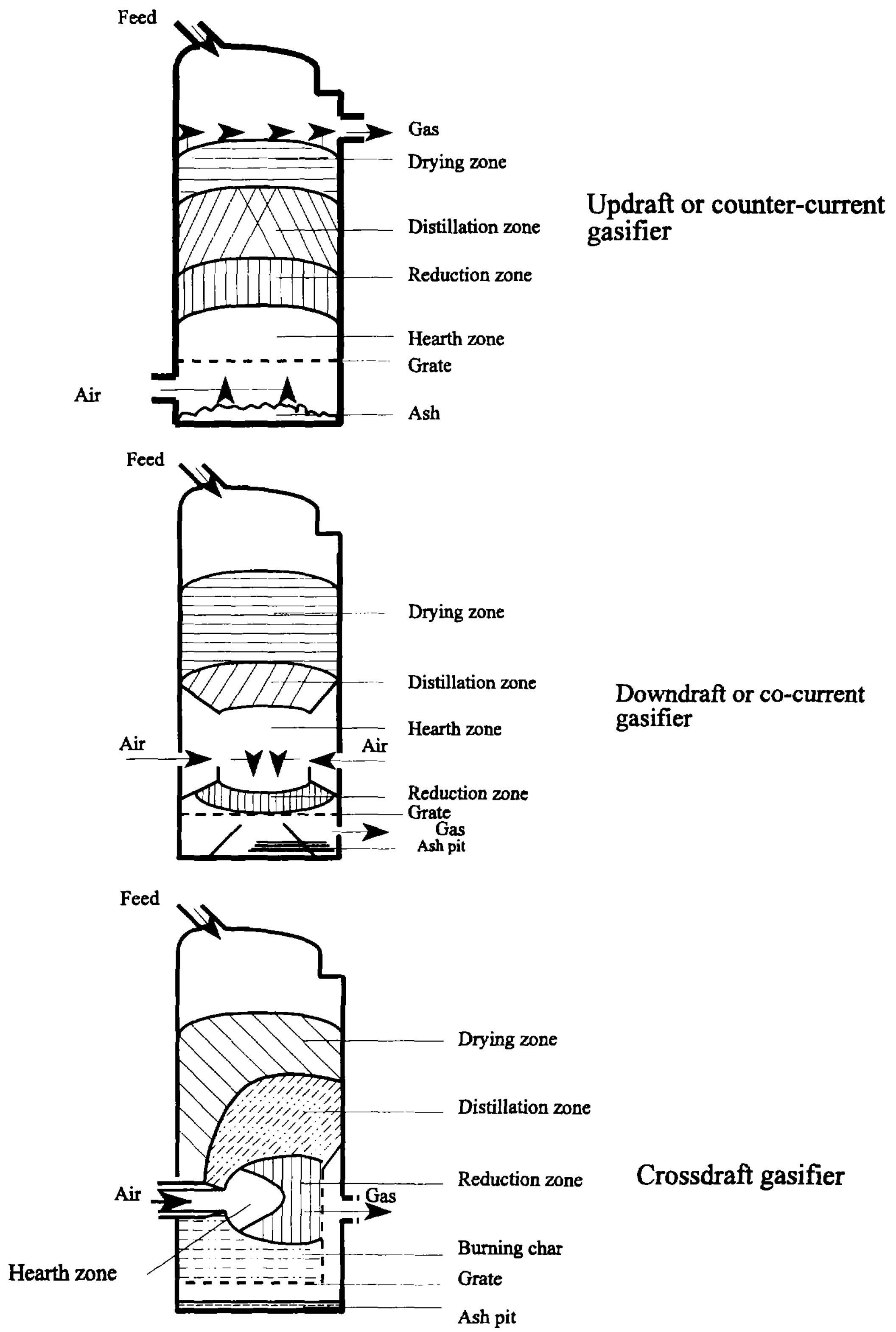
Components of a Biomass Gasification System

A biomass gasification system consists primarily of a reactor or container into which fuel is fed along with a limited (less than *stoichiometric,* 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, or about 10 to 15 percent of the heating value of natural gas. Producer gas from different fuels and different gasifier types may considerably vary in composition (Table 2.1), but it consists always of a mixture of the combustible gases hydrogen (H_2), carbon monoxide (CO), and methane (CH_4) and the incombustible gases carbon dioxide (CO_2) and nitrogen (N_2). Because of the presence of CO, producer gas is toxic. In its raw form, the gas tends to be extremely dirty, containing significant quantities of tars, soot, ash, and water.

Biomass gasification reactors are the vessels in which solid biomass is converted into producer gas. Because this report is limited to small-scale gasification, only reactors of the fixed-bed bed type are considered (larger biomass gasifiers are usually of the fluidized-bed or entrained-flow type).

The different fixed-bed reactor types are often characterized by the direction of the gas flow through the reactor (upward, downward, or horizontal) or by the respective directions of the solid flow and gas stream (co-current, counter-current, or cross-current). As Figure 2.1 shows, the following three reactor types are usually distinguished in small-scale biomass gasification: updraft or counter-current reactor, downdraft or co-current reactor, and cross-draft or cross-current reactor.

Figure 2.1 Three Types of Fixed-Bed Gasifiers



In all three reactor types, the biomass fuel is fed in at the top of the reactor and slowly moves down by gravity. During this downward movement, the fuel reacts with air (the *gasification agent*), which is supplied by the suction of a blower or an engine and is converted into combustible producer gas in a complex series of oxidation, reduction, and pyrolysis reactions. Ash is removed from the bottom of the reactor.

Updraft gasifiers, using wood and other biomass, produce a hot (300–600° C) gas that contains large amounts of pyrolysis tars as well as ash and soot. The hot gas is suitable for direct combustion in a gas burner. In engine applications, the gas must be cooled, scoured of soot and ash, and cleaned of tars by condensation or another method. Because the tars represent a considerable part of the heating value of the original fuel, removing them gives this process a low energy efficiency.

Downdraft gasifiers produce a hot (700–750°C), tar-free gas from wood and other biomass. After cooling and cleaning from ash and soot, the gas is suitable for use in internal combustion engines. Cross-draft gasifiers only produce a tar-free engine gas if fueled with good-quality charcoal (i.e., charcoal with a low content of volatile matter).

Table 2.1 Typical Gas Composition for Different Fuels and Reactor Types

Gasifier type (moisture in feed—% wet basis)	*Updraft: wood (10–20)*	*Downdraft: wood (10–20)*	*Cross-draft: charcoal (5–10)*
Hydrogen	8–14	12–20	5–10
Carbon monoxide	20–30	15–22	20–30
Methane	2–3	1–3	0.5–2
Carbon dioxide	5–10	8–15	2–8
Nitrogen	45–55	45–55	55–60
Oxygen	1–3	1–3	1–3
Moisture in gas Nm^3 H_2O/Nm^3 dry gas	0.20–0.30	0.06–0.12	< 0.3
Tar in gas g/Nm^3 dry gas	2–10	0.1–3	< 0.3
Lower heating value MJ/Nm^3 dry gas	5.3–6.0	4.5–5.5	4.0–5.2

Note: MJ = megajoule; Nm^3 = normal cubic meter.

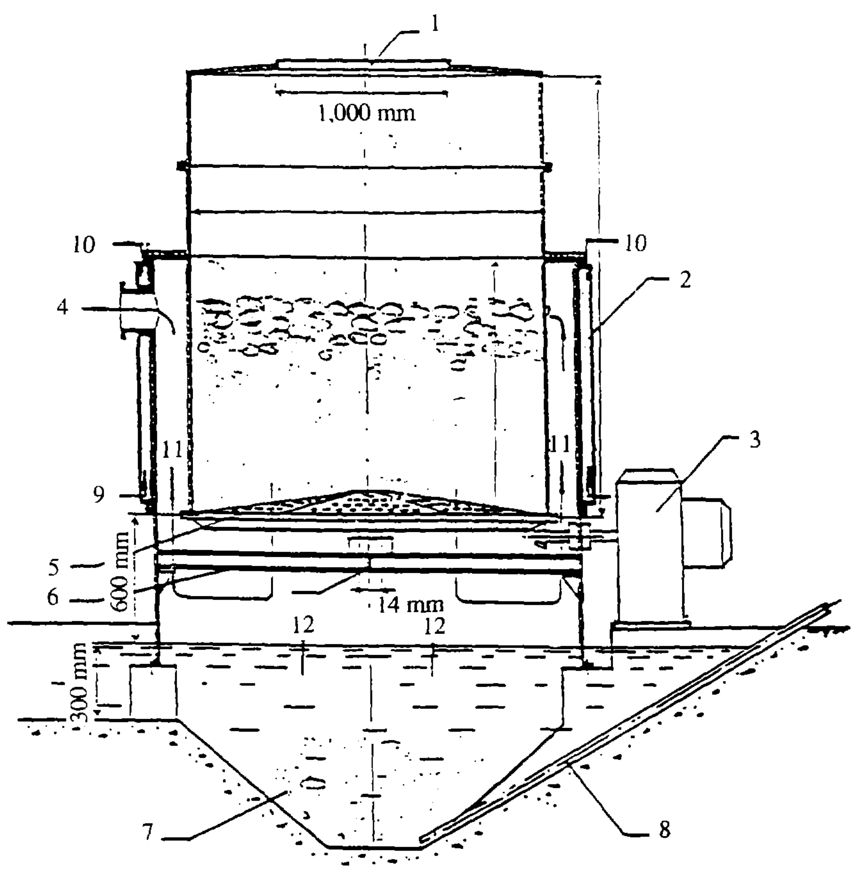
The "Turn-Down Ratio" Concept in Downdraft Gasifiers

In practice, downdraft reactors are not able to achieve tar-free gas production over the whole range of possible operating conditions. The lower the gas production (and the temperature) of the reactor, the more likely it is to produce quantities of tar that make the gas unacceptable for use in engines. This phenomenon is characterized by the value of the "turn-down ratio"—the minimum gas flow at which trouble-free operation with acceptable tar production is possible, expressed as a part of the maximum gas flow for which the reactor is designed. Thus, a turn-down ratio of 1:3 means that the minimum gas flow at which the gas can be directly applied in an engine is equal to one-third of the maximum gas flow, which (in a well-matched gasifier/engine design) is also the gas flow at maximum power output of the engine. If the gas production from the reactor is smaller then this minimum value for long periods, the engine used in combination with the reactor is likely to be damaged or to be excessively worn from tar contamination.

New Reactor Technologies

Downdraft reactors of very specific design—for gasification of rice husks—have been developed in China. Hundreds of systems employing these "open-core" rice husk reactors (Figure 2.2) have been built in China since the mid-1960s. Since then, plants of this type were also installed in countries such as Mali and Surinam. Because of its simplicity, the reactor is currently further developed in India. The objective is to construct small reactors that can gasify wood and agricultural residues. The gas is to be used in small diesel engines for water pumping.

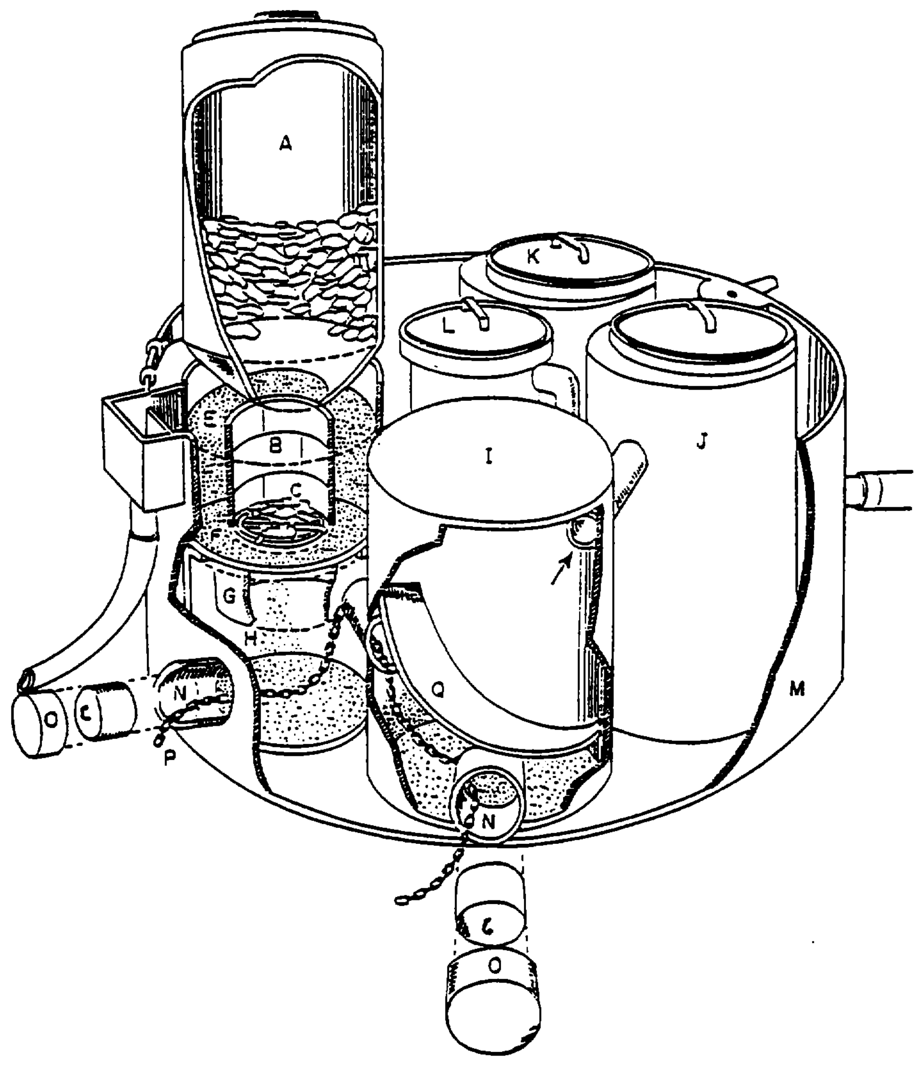
Figure 2.2 Open-Core Rice Husk Reactor Developed in China



1. Fuel and air inlet	4. Gas outlet	7. Ash-settling pond	10. Cooling-water effluent
2. Cooling-water jacket	5. Rotary grate	8. Ash-removing tube	11. Gas
3. Furnace-grate reduction box	4. Gas outlet	9. Cooling-water intake	12. Ash

The Asian Institute of Technology (AIT) has developed a reactor and gas-cleaning system for charcoal gasification (Figure 2.3) that is made almost entirely from ferrocement. This design aims at improving the financial competitiveness of gasification by minimizing the cost of the gasifier. In Thailand and in Indonesia, gasifiers of this type have been tested for prolonged periods.

Figure 2.3 The Ferrocement Charcoal Gasifier Developed at AIT, Bangkok



A	Fuel bunker	G	Metal shroud	M	Outer tank
B	Cast refractory reactor	H	Cylinder 1 (reactor)	N	Ashport
C	Charcoal fuel	I	Cylinder 2 (settling tank)	O	Ashport plug
D	Compacted rice husk ash	J	Cylinder 4 (cloth filter)	P	Cleaning chain
E	Refractory ring	K	Cylinder 5 (cloth filter)	Q	Aerodynamic fin
F	Cast refractory disc	L	Cylinder 6 (safety filter)		

Power Gasifiers and Heat Gasifiers

Although it is not a high-quality fuel, producer gas can be used effectively in several applications. One application is to fuel internal combustion (IC) engines to produce shaft power for generating electricity, water pumping, grain milling, sawing of timber, and so on. In such applications, the gasification systems are called *power gasifiers.* Alternatively, producer gas can be used to fuel external burners to produce heat for boilers, dryers, ovens, or kilns. In such applications, the gasifier systems are referred to as *heat gasifiers.*

Because they have different end-products, power and heat gasifiers are aimed at very different markets. Moreover, in many technical, economic and operational respects, power and heat gasifiers are rather different technologies. One of the principal technical differences is that power gasifiers must produce a very clean gas because of the strict fuel-quality demands of an IC engine. Thus, the resulting producer gas must be first filtered, cooled, and mixed in an elaborate gas-conditioning system, which is an integral part of a power gasifier. In contrast, producer gas combusted in external burners requires little or no gas conditioning. Because they do not require elaborate gas-cleaning systems, heat gasifiers are simpler to design and operate and are less costly compared with power gasifiers.

The methods for describing the output of power and heat gasifiers also vary. The output of a power gasifier is usually stated in terms of the peak electric power (kW_{el}) that it can produce when connected to an engine generator set. In contrast, the output of a heat gasifier is usually stated as the thermal value (kW_{th}) of the gas produced at maximum output. Typical configurations of power and heat gasifiers are shown in Figures 2.4 and 2.5.

Types and Characteristics of Engines Using Producer Gas

Spark-ignition or "Otto" engines as well as compression ignition or "Diesel" engines can be operated on producer gas. Spark-ignition engines can be operated on producer gas only. Diesel engines, however, must be operated on mixtures of diesel fuel and producer gas ("dual-fuel" or "pilot operation" mode). The latter requirement complicates the use of producer gas in diesel engines.

The temperature of the gas influences the power output of a producer-gas engine. Highest power output is realized at lowest gas temperature. Thus, in power applications, it is advantageous to cool the gas as far as is practical. Cooling, however, allows vaporized tars in the gas to condense on engine parts such as inlet manifolds and valve stems. Also, soot and ash particles in the gas may form deposits in the engine. These phenomena will result in excessive engine wear, so in power applications, it is absolutely necessary to filter and clean the gas of soot, ash, and tar.

Maximum Power

The *maximum* engine power output of a producer gas engine is lower than the output of an equivalent engine operated on conventional liquid fuel, a phenomenon known as *derating*. The efficiency of a producer-gas engine, however, is still theoretically the same as that of an Otto or diesel engine. Depending on type and size, small Otto and diesel engines may have efficiencies in the range of 20 to 24 percent and 28 to 32 percent, respectively.

Figure 2.4 A Gasifier System for Power Generation

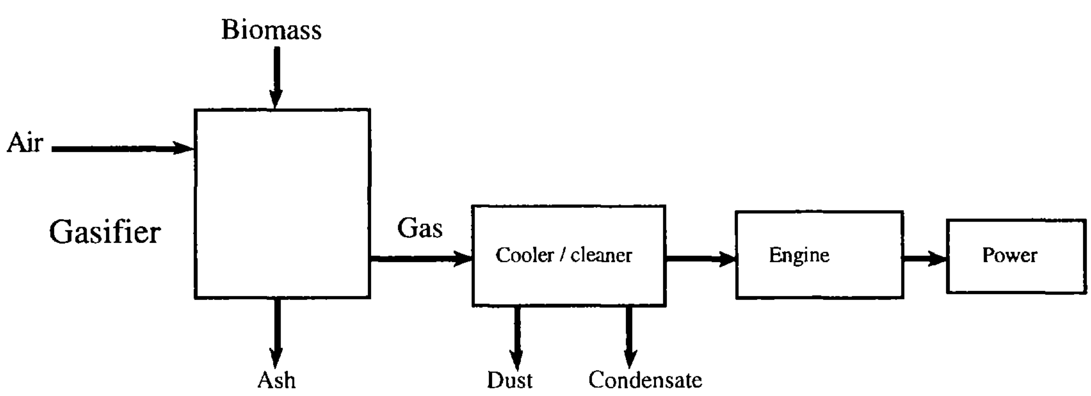
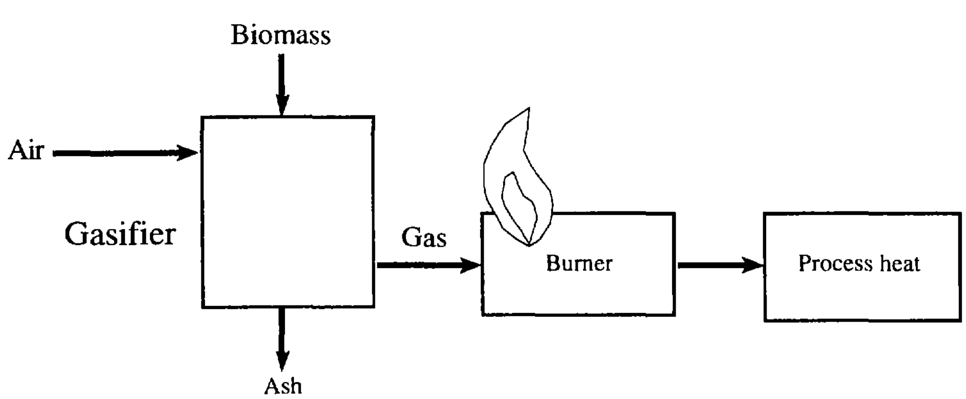


Figure 2.5 A Gasifier System for Heat Generation



Specific Fuel Consumption and System Efficiency

The *specific fuel consumption* is defined as the weight of the fuel consumption per unit output and is therefore expressed in kilogram per unit output. For power gasifiers, the output may be measured in kilowatt hours electric (kWh_{el}) or kilowatt hours mechanical (kWh_{me}), depending on whether the system produces electricity or shaft power. The heat output of heat gasifiers may be measured in kilowatt hours thermal (kWh_{th}), in megajoules (MJ), or in kilocalories (kcal). The *overall system efficiency* is defined as the ratio of the energy delivered by the system in the form of power and heat and the energy consumed by the system in the form of fuel and is mostly expressed as a percentage.

Load Factor

The *load factor* of an engine is here defined as the ratio of the actual power that is delivered and the energy that would have been delivered when the engine had run continuously at its rated power. Low load factors mean that the engine is underutilized. Low loads increase the specific fuel consumption and decrease engine efficiency.

Biomass Fuels for Gasifiers

A global review of the results of gasification projects leads to the conclusion that only a few biomass fuels have been adequately demonstrated in field operations. Several fuels can be considered acceptable for gasification, including lump charcoal, dry (less then 20 percent moisture content) wood blocks, dry coconut shells, and rice husks. Table 2.2 presents a matrix of acceptable fuels and gasification systems.

Commercial Status of Small-Scale Biomass Gasification Systems

Although a number of equipment manufacturers in Europe and the United States sell small-scale biomass power gasification systems, the actual number of such commercial units installed in developed and developing countries during the last five years is very small. In India and China, however, manufacturers of, respectively, small-scale wood power gasifiers and rice husk gasifiers appear to maintain at least some level of production.

The decline of petroleum prices in the late 1980s has left only a small number of strictly commercial small-scale biomass power gasifiers operating globally. The majority of these are about a hundred rice-husk gasifiers that are reported in commercial operation, primarily in China. A declining number of charcoal power gasifiers continue in operation in Latin America, primarily in Brazil. A few wood-fueled power gasifiers are also in commercial operation, the largest at a Mennonite settlement in Paraguay. However, an increasing number of medium- and large-scale heat gasifiers are being installed at industrial sites in developing and developed countries. The commercial status of gasifiers may thus be summarized as follows:

- Commercially proven heat gasifiers are available, especially when the fuels are charcoal, wood, coconut shells and rice husks. These systems have acceptably high reliability. As such, direct comparisons of heat gasifiers against conventional systems are acceptable.
- The recent track record for successful commercial power gasifiers is very limited and the reliability of those systems operating in the field is low compared with conventional options such as diesel-engine systems. Additional allowances for maintenance, spare parts, and operator salaries must be incorporated as part of power gasifier systems to compensate for lower reliability and performance compared with conventional systems.

Table 2.2 Gasification Systems and Gasifier Fuels

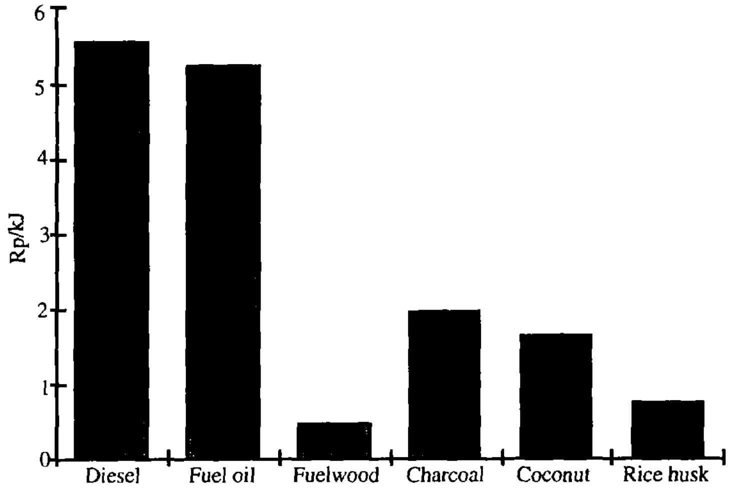
Biomass fuel	*Gasifier type*	*Capacity range*	*Application*
Power gasifiers			
Wood blocks	Fixed-bed/down-draft	< 500 kW$_{el}$	Electricity/shaft power
Charcoal	Fixed-bed/down-draft Fixed-bed/cross-draft	< 50 kW$_{el}$	Electricity/shaft power
Rice husks	Fixed-bed/down-draft (also called Fixed-bed/open-core)	< 200 kW$_{el}$	Electricity/shaft power
Coconut shells	Fixed-bed/down-draft	< 500 kW$_{el}$	Electricity/shaft power
Heat gasifiers			
Wood/charcoal/ coconut shells	Fixed-bed/cross-draft Fixed-bed/up-draft	< 5 MW$_{th}$	Process heat

Note: kW$_{el}$ = kilowatt electric; MW$_{el}$ = megawatt electric.

Economics

The economics of small-scale biomass gasifiers hinge on the savings that can be gained by switching from relatively high-cost petroleum fuels to low-cost biomass fuels. Fuel costs are the most significant component of operational costs for petroleum systems. The relatively high costs on an energy basis of petroleum fuels compared with biomass fuels is for the Indonesian situation illustrated in Figure 2.6. These potential fuel-cost savings must be measured against the additional capital costs, higher labor and other operation and maintenance costs, and lower conversion efficiencies of gasifier systems. One way to evaluate the trade-off between capital costs and operating costs is to compare the levelized costs of power produced by each system. This, along with an assessment of the financial and economic rate of return of the additional investment required for a gasifier system, when compared with a conventional petroleum system, can be used to judge the attractiveness of the alternatives.

Figure 2.6 Comparison of Petroleum Prices with Biomass Fuels on Energy Basis, Indonesia, 1990



Environmental Pollution

Biomass gasification systems produce solid, liquid, and gaseous wastes that, if not adequately controlled, could harm the environment.

Gaseous Emissions

Gaseous emissions from biomass gasifiers are not a significant factor except possibly in the immediate vicinity of the plant, where CO leakages could be hazardous to workers. Compared with fossil-based systems, biomass gasifiers are relatively benign in their environmental emissions and produce no sulfur oxides, low levels of particulates, and (if they consume biomass produced on a sustainable basis) no net increase in global CO_2 levels.

Liquid Effluents

The situation is not as encouraging when large quantities of liquid effluents are produced, as is the case with updraft gasifiers and gasification of highly volatile biomass fuels. The situation can be exacerbated if wet-gas cleaning systems are used; these can dramatically increase the volumes of tar-contaminated liquid effluents. In all cases, the liquid effluents can be highly toxic, and untreated disposal of them can contaminate local drinking water, kill fish, and have other potentially negative effects. At present, additional study is needed on treatment options for liquid effluents. Fortunately, most downdraft and cross-draft power gasification systems can be equipped with dry-gas clean-up systems, which drastically reduce the quantity of liquid effluent produced. As a result, effluents can be disposed of in a controlled and acceptable manner. The liquid effluent problem does not arise in heat gasifiers, because such systems usually combust the dirty hot producer gas completely, including the tarry components, which are gaseous at higher temperatures.

Solid Wastes

Solid wastes are primarily residue ash. Ash quantities may vary between 1 percent (wood) and 20 percent (rice husk) in weight of the original biomass fuel. In most cases, disposal of the ash is not a problem, and in some cases (e.g., with rice husks), the ash can even have a positive value for use by steel or cement industries.

Health and Safety

Operation of biomass gasifiers may result in exposure to toxic gaseous emissions (i.e., carbon monoxide); fire and explosion hazards; and toxic liquid effluents. Avoiding poisoning by toxic gases is mainly a matter of following sound workplace procedures, such as avoiding inhalation of the exhaust gas during startup and ensuring good ventilation of gas-filled vessels before personnel enter them for servicing and maintenance. Avoiding fires and explosions is also primarily a matter of following sound procedures. In addition, however, it is important that the system is designed so that any internal explosion that may occur can be relieved to avoid damage to the system. Avoiding contact with carcinogenic compounds in the condensates requires the use of protective gloves, special clothing, or both.

It may be concluded that with proper operator training, equipment, and procedures, health and safety hazards can be held to acceptable levels or even eliminated.

3

The UNDP/World Bank Biomass Gasifier Monitoring Programme

In an early stage of the BGMP, gasifier plants were selected for study. (For a detailed description of the BGMP criteria, see the UNDP/World Bank Guidelines 1985.) The first priority for study was commercially operated plants using commercially available technology with a more-or-less proven track record. Other considerations in selecting installations for monitoring related to variations in plant and input/output characteristics, such as plant capacity, reactor type, type of gas cleaning system, engine type, biomass fuel, and application (electricity, shaft power and/or heat). In addition, the program sought to identify variations in operational mode of the plants (i.e., load factors, fast and slow load variations) and the accessibility of the plants.

Monitoring Methodology

The detailed monitoring methodology used in the BGMP is presented in the monitoring guidelines document (1985). The monitoring procedures aimed at collecting data in a way that would allow for an evaluation of the system's performance in conditions that might differ from the ones prevailing at the actual site. Thus, a three-stage methodology was adopted. First, an equipment inventory was made, according to a standardized format.

Second, a baseline, in-depth performance monitoring procedure was established (i.e., measurements and data collection were taken to establish the operation and economy of the system at that time). The measurements included quantification of system inputs and outputs as well as other system parameters for three feedstock moisture contents and three system loads. Table 3.1 gives an overview of the parameters measured during baseline performance monitoring and indicates how each parameter was measured.

Third, operational data and experiences were monitored during an extended period according to standardized log sheets and performance reports.

During the course of the monitoring it became clear that execution of the baseline or in-depth monitoring according to the guidelines was difficult, time-consuming, and

Table 3.1 Overview of the Parameters Measured during Baseline Performance Monitoring

	Parameter	*Instrument or method*	*Frequency*
1	Ambient temperature	Thermometer	Per hour
2	Air relative humidity	Air hygrometer	Per day
3	Fuel input	Scale	Each filling
4	Fuel analysis		
	Moisture content	Oven drying, analytic balance	Per day
	Bulk density	Scale	Per week
	Size distribution	Sieves	Per week
	Ash content	Laboratory	
	Higher heating value	Laboratory	
	Proximate analysis	Laboratory	
	Ultimate analysis	Laboratory	
5	Pressure loss, gasifier	U-tube manometer	Per hour
6	Gasifier outlet temperature	Thermocouple, recorder	Continuous
7	Pressure loss, filters	Utube manometers	Per hour
8	Temperature after cooler	Bimetal thermometer	Per hour
9	Gas flow	Venturi, pressure transmitter	Continuous
10	Gas heating value	Gas calorimeter	Continuous
11	Gas composition	Orsat apparatus	Per hour
12	Dust content in gas	THT dust and tar sampler	Each run
13	Tar content in gas	THT dust and tar sampler Soxhlett apparatus	Each run
14	Condensate analysis		Each run
	pH, phenols, PAH, BOD	Laboratory	
15	Ash analysis		Each run
	Carbon content	Laboratory	
	Ash melting point		
16	Engine operating hours	Operation timer	Per run
17	Engine speed	Rpm meter	Per run
18	Auxiliary fuel consumption	Cumulative flow meter	Per run
19	System energy output		
	for generators	kWh-meter	Per run
	for pumps	turbine flow meter	Per run
20	Auxiliary power input	V, A, cos phi meter	Per run
21	Exhaust gas temperature	Bimetal thermometer	Per hour
22	Exhaust gas composition	Draeger tubes	Per day
	Oxygen		
	Carbon monoxide		
23	Lubrication oil analysis	Laboratory	Per monitoring
24	Engine compression	Compression gauge	Per monitoring
25	Engine frequency	Hz-meter	Per hour
26	Engine power output	kW, A, V, cos phi meter	Per hour
27	CO on-site	CO-meter	Per day

Note: BOD = biological oxygen demand; PAH = polycyclic aromatic hydrocarbons.

expensive. It also was evident that many gasifiers in developing countries were operating not only for technical or economic reasons but because of policy and institutional issues. Therefore, to get a clearer picture of the situation in the field, a more general approach in at least a few characteristic developing countries was deemed necessary. This was achieved by executing two surveys aimed at establishing the operational status of all known gasifier plants.

Monitored Plants and Sites

The BGMP monitored small-scale biomass gasifiers in Indonesia, the Philippines, Brazil, Vanuatu, Mali, Seychelles, and Burundi. The program encountered some difficulty in identifying strictly commercial operating gasifier systems, in that many plants turned out to be subsidized in one way or another. An overview of the plants and sites monitored in accordance with the original BGMP guidelines and their basic characteristics is presented in Table 3.2. An overview of number and operational status of plants that resulted from overall surveys that were conducted at all known gasifier sites in Indonesia and in the Philippines is shown in Table 3.3.

Indonesia

A large number of parallel activities focusing on wood-gas power plants took place in Indonesia in the early 1980s. Some of the projects were based on imported equipment, others relied on foreign designs manufactured under license, and still others were based on local design and manufacturing with foreign technical support. The overall survey (Table 3.3), carried out in 1989 to establish the operational mode of known gasifiers, identified 49 projects. Of these, 16 were research or pilot activities. Of the remaining plants, all 24 power gasifiers must be classified as demonstration projects, wholly or partly financed by a foreign or national donor. None of those units could be considered truly commercial in the sense that the client paid the full price of the gasifier. Twenty-one power plants were operated with wood fuels, two with rice husks, and one with charcoal. The nine industrial heat gasifiers were operated on wood, on coconut shells, or on multiple or mixed fuels. All heat gasifier projects were purely commercial.

The BGMP has performed in-depth monitoring of four power gasifiers and one heat gasifier (Table 3.2). The two generator sets in Balong and Sebubuk (respectively 20 and 30 kW_{el}) used wood gasifiers in combination with, respectively, a dual-fuel diesel engine and an Otto engine. The Balong plant was designed and constructed by the Department of Chemical Engineering (ITB/TK) and the Center for Research on Energy (CRE) of the Institute of Technology in Bandung (ITB), with technical assistance from the Netherlands. The Sebubuk gasifier was of Italian design and manufacture. The third generator set, in Majalengka (15 kW_{el}), used a rice husk gasifier of local ITB design in combination with a dual-fuel diesel engine. The fourth plant, in Lembang, used an Otto engine (10 kW_{me}) equipped with a ferrocement downdraft open-core charcoal gasifier, as originally developed at the Asian Institute of Technology (AIT) in Bangkok, Thailand. Finally, BGMP monitored a rubber wood-fueled heat gasifier (600 kW_{th}) in Rajamandala.

Table 3.2 BGMP Sites and Plants

Site	*Capacity*	*Reactor*	*Gas-cleaning system*	*Engine type*	*Biomass fuel*	*Application*
			Power			
Indonesia						
Balong	20 kW_{el}	downdraft	cyclones, stone rockwool, impingement filter	diesel	rubber wood	community electricity
Sebubuk	30 kW_{el}	downdraft	spiral flow separator, scrubbers, fabric filter	Otto	waste wood	industrial electricity
Majalengka	15 kW_{el}	cross-draft (open-core)	cyclones, scrubbers, coconut fiber	diesel	rice husk	community electricity
Lembang	10 kW_{el}	ferrocement downdraft	bag filter	Otto	charcoal	electricity
Philippines						
Bago	28 kW_{me}	downdraft	cyclone, scrubbers, oil bath filter	diesel	charcoal	irrigation
Bolo	38 kW_{me}	downdraft	cyclone, scrubbers, oil bath filter	diesel	charcoal	irrigation
Brazil						
Itamarandiba	40 kW_{el}	cross-draft	cyclone, paper filter	Otto	charcoal	industrial electricity
Chacara	23 kW_{el}	cross-draft	cyclone, paper filter	Otto	charcoal	irrigation
Vanuatu						
Onesua	25 kW_{el}	downdraft	cyclone, baffle filter, bag filter	Otto	wood (leuceana)	community electricity
Mali						
Dogofiri	160 kW_{el}	downdraft (open-core)	scrubbers, dry sponge filter	Otto	rice husk	industrial electricity
Seychelles						
Mahé	35 kW_{el}	downdraft	cyclone, scrubbers, fabric filter	Otto	wood, coconut shell/husk	electricity
Burundi						
Tora	36 kW_{el}	downdraft	cyclone, scrubbers, oil bath filter	diesel	peat	industrial electricity
			Heat			
Indonesia						
Rajamandala	600 kW_{th}	downdraft	no gas cleaning	n.a.	wood	industrial heat
Brazil						
Espara Feliz	2 x 670 kW_{th}	downdraft	no gas cleaning	n.a.	wood	industrial heat
St. Luzia	4,060 kW_{th}	up-draft	no gas cleaning	n.a.	charcoal	industrial heat

n.a. = not applicable.

Note: kW_{el} = kilowatt electric; kW_{me} = kilowatt mechanic; kW_{th} = kilowatt thermal.

This unit was used for cocoa-bean drying and was constructed by Guthrie in Malaysia under license from New Zealand.

Power Gasifier Results. The overall survey indicated that in 1989 about half of the (demonstration type) power gasifiers were not working. Nonoperational installations were found both in projects using imported equipment as well as in projects based on gasifiers of local design and manufacture. The in-depth monitoring indicated that the projects succeeded or failed for mixed technical, financial, and institutional reasons.

The technical factors were as follows:

- The in-depth monitoring of the two wood gasifiers showed that in both projects, major technical modifications and improvements were necessary before the plants functioned satisfactorily. After this, especially the Balong unit operated quite reliably during more than 11,000 uptime hours. No long intermediate shutdown periods are reported. The recorded technical availability of this plant in 1988 was 85 percent.
- The locally developed small-scale rice-husk gasifiers never reached that stage. This equipment is clearly in need of further technical development work before it can be demonstrated or marketed.
- The AIT ferrocement charcoal gasifier plant showed no initial problems or shortcomings, and no major modifications were necessary. However, the maximum capacity of the current design may be limited to about 20 kW_{el}.

The financial factors were as follows:

- For reasons of costs, maintenance, service, and spare parts availability, the national Indonesian projects worked with locally manufactured dual-fuel diesel engines. The BGMP results indicate that especially when operated with less experienced or less motivated personnel, dual-fuel systems tended to consume more diesel fuel than expected. This factor served to decrease the sometimes already marginal financial viability of the project, itself caused mainly by short operation times and low load factors. However, when conditions on site are favorable, financially feasible dual-fuel operation is possible, as indicated by the monitoring results from the Balong project.
- Indonesian authorities and gasifier customers alike rightly considered the high cost of imported gasifiers and spare parts as prohibitive for commercial exploitation.
- CRE found the AIT ferrocement gasifier interesting because of its low capital cost. However, the relatively high price of charcoal, compared with commercial liquid fuels, made the current design not financially viable in the Indonesian context. Therefore, the technology was never commercially introduced or marketed.

The institutional factors were as follows:

- When comparing the good performance of the Balong plant with less favorable experiences from other installations equipped with similar technology, the extensive technical support provided by ITB/TK during the initial year(s) of the project appears to be the major institutional factor. It created motivated staff who were willing and able to operate the gasifier. Later plants based on ITB designs have not received similar technical support because of limited personnel resources and logistical problems.
- In projects using imported technology, initial technical problems often resulted in prolonged shutdown of the equipment to await foreign technicians, equipment, and spare parts. The long periods of inactivity discouraged gasifier owners and operators alike. This problem was exacerbated by the fact that many imported gasifiers were installed in situations without commercial significance. This is illustrated by the case of the 30 kW_{el} Sebubuk plant, installed in a sawmill generating 3 MW_{el} by means of diesel gensets. Under such circumstances, the impact of the fuel cost savings realized through gasifier operation is doubtful.

Table 3.3 Operational Status of Plants from Overall Country Surveys

Country	*Gasifier type*	*Installed*	*Operating*	*Operating (% of total)*
Indonesia	power	24	11	46
Indonesia	heat	9	7	78
Indonesia	research/pilot	16		
Philippines	power	297	15	5
Philippines	power	248	3	1

Heat Gasifier Results. The overall gasifier survey of 1989 shows that at the time seven out of nine plants were functioning. The reasonable percentage of operating plants, serves to indicate that this technology is generally technically proven and reliable. This impression was confirmed by the outcome of the in-depth monitoring that was executed at a cocoa bean drying plant in Rajamandala. The monitoring report states that the plant worked technically satisfactorily and efficiently and that the drying costs using the heat gasifier were (marginally) lower compared with those of using a diesel oil burner.

Philippines

A program to commercialize locally designed and manufactured charcoal power gasifiers was initiated in the early 1980s by the Philippine government and supporte financially by U.S.AID. The program aimed at providing gasifier options in irrigatio rural electrification, and motive power for boats and trucks. A government-o company (Gemcor) was set up for mass production of gasifiers. Under the pr nearly a thousand gasifiers were manufactured. The equipment went agricultural cooperatives, who paid for it by means of a soft loan scheme. The two pump sets (30 to 40 kW shaft power) that were actually monitored used charcoal gasifiers in combination with dual-fuel diesel engines. Aside from this in-depth monitoring, the BGMP conducted quick surveys to establish the operational status of known power gasifiers in 1989 and 1990.

The surveys (Table 3.3) showed that in 1989/1990 only 1 to 5 percent of the charcoal power gasifiers installed between 1983 and 1986 were still in use. This disappointing figure can be explained by examining the outcomes of the in-depth and operational monitoring. Those reports suggest a number of reasons for the project and program failure. Causes appear to be partly technical, partly financial, and partly institutional in nature and are summarized below.

The technical reasons for failure are as follows. The in-depth monitoring indicates that the locally developed charcoal gasifier technology was insufficiently debugged. To reduce costs, no control or measuring equipment was installed, which made reliable operation of the gasifier difficult. Modifications were made as problems arose, leading to better and more reliable equipment over time. But poor plant maintenance, resulting in engine failure and in some cases permanent damage to engines, remained a problem for the duration of the project.

The financial problems were several. In the period 1982–87, profound changes occurred in the relative prices of charcoal and diesel fuel, thus making charcoal gasification sometimes flatly unprofitable. Even in periods of low charcoal cost, most irrigation systems were not used sufficiently to cover gasifier capital costs from savings in diesel fuel costs. Poor operation and maintenance of plants were partly a result of the way operators were paid, which did not give them any direct incentive to maximize performance at minimum costs.

On the institutional side, several shortcomings were apparent as well. To meet "political" installation dates, manufacture and installation of gasifiers was rushed. Thus, although sensible project identification, installation, and operating procedures were developed, they were often waived under political pressure. Plants often were installed in circumstances of doubtful technical and economic viability, and training of operators was hasty and inadequate, leading to poor operation and maintenance practices. Finally, the dual-fuel systems did not completely displace the use of diesel fuel, leaving the users with the inconvenience of procuring two fuels.

Brazil

The four installations selected for in-depth monitoring in Brazil were all financed by the private sector, without foreign donor assistance or local subsidy. The BGMP monitored two power gasification systems and two heat gasifiers. The outcome representative of the performance of many more installations of the same type.

Power Gasifiers. The two power systems (20 to 40 kW_{el}) used cross charcoal gasifiers in combination with Otto engines. One system was used for electric generation, the other for water pumping. The BGMP established that both systems suffered from operational problems, mainly caused by the use of a charcoal of unsuitable quality, the use of plant construction materials of insufficient heat resistance and consequently short lifetime, and inadequate matching of gasifier and engine capacity. When in operation, the system had a maximum power output considerably lower than expected and service and maintenance costs higher than anticipated. This may have been due in part to less-motivated operators. Those problems and shortcomings soon resulted in unfavorable economics, which were exacerbated by rising charcoal prices. Therefore, operation of the gasifier was eventually abandoned.

Heat Gasifiers. One heat gasifier (4.0 MW_{th}) used charcoal and produced gas that was used to fuel ceramic tunnel kilns. No operational problems were reported, but after four years of operation the system was closed down. The cause was the unfavorable economics that followed a relative change in the price of charcoal and fuel oil. At the second site, two wood-fueled heat gasifiers of 670 kW_{th} each produced gas for the drying of kaolin. This system was a technical and financial success. Kaolin drying with producer gas cost only one-third of drying with fuel oil.

Vanuatu

As a result of the Pacific Regional Energy Programme (PREP), a generator set equipped with a wood gasifier and a gas (Otto) engine was installed in 1986 at Onesua High School, located in a rural area of Efate island in Vanuatu (South Pacific). PREP was a technology demonstration program financed from the EC/LOME II budget and co-executed by the South Pacific Bureau for Economic Cooperation (SPEC) in Suva, Fiji. The 25 kW_{el} plant was designed and built in the Netherlands. The complete installation (inclusive of transport, installation, and training) was paid for by PREP, and the school only had to carry the operating costs. By coincidence, an expatriate engineer with considerable experience in operating and maintaining gasifiers was based in Onesua during 1987 and 1988 and was able to assist in early operational troubleshooting. The plant was monitored by BGMP straight after installation, and has been revisited several times for operational monitoring.

In its first year, the Onesua plant had significant technical problems. Several parts of the reactor and the gas-cleaning section had to be redesigned or modified because of malfunctioning and excessive wear. The expatriate gasification engineer helped the project execute some of the modifications on site. However, the plant has also been down for considerable periods awaiting spare parts from the Netherlands. After a break-in period of about a year and a half, the gasifier performed surprisingly well. Since 1989, the unit has been operated solely by local Vanuatu personnel, with very limited technical backstopping. In 1992, a visit established that the plant had been operating for over 9,000 hours and was still running well.

Because Onesua High School paid only for operational costs, the plant was financially very successful from the school's standpoint. The BGMP operational monitoring report states that "the monthly cost of operating the gasifier was less than 10 percent of equivalent diesel operation." Cash savings were to be measured in millions of Vatu per year (1 Vatu equals 0.01 US$). The magnitude of the profit is somewhat misleading, however, because the school used free student labor for establishing a leuceana wood plantation and for fuelwood harvesting and preparation. However, it was established that the operating cost of a gasifier, with all labor paid for, amounted to only 50 percent of the cost of diesel operation on Efate island and to about 30 percent on outer islands. Real electricity costs (including capital charges) of the Onesua plant are high compared with a conventional diesel alternative. This is partly because of the very high cost of the imported Dutch installation.

The success of the Onesua unit may be explained by the following factors, which are again mixed technical, financial, and institutional.

On the technical side, the prolonged presence of the expatriate gasifier engineer was essential in identifying and finding solutions for the initial technical problems, which were caused by insufficiently developed and tested equipment, and in convincing the local operator, after the debugging was over, that a reasonable effort to follow strict procedures and execute logical service and maintenance operations would result in efficient and profitable gasifier operation.

Among the positive economic aspects of the project was the fact that the school management, from an early stage, was aware of the great financial benefits that could be realized through gasification and therefore made it a point to support the national gasifier operator, who was highly motivated by this attitude and showed great persistence during the difficult initial stage.

Institutional factors also played a role in the positive outcome. During the major part of the PREP, SPEC employed an (EC funded) official specially charged with backstopping of projects. In the Onesua project this has worked exceptionally well. His presence and persistency enabled Onesua project personnel to keep in contact with the Dutch manufacturer, discuss possible equipment modifications, and press for speedy delivery of spare and modified parts.

Mali

By the mid-1960s, as a result of cooperation between the governments of Mali and China, rice husk gasifiers were installed at large, government-owned rice mills in Mali. The BGMP monitored a 160-kW_{el} generator set, situated near the remote village of Dogofiri, that used a rice husk gasifier in combination with a large Otto engine. The actual maximum power demand on site was only 90 kW_{el}. The electricity produced by the gasifier plant was the major power source for the mill and compound. The plant (one of three originally commissioned in Mali) was built in and imported from China, where this type of gasification technology was developed and commercialized. Installation and commissioning were effected by Chinese personnel, and Chinese engineers apparently were on site for at least a year after startup, presumably to train the Malinese operators.

The Dogofiri rice husk gasifier was installed in 1967 and had accumulated more than 55,000 hours of operation. In the 20 years since startup, a number of major technical problems were encountered, and the plant was down for prolonged periods (mainly while awaiting spare parts from China), but the local Malinese technicians and operators have consistently restored the plant to working condition, with overall availability of the unit since 1968 apparently about 90 percent.

The plants in Mali cannot be considered truly commercial because of the soft conditions under which the government of China made the gasifiers available. In practice, this meant that the rice mill management only considered operation and maintenance costs in comparing gasifier operation with diesel operation or connection to the local grid. On this basis, gasifier operation is cost efficient. However, when all costs are taken into account, the cost of power production on site (US$0.2/kWh) by means of gasifier is more or less the same as for diesel power generation. It may be noted, however, that the relatively high cost of gasifier power is attributable mainly to the fairly high plant cost quoted to BGMP by the Chinese manufacturer.

The BGMP monitoring report suggests that the prolonged successful operation of the Dogofiri and other rice husk gasifiers in Mali results from a sound project setup, of which the main characteristics are thorough training of local personnel, highly profitable operation (at least from the viewpoint of the mill management), and consistent technical backup in the first and most difficult stage of project.

Despite its apparent success in Mali, the rice husk gasification technology, as installed in Dogofiri, has at least two drawbacks that must be remedied before further implementation can be considered. The major problem with the technology is the gas-cleaning component, which contains a number of water scrubbers. These are not particularly efficient in removing tar from the gas stream and produce large amounts of scrubber water seriously contaminated with phenolic tars. The phenol content of the waste water from the scrubbers constitutes a clear environmental and health problem. Therefore, it is *absolutely necessary* to devise and install equipment that either prevents scrubber waste water from being contaminated or safely and efficiently removes the tarry phenols from it. Second, the gas cleaning equipment has limited tar removal capacity, requiring labor-intensive engine maintenance that may adversely affect economy of operation.

Seychelles

In the early 1980s, Seychelles initiated a test program aimed at the use of mixtures of coconut husk and shell in small (15 to 40 kW_{el}) gasifier generator sets. The intention was to use the gasifiers on the outer islands, where this feedstock is abundantly available. Three gasifiers—from Switzerland, Sweden, and France, respectively—were provided through bilateral arrangements to the government of Seychelles and subsequently tested by local and BGMP personnel on the main island, Mahé. The test program revealed that none of the gasifiers could be made to work reliably on the mixed husk/shell fuel. No commercial gasifiers were ever installed by the government of Seychelles. To confirm that the fuel itself was the cause of the unreliability, BGMP also tested the gasifier from France using wood blocks as fuel. No serious problems were experienced during this test.

Burundi

By 1984, a 36 kW_{el} dual-fuel diesel generator set equipped with a downdraft gasifier was installed at the Tora tea factory in Burundi. The installation was designed and built in Belgium, paid for by the EC/LOME II program and provided at no cost to the factory through the government of Burundi. Although the unit was tested only with woodfuel, it was sold as suitable also for peat gasification. BGMP monitoring established, however, that the plant could not be operated for any sustained period on Burundi peat, the only fuel available. This conclusion marked the end of biomass gasification efforts at Tora factory.

Summary

Power Gasifiers

The introduction and demonstration of power gasifiers in developing countries has relied heavily on the support and subsidies of third parties (governments, donors, or both). Almost none of the projects identified became fully commercial, and most proved unsustainable for technical, financial/economic, and institutional reasons.

Several power gasifier projects did become more or less successful, however. A comparison of four of them—Balong, Lembang, Onesua, and Dogofiri—reveals a number of common characteristics. Like the unsuccessful projects, the successful ones experienced many technical problems that plagued the initial year or two of operation. But unlike the unsuccessful projects, the successful ones were able to overcome these hurdles. The reasons were several.

First, the management and operators alike were strongly motivated to make the gasifier work. In Balong, Onesua, and Dogofiri, this motivation had a financial background. In Lembang, the gasifier was operated by personnel hired by CRE, and both CRE and the operators considered it a challenge and an honor to make the gasifier operate properly. The other essential common element of success was that the operators on site could rely for a minimum of a year on speedy and reliable expert technical backstopping to advise on technical problems, to design and manufacture modified equipment if necessary, and to help secure a timely supply of spare and modified parts.

Heat Gasifiers

In contrast to the situation with power gasifiers, dissemination of heat gasification technology in developing countries was achieved without significant government or donor support. Almost all heat gasifier projects identified or monitored by the BGMP were technically successful. The few projects that were abandoned were terminated for clear financial reasons or problems of fuel provision.

4

Gasifier Performance

Part of the first objective of the BGMP was to determine whether gasifiers are meeting the technical and operational expectations of those using the technology. As a way of comparing the users' initial expectations (i.e., essentially the manufacturer's specifications) with the users' experience of the technology's performance, and to compare different systems with one another, the following performance factors were considered:

- *Equipment performance.* This measure comprises the key technical parameters that quantify the equipment performance of a gasification system and includes maximum power output, specific fuel consumption, system efficiency, and diesel fuel substitution (for dual-fuel diesel engines only).
- *Quality performance.* The quality performance of a system is normally defined as the useful technical lifetime in normal operation, with specified normal maintenance. The BGMP included measurements and observations that were aimed at quantifying this type of quality for the producer gas engine and for the reactor and other nonmoving parts.
- *Operational performance.* The operational performance was evaluated by monitoring labor, health and safety, and environmental parameters.

Equipment Performance

Table 4.1 summarizes equipment performance data measured on site during the baseline or in-depth monitoring as well as during operational monitoring (basic characteristics of the gasifiers that were monitored were presented in Table 3.2).

Maximum Power Output

The BGMP measurements established that Otto engines operating on producer gas must be derated by approximately 50 percent (i.e., the maximum power output of an Otto engine on producer gas was about half of the output on gasoline). For dual-fuel diesel engines, derating was variable; the maximum power output on dual fuel ranged from about 60 percent to about 90 percent of the output on diesel fuel only. For wood gasifier power plants, the measured maximum power output was reasonably close to manufacturer-stated or rated maximum power. But this was far from true for the manufacturers' stated ratings of charcoal power gasifiers. Thus, the measured maximum power of the Philippine as well as of the Brazil plants was half or less of the values the manufacturers specified.

The power output of the rice husk power gasifiers appears to be in good agreement with manufacturers' data. The power output of the peat power gasifier was low, but because the gasifier connected to this plant was not working at all on peat fuel, the output given in Table 4.1 is only representative of an air-starved diesel engine. The heat gasifiers that were monitored performed roughly in accordance with manufacturers' specifications.

Table 4.1 Comparison of Manufacturer-Stated and BGMP-Measured Performance for Different Plants

	Maximum output		*Specific fuel consumption*		*System efficiency (%)*	
Site	*Manufacturer*	*BGMP*	*Manufacturer*	*BGMP*	*Manufacturer*	*BGMP*
Wood power gasifiers						
Balong	20 kW_{el}	15 kW_{el}	1.33 kg/kWh	1.10 kg/kWh	n.s	21.8
Sebubuk	30 kW_{el}	26.2 kW_{el}	1.30 kg/kWh	1.32 kg/kWh	n.s	18.9
Onesua	27.5 kW_{el}	23.7 kW_{el}	1.25 kg/kWh	1.43 kg/kWh	19.0	16.2
Mahé	35 kW_{el}	35 kW_{el}	1.33 kg/kWh	1.40 kg/kWh	23.8	16.0
Charcoal power gasifiers						
Lembang	n.s	13 kW_{el}	n.s.	0.80 kg/kWh	n.s	15
Bago	28.4 kW_{me}	8.7 kW_{me}	0.80 kg/kWh	0.8–1.1 kg/kWh	n.s.	12–13
Bolo	38.8 kW_{me}	16.3 kW_{me}	0.80 kg/kWh	0.7–0.9 kg/kWh	n.s	11–14
Itamarandiba	41 kW_{el}	20 kW_{el}	n.s.	0.84–1.37 kg/kWh	n.s	9.4
Chacara	23 kW_{me}	11.5 kW_{me}	n.s.	4–10 kg/kWh	n.s.	< 2
Rice husk power gasifiers						
Majalengka	15 kW_{el}	15 kW_{el}	2.5 kg/kWh	1.82 kg/kWh	12	14
Dogofiri	160 kW_{el}	> 95 kW_{el}	n.s	3.6 kg/kWh	n.s.	7.1
Peat power gasi.er						
Tora	36 kW_{el}	23 kW_{el}	n.s.	n.m.	n.s.	n.m.
Wood heat gasifiers						
Rajamandala	n.s.	600 kW_{th}	n.s.	0.30 kg/kWh	n.s	68
Espara Feliz	2 x 670 kW_{th}	2 x 522 kW_{th}	0.45 kg/kWh	0.37 kg/kWh	75	76
St. Luzia	4,060 kW_{th}	3,480 kW_{th}	0.17 kg/kWh	0.16 kg/kWh	80	77

n.s. = not stated.

n.m. = not measurable.

Note: kWh = kilowatt-hour; kW_{el} = kilowatt electric; kW_{me} = kilowatt mechanic; kW_{th} = kilowatt then.

Specific Fuel Consumption

Measured and manufacturer-specified values of the specific fuel consumption for different plants are given in Table 4.1. The BGMP data indicate that at full load, the *specific wood consumption* of wood gasifiers in combination with Otto engines is around 1.4 kg/kWh, which is marginally higher then the values stated by the gasifier manufacturers. Wood gasifiers operating with diesel engines (Balong) showed a somewhat lower specific wood consumption. The *specific charcoal consumption* of most charcoal gasifiers is measured at about 0.9 kg/kWh. This is somewhat higher than the values stated by the manufacturers. What happens to the specific fuel consumption when a gasification system is operated at very low loads is shown by the specific charcoal consumption (4 to 10 kg/kWh) of the Chacara plant in Brazil.

The *specific rice husk consumption* of monitored rice husk gasifiers varied between 1.8 and 3.2 kg/kWh for different installations. Because of the low or even negative value of rice husks in most places and their abundant availability, the specific rice husk consumption is mostly not considered as an important decision factor in rice husk gasification. The measured *specific fuel consumption* of heat gasifiers was in good agreement with manufacturers data.

System Efficiency

Table 4.1 gives overall system efficiency values as measured by the BGMP. The systems employing wood gasifiers in combination with Otto engines showed full-load overall system efficiencies from 16 to 19 percent. These are reasonable values that are in good agreement with the theory. However, the values are low when compared with the efficiency ratings given by the manufacturers. For example, the Mahé gasifier was rated at about 24 percent efficiency by the manufacturer, but the de facto efficiency was only 16 percent. In practice, this means that the gasifier consumes about 50 percent more wood than the manufacturer's information indicates.

Systems using wood gasifiers in combination with diesel engines show somewhat higher overall efficiencies because of the superior efficiency of the diesel engine compared with the Otto engine. In general, the charcoal systems show somewhat lower overall efficiencies than the wood systems. Values range between 10 and 15 percent. The intrinsic reason for this lower efficiency is the higher working temperature of charcoal gasifiers compared with wood gasifiers, which results in greater heat losses. Overall system efficiencies of rice husk gasifiers vary from 7 to 14 percent. The main reason for those low values is the incomplete burning of rice husks in this type of plant. Heat gasifiers show very reasonable efficiencies of 68 to 77 percent. In this respect it should be noted that the data for heat gasifiers in Table 4.1 refer to chemical energy in the gas. By adding the sensible heat in the hot gas to those values, the *practical overall heat efficiency* of heat gasifiers may be estimated as from 85 to 95 percent.

Diesel Fuel Substitution

The BGMP monitored five systems that used dual-fuel diesel engines in combination with gasifiers (see Table 3.2). Measured diesel fuel substitution at full engine load ranged from about 60 percent (Majalengka and Balong) to about 70 percent (Bago and Bolo). The diesel engine of the quasi-functioning peat gasifier plant at Tora consumed at full engine load in dual-fuel mode only 20 to 30 percent less diesel than it did in full-diesel mode.

The BGMP also measured diesel fuel substitution values at varying engine load levels. The outcome of those measurements is somewhat ambiguous, but it appears that up to a point decreasing engine loads resulted in decreased relative diesel fuel consumption. This tendency was reversed, however, when the engine load was still further decreased. For example, at full engine load (15 kW_{el}), the diesel engine of the Balong plant consumed about 60 percent less diesel fuel than it would have in full-diesel operation. At 66 percent load (10 kW_{el}) and 40 percent load (6 kW_{el}), diesel fuel substitution was measured at, respectively, about 90 percent and about 75 percent. Those data indicate that the practical diesel fuel savings of dual-fuel diesel plants depend very much on the plant load pattern. Of all dual-fuel plants monitored by the BGMP, only the Balong unit has succeeded in realizing overall diesel fuel savings of about 70 percent. All other plants have done considerably worse.

Quality Performance

Producer Gas Engines

BGMP requirements included several measurements that bear on the lifetime that can be expected for engines that are operated on producer gas, including the amount of dust and tar in the gas, after cleaning, at the gas inlet manifold of the engine and the amounts of metal in the engine oil. Below, results are presented for six different BGMP-monitored plants. The engines of the first four plants worked well, requiring only normal service and maintenance. But the engines of the latter two plants were subject to abnormal wear, requiring frequent oil changes and frequent replacement of parts.

Dust Content

Table 4.2 gives values of dust concentrations that were measured on site at the engine inlets of specific plants. It also provides the "acceptable" and "preferable" dust concentrations usually quoted by engine manufacturers as guaranteeing normal engine operation and lifetime. Data indicate that most plants produce a fairly dust-free gas, although the values are generally somewhat worse then requested by engine manufacturers. The gas filter unit of the Onesua plant was undoubtedly the best with respect to dust, whereas the amount of dust in the gas from the Dogofiri gasifier may be on the borderline of what is acceptable in the long run.

Table 4.2 Factors Affecting Life Spans of Producer Gas Engines and Gasifiers at Six BGMP-Monitored Sites

	Life-span factor		
Site	*Gas dust content (mg/Nm^3)[a]*	*Gas tar content (mg/Nm^3)[b]*	*Metal amount in engine oil*
Balong	120–150	120–150	low
Sebubuk	40–80	100–400	low
Onesua	< 5	< 10	low
Mahé	10–30	500–700	medium
Dogofiri	250–300	3,000–4,000	high
Majalengka	< 100	1,000–2,000	high

Note: Nm^3 = normal cubic meter.

[a] < 50 (acceptable); < 5 (preferable). [b] < 100 (acceptable); < 50 (preferable).

Tar Content

Table 4.2 presents also values for measured and specified tar concentrations at the engine inlet manifolds. It indicates a big difference between the wood gasifiers (Balong, Sebubuk, Onesua, and Mahé) and the rice husk gasifiers (Dogofiri and Majalengka). For the first group, the tar concentrations were more or less in line with the values requested by engine manufacturers. Values measured for the Onesua plant were especially low, but the amount of tar entering the engine of the Mahé plant was on the high side. The values for the rice husk gasifiers are 10 to 40 times higher than allowable, which means that the gas cleaning of those plants must be improved if long-term trouble-free engine operation is to be guaranteed.

Engine Oil

The results of the engine oil analyses, also detailed in Table 4.2, indicate that the oil of the engines from the rice husk gasifiers contained large amounts of metal (mainly iron and aluminum), indicating abnormal engine wear. Evaluation of the dust, tar, and engine oil measurements thus leads to the clear conclusion that the tar amount in the gas is the decisive factor governing wear and lifetime of producer gas engines.

Turn-down Ratio

The first four plants from Table 4.2 use downdraft reactors. This type of reactor is vulnerable to increased tar production at low load. Therefore, in order to establish the "turn-down ratio," the BGMP executed tar measurements at different reactor load levels. Those measurements indicated that all monitored downdraft reactors had acceptable turn-down ratios, of about 25 to 50 percent of full load.

Gasifier and Other Nonmoving Parts

The journals kept during operational monitoring show that almost all monitored power gasifier plants, especially during the startup period directly after commissioning, were subject to a continuing series of more or less serious technical defects. Examples ranged from badly fitting fuel and ash removal covers, warped service hatches, leaking gaskets, and blocked valves, pipes, and filters to completely destroyed high-temperature sections and burned grates as well as accelerated corrosion of many parts of the reactor, gas-cleaning sections, and connecting piping. This suggests that the plants were not fully commercial and mature technical concepts. In fact, they were prototypes, developed and tested in the laboratory but not subjected for a sufficient time to the rigors of daily use. Manufacturers had received insufficient feedback on how to improve designs and materials in order to achieve sufficient quality. The BGMP reports indicate that this initial deficit in quality, especially with respect to factors such as resistance to heat and corrosion, appears to be a major reason for project failure. The small and large technical problems that were caused by the poor quality of materials and design resulted in unreliable operation that discouraged and demoralized operators and owners. Thus, only the small number of installations that had sufficient and sustained technical backup were able to overcome this quality problem by installing better-designed or -fabricated parts; it was they who thus could evolve to more or less trouble-free operation.

Behind this scenario of trouble lies the fact that the commercial market for small-scale gasifiers has never been large enough to carry the expenses associated with development from prototype to mature commercial plant. Developers of gasifiers in developed and developing countries were able, however, to get grant money to design prototypes and to test them under operational circumstances. Under these circumstances, 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. Even so, the results of the BGMP show that some small-scale wood gasifiers did achieve reliable and relatively trouble-free operation, and this means that experience and expertise in building and operating reliable, safe, and pollution-free wood gasifiers is now definitely available, at least in some locations.

Operational Performance

Labor

The labor necessary for operating a gasification plant is considerably different from the input required for running an equivalent diesel engine. This difference is both quantitative and qualitative. During operation, the gasifier operator must frequently check a number of temperature and pressure meters and, based on this information, make decisions on actions such as adding new fuel, shaking the grate, deblocking filters, and adjusting valves. At the end of daily operation the operator must normally clean reactor and filters from ash and dust. Finally, the operator may be also in charge of fuel preparation and fuel quality control. Thus, unlike diesel engine operations in which the engine driver may also be given other, unrelated tasks, the running of a small-scale gasification system is basically a full-time job.

The operational history of the gasifiers monitored under the BGMP shows that not every operator is easily able to attain the required level of competence. Motivation and discipline are necessary, but the ability to react adequately to two or three input parameters and some basic technical skills are also crucial. Achieving this level of expertise and quality of operation appears to require not only an adequate initial training programme but also continuous technical backup for a period of at least a year.

Recent developments in the automotive industry have resulted in mass-produced hardware and software that may greatly increase possibilities for automatic control of gasifiers. The auto industry manufactures and uses a number of inexpensive as well as temperature- and shock-resistant sensors and attenuators. In combination with their corresponding multi-parameter input logic software, such instruments could conceivably monitor and control gas engines and reactors, correspondingly reducing or eliminating the need for highly trained and experienced gasifier personnel. Such a development would improve the current economic competitiveness of small wood and charcoal gasifiers only marginally, but it would certainly increase the possibilities for speedy introduction of the technology.

Health and Safety

To assess the danger of carbon monoxide poisoning, the BGMP measured carbon monoxide concentrations at the gasifier site. On all sites except one, the concentrations were found to be around or below 20 parts per million (ppm), which means that there are no health signs or symptoms. At one site (Sebubuk), a CO concentration of 1,000 ppm was measured during gasifier refueling. Operators at this site complained of headaches. Another CO poisoning incident was reported from Itamarandiba, Brazil. It resulted from working on a hot reactor, in defiance of safety regulations.

Gas explosions may occur in a reactor when, because of leakages, a hot combustible gas is mixed with sufficient air to cause spontaneous combustion. The heat gasification system of S. Lucia, Brazil, reported a number of gas explosions, but none caused fatalities or major equipment damage. Fires may result from the high surface temperatures of equipment and from sparks emitted during refueling, but no fires were recorded in any plant monitored by the BGMP.

Environmental Pollution

Biomass gasifiers may produce tar/phenol-containing condensates. The amounts produced depend on fuel and reactor type. Condensate analyses from different BGMP plants show a wide range of carcinogenic compounds in different concentrations. Not all those compounds are biodegradable. None of the plants that were monitored took special measures in dealing with the condensates. In all cases the pollutants were freely discharged to the environment. None of the operators dealing with contaminated condensates used protective clothing or hand gloves.

Table 4.3 compares the toxic effluent production at the Onesua downdraft wood gasifier with that at the Dogofiri open-core rice husk gasifier. The Onesua gasifier

Table 4.3 Comparison of Toxic Effluents at Two Gasifier Sites

Site	*Amount (l/hour)*	*Phenols (mg/l)*	*Phenols (kg/hour)*	*Phenols (kg/kWh$_{el}$)*
Onesua[a]	0.5	100–200	0.05–0.10	0.002–0.004
Dogofiri[b]	500	30	15	0.167

Note: kg = kilogram; kWh$_{el}$ = kilowatt-hour electric; l = liter.
[a] Downdraft wood gasifier. [b]Open-core rice-husk gasifier.

produces small amounts of tar that are relatively easy to deal with. But the Dogofiri plant produces and discharges 500 liters of contaminated condensates, containing 15 kilograms of toxic phenols, each hour. Without the addition of effective effluent treatment facilities, the operation of this and similar plants gives rise to a major environmental pollution problem.

Summary

A summary of the performance that may be expected from different types of gasification plants is provided in Table 4.4.

Table 4.4 Performance of Gasifier Plants

Gasifier type	*Engine derating (%)* [a]	*Specific fuel consumption kg/kWh* [b]	*System overall efficiency (%)* [b]	*Diesel savings (%)* [c]	*Engine life-time*	*Gasifier quality*	*Problems* *Health and safety*	*Environ-mental*
Power gasifiers								
Wood Otto	50–60	1.4	> 16	n.a.	√	?	none	minor
Wood diesel	60–90	1.1	> 21	60–90	√	?	none	minor
Charcoal Otto	50	0.9	> 10	n.a.	√	?	none	none
Charcoal diesel	50–80	0.9	> 12	40–70	?	?	none	none
Rice husk Otto	50–60	> 3.5	> 7	n.a.	?	√	none	major
Rice husk diesel	60–90	> 2.0	> 12	50–75	–	?	none	major
Peat diesel	20–50	high	very low	very little	–	X	possible	major probable
Heat gasifiers								
Wood	n.a.	0.30–0.35[d]	> 75[e] > 90[f]	n.a.	n.a.	+	none	none
Charcoal	n.a.	0.15–0.17[d]	> 75[e] > 90[f]	n.a.	n.a.	+	none	none

√ = normal; + = good; ? = doubtful; – = shortened; X = bad; n.a. = not applicable.

Note: kg = kilogram; kWh = kilowatt-hour.

[a]Maximum engine output on producer gas as a percentage of maximum power output on gasoline/diesel. [b]At full engine load. [c]As a percentage of equivalent diesel engine fuel consumption at equivalent engine load. [d]Fuel consumption per kWh$_{th}$. [e]Efficiency with respect to chemical energy in the gas. [f]Overall heat energy efficiency.

5

Economics of Biomass Gasifiers

Because producer gas is an alternative to gasoline or diesel, the financial and economic feasibility of biomass gasifiers depends on the cost savings that are realized by switching from those petroleum fuels to biomass. Those cost savings must be measured against the higher capital and operational costs of the biomass system.

This chapter presents capital and operational costs for gasifier plants based on field data and a simple cost model. Comparison with the costs of petroleum-based alternatives results in break-even figures as a function of fuel prices and number of operating hours. It must be stressed that in practice the outcome of financial and economic evaluations depends also on the values of a number of other site-specific parameters. The figures presented below are therefore useful to illustrate trends, but they should not be taken as absolute.

Financial Cost and Performance of BGMP Gasifiers

Table 5.1 presents investment costs, as established during baseline monitoring, for the gasifier plants monitored by the BGMP. Because of the large differences, a distinction is made between gasifier power plants made in developed countries (imported systems), plants made in developing countries (local systems), and heat gasifiers. Although in practice the plants were paid for in many different currencies, for reasons of comparison, all costs have been converted to U.S. dollars (1990). So far as possible, the data take the following investments into account:

- Cost of gasifier, fuel handling system, gas cleanup system, and all other related auxiliary and control equipment
- Cost of diesel engine or Otto engine, including all auxiliary and control equipment
- Cost of generator, water pump, or compressor
- Cost of freight, insurance, installation, and civil works.

The cost data indicate that imported power gasifiers tend to be more expensive then domestically manufactured systems. In both categories, however, the most expensive systems (Onesua and Balong, respectively) performed technically best. The

Table 5.1 BGMP Gasifier Costs and Profitability

Site	Total investment US$ (1990)	Specific investment US$/kW$_{el}$ [a]	Specific investment US$/kW$_{el}$ [b]	Operational costs (US$/kWh)	Profitability
Imported power gasifiers					
Sebubuk	60,000	2,000	2,300	0.07	nil
Onesua	100,000	3,600	4,200	0.09	nil
Mahé	30,000	850	850	0.25	marginal
Dogofiri	415,000	2,600	2,600	0.23	marginal
Tora	(15,000)[c]	(425)[c]	(650)[c]	0.12	nil
Local power gasifiers					
Balong	23,000	1,150	1,550	0.08	marginal
Majalengka	10,000	650	650	0.06	marginal
Lembang	6,500	650	500	0.12	nil
Bago	12,000	425	1,400	0.04	nil
Bolo	12,000	300	750	0.03	nil
Itamarandiba	8,000	200	400	0.11	nil
Heat gasifiers					
Rajamandala	40,000	66[d]	65[d]	41.6[e]	marginal
Espara Feliz	30,000	25[d]	30[d]	3.27[e]	profitable
Santa Luzia	310,000	75[d]	90[d]		nil

Note: kWh = kilowatt-hour; kW$_{el}$ = kilowatt electric.
[a] Specific investment cost based on manufacturer maximal power output.
[b] Specific investment cost based on BGMP measured maximal power output.
[c] Gasifier not properly working.
[d] As kW thermal.
[e] In US$ per tonne biomass fuel.

exception was the ferrocement charcoal gasifier (Lembang), which was cheap but still had good performance. Although less price information is available for heat gasifiers, it appears that this equipment can also be divided between relatively low- and high-cost installations.

Gasifier operating costs, as established for different plants during baseline monitoring, are presented in Table 5.1. Operating costs include personnel costs, fuel costs, and costs of service and maintenance. The data are thus very site-specific, but they still indicate the operational cost values that can be attained in power and heat gasifier operation.

Table 5.1 also indicates that only one heat gasifier (Espara Feliz) operat profitably compared with a liquid-fuel-system alternative. A few power plants we marginally profitable. On most sites, operating a gasifier turned out to be more expensive than using an equivalent diesel engine. The most important causes of unprofitability were the high cost of biomass fuel (especially charcoal), high capital cost, low diesel fuel savings, and low number of operating hours.

Power Gasifiers

Cost Model

A simple cost model was developed for a general investigation of power gasifier economics. The model is based on the BGMP observation that costs of locally manufactured acceptable power gasifiers (e.g., Lembang) can be considerably lower than those of imported plants (e.g., Onesua).

Capital Costs. Tables 5.2 and 5.3 present estimated installed investment for different power gasifiers of variable power output. Table 5.2 shows total investments for imported expensive systems, which were obtained by adding estimated costs of the different major parts of the plant. Estimates are based on actual data from the BGMP. Costs of freight, installation, and training were taken as part of the investment and therefore incorporated into the capital costs. Table 5.3 repeats the same exercise for local, inexpensive plants. Both tables also indicate effective investments required to establish equivalent diesel plants. For example, the installed cost of a 30 kW imported wood gasifier plant with an Otto engine is estimated at US$61,800 (US$2,060/kW), whereas a locally manufactured plant is estimated at US$31,380 (US$1,046/kW). The cost of an equivalent diesel engine plant is estimated at US$18,570 (US$619/kW).

Operating Costs. Operating costs for both biomass and diesel systems were based on costs of fuel, labor, and maintenance measured by the BGMP.

Economy

Break-Even Diesel Fuel Price. One way to evaluate the viability of a gasification system is to establish the break-even diesel fuel price (BEDP). This is diesel fuel price at which an equivalent diesel engine system would produce power at the same cost as the gasifier system. Three important parameters influencing BEDP of gasifiers are gasifier cost, number of full-load operating hours per year, and cost of woodfuel. Figures 5.1 and 5.2 show BEDP values for different gasifiers.

Wood Gasifiers. Figure 5.1 establishes BEDP for low-cost wood gasifiers working with Otto engines. It presents data for gasifiers with three different capacities (10 kW_{el}, 30 kW_{el}, and 100 kW_{el}) and shows how BEDP values vary with the annual number of operating hours and the cost of woodfuel. For example, economic operation of a 10 kW_{el} wood gasifier generator set working for 1,000 hours per year with free wood (US$0/tonne), results in a BEDP of US$600/tonne. On the other hand, a 100 kW_{el} wood gasifier plant, operating for 4,000 hours per year and working with wood priced at US$20/tonne, has a BEDP of about US$225/tonne.

When high-cost imported gasifier plants are used, BEDP values incre enormously. For example, the BEDP of a 30 kW high-cost wood gasification system ι. is operated for 3,000 hours per year is approximately US$300/tonne higher than th equivalent BEDP of a low-cost gasifier plant. Retrofitting existing engines with gasifiers is an option that can be realized at lower diesel prices. The BEDP of a 100 kW_{el} plant operating 3,000 hours per year is about US$100/tonne lower than the BEDP of an equivalent low-cost gasifier system. Finally, the model shows that below 80 percent diesel substitution, dual-fuel diesel engine plants always have higher BEDPs than equivalent Otto plants. Only very high diesel substitutions (in excess of 80 percent), in combination with high wood costs and few operating hours, result in a BEDP that is somewhat lower than that of an equivalent Otto plant.

Small Charcoal Gasifiers. Figure 5.2 presents BEDPs for two small 10 kW_{el} charcoal gasifier plants locally made, from steel and ferrocement, respectively. At a charcoal cost of US$50/tonne, and at 4,000 operating hours, the BEDP of the steel system and the ferrocement system were about US$425/tonne and US$380/tonne, respectively. The small difference between the two systems follows from the relatively small cost difference (about 15 percent) between locally made steel charcoal gasifiers and ferrocement gasifiers. The BEDP of small-scale high-cost gasifier plants is again much higher than that of equivalent low-cost plants. At 3,000 operating hours, the BEDP increases by approximately US$250/tonne. Retrofitting decreases the BEDP by 200 to US$450/tonne depending on the number of operating hours. At diesel substitution rates below 80 percent, BEDPs from dual-fuel plants will always be higher then those of equivalent Otto plants.

Rice Husk Gasifiers. Figure 5.2 also presents BEDP values for rice husk gasifier plants with outputs ranging from 30 kW_{el} to 100 kW_{el}. Low-cost rice husk gasification systems at 1,000 full-load operating hours have BEDPs of US$290/tonne to US$430/tonne. At 3,000 annual operating hours, the BEDP values for low-cost systems drop considerably, ranging from US$150/tonne to US$250/tonne.

Conclusion

At world market oil prices of approximately US$18/barrel, the cost price of diesel is about US$190/tonne. International and local transport costs can add a maximum of about US$60/tonne. Therefore, the maximum economic cost of diesel at most locations in the world is about US$250/tonne. These BEDP values make it clear that biomass gasification is not economically attractive at current oil prices. World market oil prices must rise by a factor one-and-a-half to two for biomass gasification to become attractive again. The possible exception to this statement may be low-cost wood and rice husk gasifiers, which may have BEDP values ranging from 150 to US$250/tonne. But low-cost rice husk gasification systems are not yet technically proven, and wood is not usually available for free. The situation may be different when biomass gasification is approached from a financial point of view, however. Local taxes may cause actual market prices for diesel oil to be substantially higher then US$250/tonne. At diesel oil market prices of US$400/tonne to US$500/tonne, then, low-cost gasifier plants that run for long periods, as in some industrial applications, may be financially viable.

Heat Gasifiers

Cost Model

Capital Costs. On basis of real heat gasifier costs (Table 5.1), a simple capital cost model was developed for heat gasifiers. Because of the fairly wide variations in specific investment found in practice, the model makes a distinction between low-cost and high-cost systems. Table 5.4 presents cost estimates for both categories at three output levels (500 kW_{th}, 1,000 kW_{th}, and 4,000 kW_{th}). The model arrives at specific capital costs ranging from US\$34/kW_{th} to US\$44/kW_{th} for low-cost systems and US\$130/kW_{th} to US\$152/kW_{th} for high-cost systems. Those values are conservative. A Biomass Technology Group (1989) study documented that in Thailand complete heat gasification systems, including burner, have been delivered and installed for US\$12 to 14/kW_{th}. A World Bank study (ESMAP 1990) quotes local installed costs of heat gasifiers ranging from 250 kW_{th} to 1,000 kW_{th} at US\$12.5/kW_{th}.

Operating Costs. Operating costs of heat gasifiers depend on fuel costs, labor costs, and costs of service and maintenance. On basis of the data collected by the BGMP, values have been estimated for costs.

Economy

Figure 5.3 presents the outcome of the model calculations for low-cost heat gasification systems at three different capacity levels, respectively, of 500 kW_{th}, 1,000 kW_{th}, and 4,000 kW_{th}. It is also assumed that the overall system efficiency (gasifier/furnace) is 75 percent, whereas for an oil-fired system 85 percent is assumed. Such low-cost wood heat gasifiers, using wood at a cost of US\$20/tonne and operating between 2,000 and 4,000 hours per year, appear to have BEDP values of about US\$120/tonne. In equivalent operation, BEDP values for high-cost heat gasification systems are about US\$160/tonne. At a wood cost of US\$10/tonne, the low-cost and the high-cost systems have BEDP values, respectively, of about US\$75/tonne and US\$115/tonne.

Conclusion

At a world oil market price of about US\$18/barrel, the price of fuel oil is approximately US\$120/tonne. Adding US\$60/tonne for international and local transport, the maximum economic price of fuel oil is about US\$180/tonne. Some care must be taken in drawing too-optimistic conclusions because the technical feasibility of heat gasifiers has not been proven on a very large scale for all conditions assumed in the model. Nevertheless it appears that a considerable array of practical combinations of heat demand, gasifier cost, and wood fuel costs possible, specifically in the agro-industrial sector in developing countries, where biomass gasification for heat applications is attractive.

Table 5.2 Capital Costs and Performance Parameters for Small Diesel and Biomass Gasifier Power Plants (High Cost Systems)

		Capital investment estimate: Specific equipment cost (US\$/kW$_{el}$)				*Other investment*			*Other cost and performance parameters*			
System type	*Installed capacity (kW$_{el}$)*	*Gasifier system*	*Engine*	*Generator, control, and electrical*	*Total*	*Training, commissioning (US\$)*	*Freight, installation, and other (US\$/ kW$_{el}$)*	*Total capital investment (US\$/kW$_{el}$)*	*Economic lifetime (years)*	*System efficiency (%)*	*Number of operators*	*Maintenance and service cost (% per 1,000 hours)*
Diesel	10	n.a.	325	402	727	1,000	182	1,009	10	23	1	4
Full gas												
Charcoal/ferrocement	10	57	466	402	925	2,000	231	1,356	7	12	2	4
Charcoal/steel	10	1,001	466	402	1,868	2,000	467	2,535	7	12	2	4
Wood/steel	10	1,201	466	402	2,069	2,000	517	2,786	7	12	2	4
Dual fuel												
Charcoal/ferrocement	10	40	387	402	828	2,000	207	1,235	7	15	2	4
Charcoal/steel	10	731	387	402	1,520	2,000	380	2,100	7	15	2	4
Wood/steel	10	877	387	402	1,666	2,000	416	2,282	7	15	2	4
Diesel	30	n.a.	210	259	469	1,000	117	619	10	25	1	4
Full gas												
Wood/steel	30	1,035	300	259	1,594	2,000	399	2,060	7	16	2	4
Rice husk/steel	30	1,553	300	259	2,112	2,000	528	2,707	7	9	3	4
Dual fuel												
Wood/steel	30	756	249	259	1,265	2,000	316	1,647	7	18	2	4
Rice husk/steel	30	1,134	249	259	1,643	2,000	411	2,120	7	10	3	4
Diesel	100	n.a.	130	160	290	1,000	72	372	10	28	1	4
Full gas												
Wood/steel	100	880	185	160	1,225	2,000	306	1,552	7	17	3	4
Rice husk/steel	100	1,320	185	160	1,665	2,000	416	2,102	7	10	4	4
Dual fuel												
Wood/steel	100	643	154	160	957	2,000	239	1,216	7	19	3	4
Rice husk/steel	100	964	154	160	1,278	2,000	320	1,618	7	11	4	4

Note: kW$_{el}$ = kilowatt electric.

Table 5.3 Capital Costs and Performance Parameters for Small Diesel and Biomass Gasifier Power Plants (Low Cost Systems)

		Capital investment estimate Specific equipment cost (US\$/kW$_{el}$)				*Other investment*			*Other cost and performance parameters*			
System type	*Installed capacity (kW$_{el}$)*	*Gasifier system*	*Engine*	*Generator, control, and electrical*	*Total*	*Training, commis-sioning (US\$)*	*Freight, installation, and other (US\$/kW$_{el}$)*	*Total capital investment (US\$/kW$_{el}$)*	*Economic lifetime (years)*	*System efficiency (%)*	*Number of operators*	*Maintenance and service cost (% per 1,000 hours)*
Diesel	10	n.a.	325	402	727	1,000	182	1,009	10	23	1	4
Full gas												
Charcoal/ferrocement	10	57	466	402	925	2,000	231	1,356	7	12	2	4
Charcoal/steel	10	217	466	402	1,085	2,000	271	1,556	7	12	2	4
Wood/steel	10	261	466	402	1,128	2,000	282	1,610	7	12	2	4
Dual fuel												
Charcoal/ferrocement	10	40	387	402	828	2,000	207	1,235	7	15	2	4
Charcoal/steel	10	159	387	402	947	2,000	237	1,384	7	15	2	4
Wood/steel	10	190	387	402	979	2,000	245	1,424	7	15	2	4
Diesel	30	n.a.	210	259	469	1,000	117	619	10	25	1	4
Full gas												
Wood/steel	30	225	300	259	784	2,000	196	1,046	7	16	2	4
Rice husk/steel	30	225	300	259	784	2,000	196	1,046	7	9	3	4
Dual fuel												
Wood/steel	30	164	249	259	672	2,000	168	907	7	18	2	4
Rice husk/steel	30	164	249	259	672	2,000	168	907	7	10	3	4
Diesel	100	n.a.	130	160	290	1,000	72	372	10	28	1	4
Full gas												
Wood/steel	100	159	185	160	505	2,000	126	651	7	17	3	4
Rice husk/steel	100	159	185	160	505	2,000	126	651	7	10	4	4
Dual fuel	2	2										
Wood/steel			154	160	453	2,000	113	587	7	19	3	4
Rice husk/steel			154	160	453	2,000	113	587	7	11	4	4

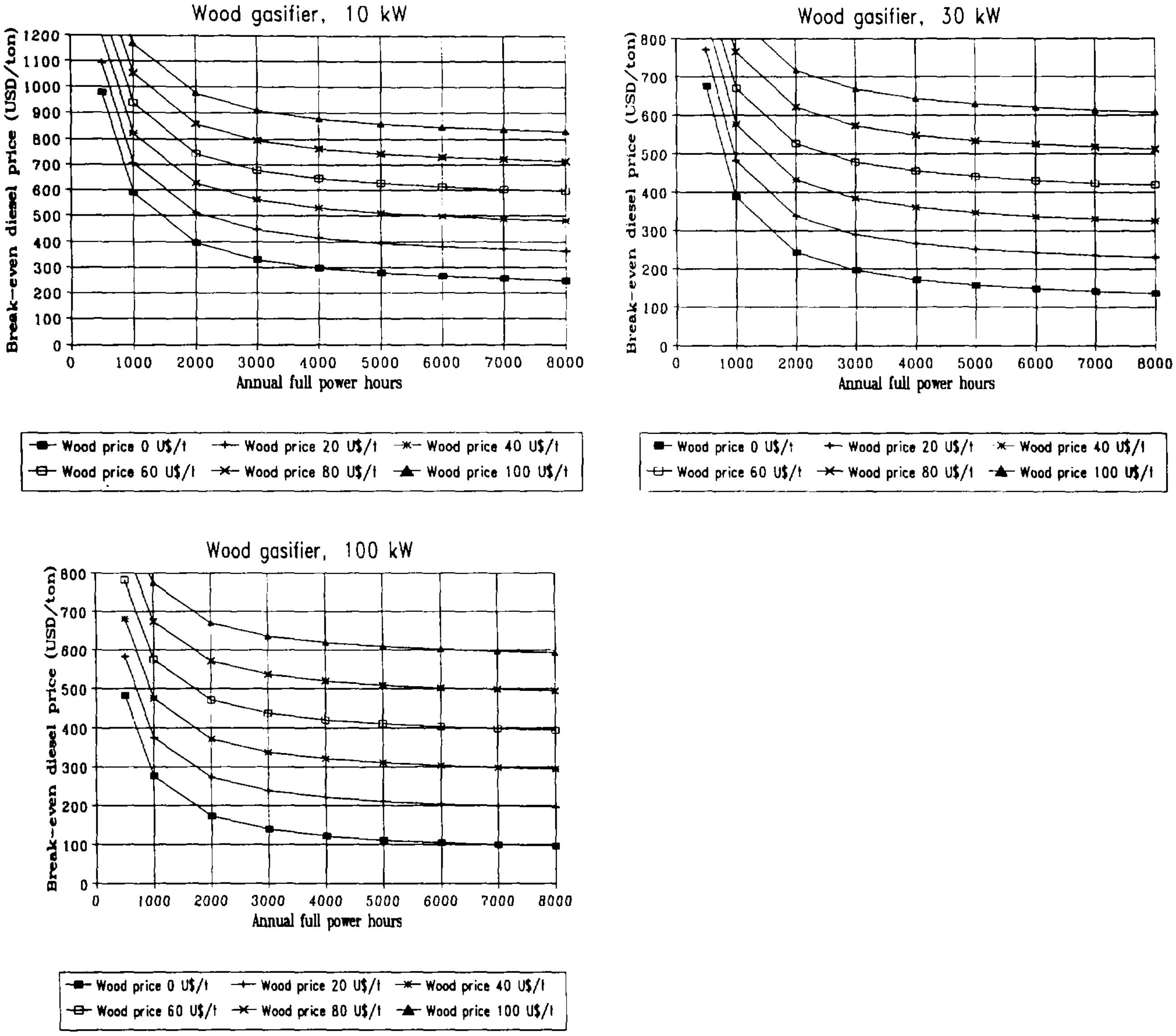
Note: kW$_{el}$ = kilowatt electric.

Table 5.4 Capital Costs and Performance Parameters for Heat Gasification Plants

System type	Installed capacity (kW_{th})	*Minimum capital investment estimate* Gasifier system (US$/$kW_{th}$)	Fuel handling (US$/$kW_{th}$)	Total equipment (US$/$kW_{th}$)	Freight, installation, and other (US$/$kW_{th}$)	Total capital investment (US$/$kW_{th}$)	*Other cost and performance parameters* Economic lifetime (years)	System performance (%)	Number of operators	Maintenance and service cost (% per 1,000 hours)
High-cost system										
	500	117	0	117	35	152	12	85	2	2
	1,000	106	0	106	32	138	12	85	3	2
	4,000	88	12	100	30	130	12	85	3	2
Low-cost system										
	500	29	0	29	9	37	5	85	2	2
	1,000	26	0	26	8	34	5	85	3	2
	4,000	22	12	34	10	44	5	85	3	2

Note: kW_{th} = kilowatt thermal.

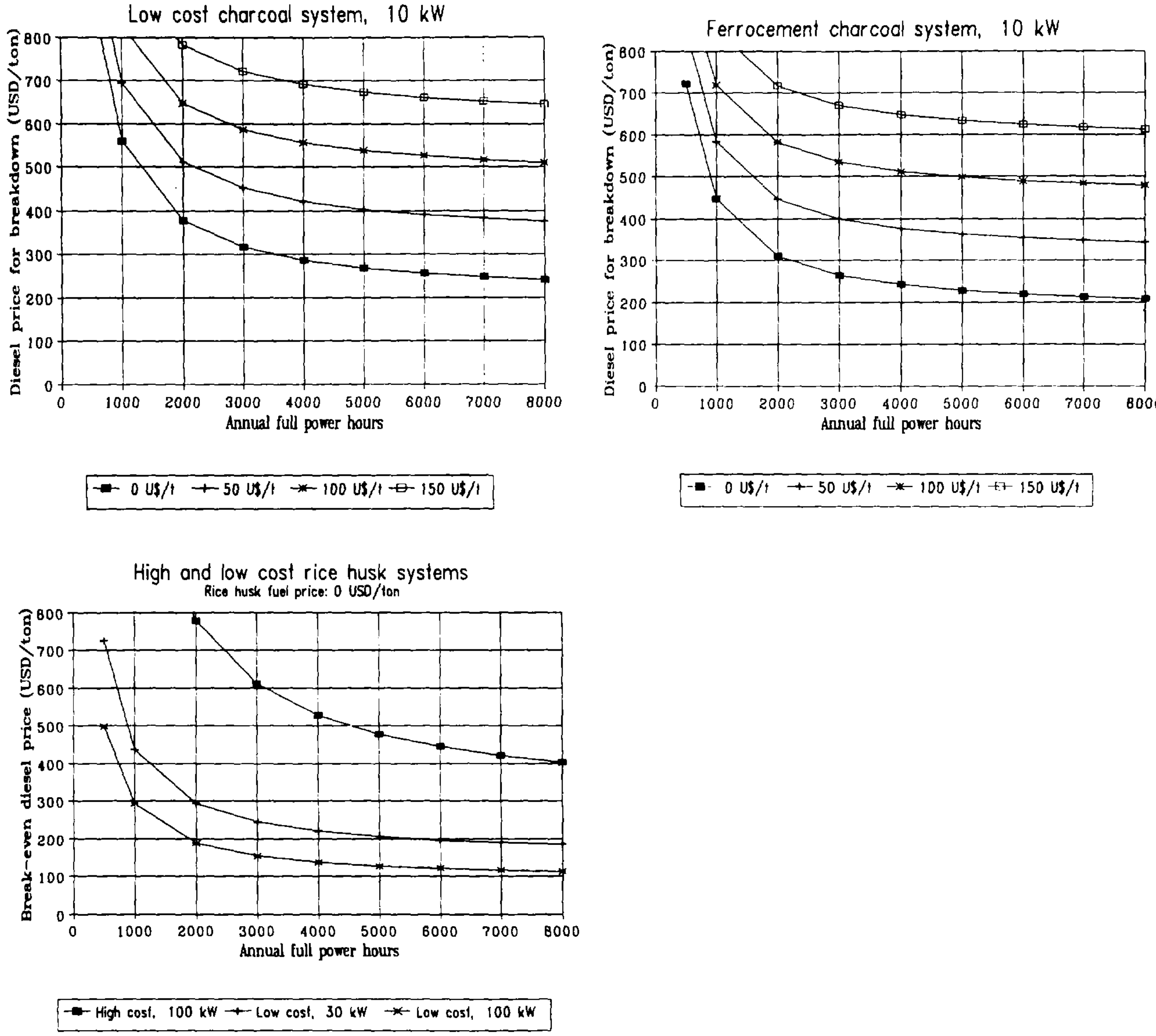
Figure 5.1 Break-Even Diesel Price: Gasifier Systems Using Wood



Wood gasifier systems; effects of different hardware configurations on break-even diesel price:

	10 kW	30 kW	100 kW
High cost rather than low cost gasifier system	Required increase of diesel price for break-even:		
1000 hours/year	600-700 USD/ton	about 600 USD/ton	about 600 USD/ton
3000 hours/year	about 300 USD/ton	about 300 USD/ton	about 300 USD/ton
Back-fitting to existing generator set:	Reduction of diesel price for break-even:		
1000 hours/year	about 500 USD/ton	about 350 USD/ton	about 200 USD/ton
3000 hours/year	about 200 USD/ton	about 150 USD/ton	about 100 USD/ton
Dual-fuel rather than full-gas system	At 80% diesel substitution, dual-fuel is marginally more economic for high biomass fuel price and few annual operating hours. If less than 80% substitution is achieved, break-even diesel price will be higher.		

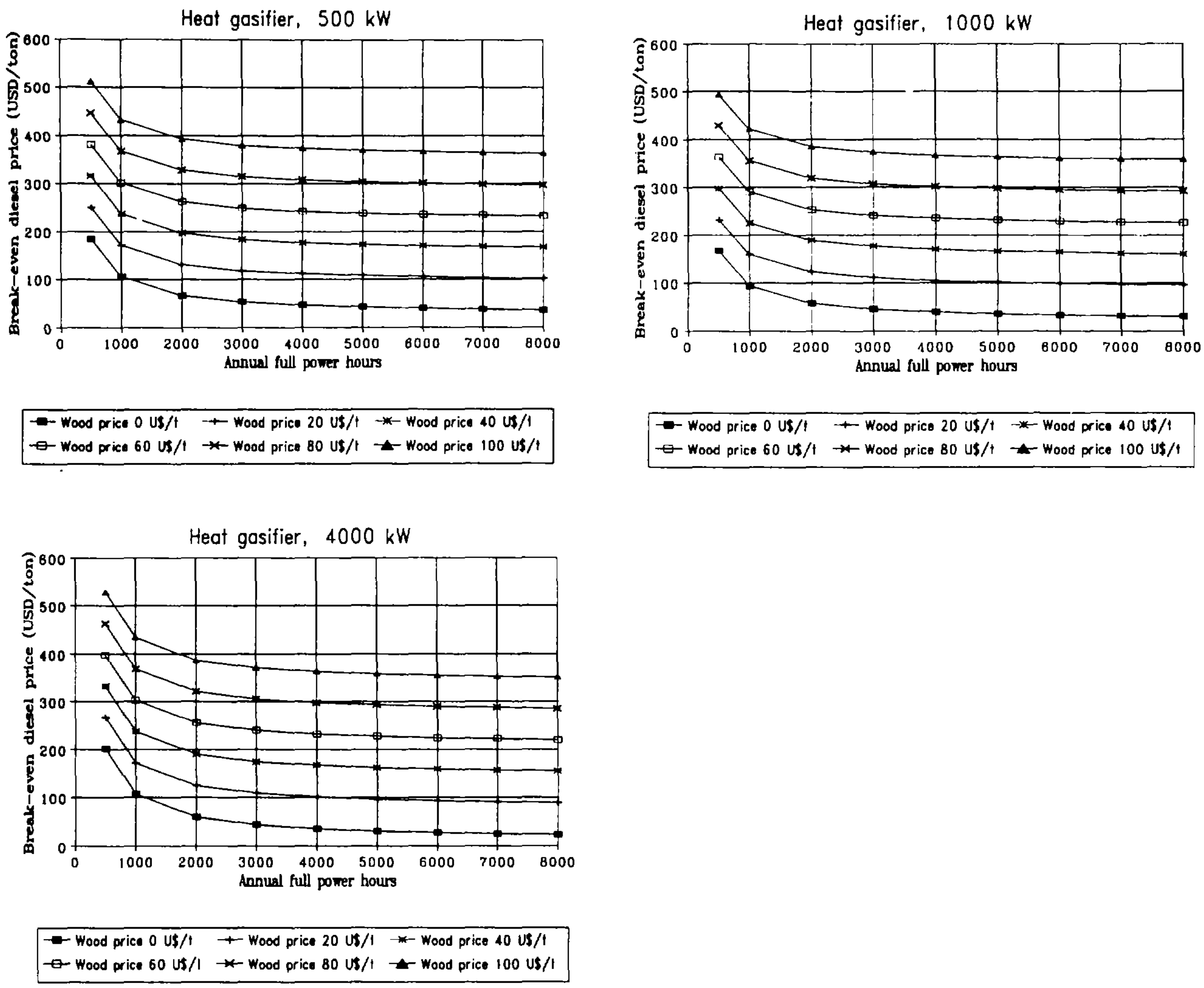
Figure 5.2 Break-Even Diesel Price: Gasifier Systems Using Charcoal or Rice Husks



Effects of different hardware configurations on break-even diesel price for charcoal systems:

	10 kW steel system	10 kW ferrocement system
High cost rather than low cost gasifier system	Required increase of diesel price for break-even:	
1000 hours/year	about 550 USD/ton	not applicable
3000 hours/year	about 250 USD/ton	not applicable
Back-fitting to existing generator set:	Reduction of diesel price for break-even:	
1000 hours/year	about 450 USD/ton	about 500 USD/ton
3000 hours/year	about 200 USD/ton	about 200 USD/ton
Dual-fuel rather than full-gas system	At 80% diesel substitution, dual-fuel is marginally more economic for high biomass fuel price and few annual operating hours. If less than 80% substitution is achieved, break-even diesel price will be higher.	

Figure 5.3 Break-Even Fuel Oil Price: Low-Cost Heat Gasifier Systems Using Wood



Heat gasifiers; effects of different hardware configurations on break-even diesel price:

	500 kW	1000 kW	4000 kW
High cost rather than low cost gasifier system	Required increase of diesel price for break-even:		
1000 hours/year	about 100 USD/ton	about 150 USD/ton	about 50 USD/ton
3000 hours/year	about 50 USD/ton	about 40 USD/ton	about 30 USD/ton
5000 hours/year	about 35 USD/ton	about 30 USD/ton	about 25 USD/ton

Fuel: wood Efficiency oil fired installation: 85% Heat gasifier system efficiency: 75%

6

Conclusions and Recommendations

Small-Scale Power Gasifiers

Gasification combined with use of the gas in an internal combustion engine is the most efficient way of converting solid fuels into shaft power or electricity. Small-scale power gasification allows the use of biomass instead of petroleum derivatives in small internal combustion engines. Gasifiers use a renewable energy resource, one that is available almost everywhere in one form or another. Therefore, biomass gasification presents a local fuel alternative for countries that have no fossil fuel resources. Providing that the biomass used for gasification is grown on a sustainable basis, its use does not increase the amount of CO_2 in the atmosphere and hence does not add to the "greenhouse effect." The technology may find application where petroleum fuels are either unavailable or where the cost of power from engines fueled by producer gas is lower than from diesel- or gasoline-fueled engines.

Commercial Status of Small-Scale Power Gasifiers

Although a number of equipment manufacturers in Europe and the United States sell small-scale biomass power gasification systems, only a few units have been installed in developed and developing countries during the last five years. The situation is somewhat different in India and China, where manufacturers of small-scale wood power gasifiers and rice husk gasifiers, respectively, appear to maintain at least some level of production.

At present, only a few commercial small-scale biomass power gasifiers are operating globally. The majority are about a hundred rice husk gasifiers, located primarily in China. A declining number of charcoal gasifiers continue operation in Latin America, primarily Brazil. A few wood-fueled power gasifiers are in commercial operation in Latin America as well. The largest unit, about 1 MW_{el}, is installed in Paraguay.

The short-term commercial prospects of small-scale biomass power gasifiers in developing countries at present appear limited. Three major factors can be cited:

- Unfavorable economics compared with fossil-fuel alternatives

- Low quality and reliability of equipment, resulting in operational difficulties
- Inherent difficulties in training sufficiently qualified or experienced personnel, resulting in substandard 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 the quality of the equipment and in simplifying operating procedures.

Power Gasifier Economics

The economics of biomass gasification are highly dependent on the price of diesel fuel. At world market oil prices of approximately US$18/barrel, diesel costs about US$190/tonne. International and local transport costs can add a maximum of about US$60/tonne. Therefore, the maximum cost of diesel at most locations in the world is about US$250/tonne.

Charcoal and Wood Gasifiers. At a diesel cost of US$250/tonne, small charcoal gasifiers are not economic. Such plants require at least a 100 percent increase in diesel-fuel cost even to be considered as an alternative to diesel power.

Low-priced wood gasifiers of local manufacture and relatively large capacity (> 100 kW_{el}) require low woodfuel prices (< US$20/tonne), high load factors (close to 1), and high total operating hours (about 4,000 hours per year) for them to recover, through fuel cost savings, the additional capital investments associated with the current gasification systems. Only a regular and fairly constant power demand would make the such power gasifiers economically attractive. The latter two factors alone invalidate the economic application of those gasifier plants at most rural power applications in developing countries. Better possibilities may exist in relatively isolated agro-industries. Also, the economics of small-scale biomass gasifiers for base-load power generation in small local grids in developing countries should be studied.

Rice Husk Gasifiers. The economic data from the BGMP suggest that the biomass power gasifiers that may be closest to commercialization are low-cost "open core" rice husk gasifiers. At 3,000 to 4,000 annual operating hours and high load factors, these plants require for diesel prices of only US$150 to 250/tonne to break even. It is probable that operating and load conditions of this sort exist in large rice mills in some developing countries. The potential for this technology therefore may be significant. Although high-cost rice husk gasifiers of Chinese design and manufacture are a proven technology, they are still associated with unacceptable environmental pollution. The same drawbacks apply to low-cost rice husk gasifiers, and they are also burdened by low quality and reliability.

Nonetheless, experiences with low-cost rice husk gasifier designs in Indonesia have been encouraging. The pollution problem may be overcome by employing the same high-temperature catalytic tar-cracking techniques that have been developed for the large fluidized-bed biomass gasifiers. In view of their potential, low-cost, low-tar fixed-bed rice husk gasifiers, ranging in output from 100 kW_{el} to 500 kW_{el}, should be developed further. Once the environmental problems have been solved, "open core" gasifiers may be adapted for using other agricultural residues such as coffee husks, maize cobs, and cotton gin trash.

Equipment Performance

Several aspects of gasifier power plant performance were much below manufacturers' specifications. Specifically, maximum engine power output and diesel-fuel savings (in dual-fuel systems) of some plants were much lower than would be expected from the manufacturers' information. In addition, although most wood and charcoal plants produced a gas that can be used in internal combustion engines without considerably worsening their lifetime and maintenance needs, this was not the case for rice husk gasifiers, which at present only work with special sturdy low-speed engines that must have frequent maintenance.

Because they were prototypes, almost all plants experienced significant problems relating to material selection and corrosion. Staff at some installations were able to overcome those problems, but most did not. None of the plants presented serious dangers with respect to operator health and safety, but operation of even state-of-the-art open-core rice husk plants still results in serious environmental pollution. Other gasifier types produced much more manageable environmental problems that can be overcome relatively easily.

Equipment Reliability

A comparison of relatively successful and unsuccessful projects reveals that both sorts experienced problems during the initial period after startup, but the successful projects were those that had the expertise and resources to modify and "debug" their plants and—in the end—arrive at more-or-less trouble-free operation. Successful projects had the commitment of the gasifier manufacturer for a prolonged period to help the local operators immediately with technical, material, or spare-part supply problem. The successful projects also evidenced a strong (usually financial) motivation of management and operator alike to keep the gasifier working.

Equipment Quality

The commercial market for small-scale gasifiers has never been large enough to carry the expenses of development from prototype to mature commercial plant. Plants that were installed were generally prototypes funded by grants. Under such circumstances, technical and operational problems are 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. Nevertheless, the results of the BGMP show that some small-scale wood gasifiers finally achieved reliable and relatively trouble-free operation. Experience and expertise in building and operating reliable, safe, and pollution-free wood gasifiers is thus now available.

Operating Personnel

Properly operating a biomass gasification system requires training and experience. The labor required to operate a gasification plant is quite different from that required to run a diesel engine of equivalent output. This difference is not only quantitative but qualitative. During operation, the operator must frequently check a number of temperature and pressure meters and use the information so gleaned to make decisions on adding fuel, shaking the grate, deblocking filters, and adjusting valves. At the end of daily operation the operator normally cleans reactor and filters of ash and dust. The operator may also be in charge of fuel preparation and fuel quality control. All this means that, contrary to diesel engine operation, where the engine driver has time to take on additional unrelated tasks, a small-scale gasifier requires a full-time operator.

The operational history of the gasifiers in the BGMP shows that not every operator can master the required competencies. Motivation and discipline are necessary, but the operator also must be able to react adequately on two or three input parameters and must master some basic technical skills. Biomass gasifier operations thus appear to require not only an adequate initial training program for operators but also continuous technical backup for a period of at least a year.

Recent developments in the automotive industry have resulted in mass-produced hardware and software that may greatly increase possibilities for automatic control of gasifiers. The automotive industry manufactures and uses a number of inexpensive temperature- and shock-resistant sensors and attenuators. In combination with the corresponding multiparameter input logic software, such instruments could conceivably monitor and control a biogas engine and reactor, thereby largely reducing or eliminating the need for highly trained and experienced gasifier personnel. Although such a development would improve the current economic competitiveness of small wood and charcoal gasifiers only marginally, it would certainly increase the possibilities for speedy introduction of the technology.

Environmental Pollution

Biomass gasification systems produce solid, liquid, and gaseous wastes, which, if not adequately controlled, harm the environment. Solid wastes are primarily residue ash. The amount produced may vary between 1 and 20 percent, depending on the biomass fuel. In most cases, disposal of this ash is not a problem, and in some cases, such as rice husks, the ash may have value for use by steel or cement industries. Gaseous emissions from biomass gasifiers are also not a significant factor except possibly in the immediate vicinity of the system, where CO leakages could be hazardous to workers. Compared with alternatives—especially fossil-fuel-based systems—biomass gasifiers are relatively benign in their environmental emissions, producing no sulfur oxides and only low levels of particulates.

The situation is not as encouraging when large quantities of liquid effluents are produced, as is the case in updraft and "open core" power gasifiers. The situation is exacerbated if wet-gas cleaning systems are used, which can dramatically increase the volumes of contaminated liquid effluent. In all cases, the effluent can be highly toxic, and untreated disposal of such effluent can lead to contamination of drinking water, fish kills, and other negative impacts. At present, additional research and development are needed to find solutions to this problem. Fortunately, most downdraft 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 more controlled and acceptable manner. The problem does not arise in heat gasifiers, because such systems usually combust the dirty hot producer gas completely—that is, inclusive of the tarry components, which are gaseous at higher temperatures.

Health and Safety

Operation of biomass gasifiers may result in exposure to toxic gaseous emissions (i.e., carbon monoxide); fire and explosion hazards; and toxic liquid effluents. Avoiding poisoning by toxic gases is mainly a matter of following sound workplace procedures, such as avoiding inhalation of the exhaust gas during startup and ensuring good ventilation of gas-filled vessels before personnel enter them for service and maintenance. Avoiding fires and explosions is also primarily a matter of following sound procedures. In addition, however, it is important that the system is designed so that any internal explosion that may occur can be relieved to avoid damage to the system. Avoiding contact with carcinogenic compounds in the condensates requires the use of protective gloves, clothing, or both. From the above, it may be concluded that with proper operator training, equipment and procedures, health and safety hazards can be minimized or even eliminated.

A Long-Term Approach to Technology Transfer

From the BGMP it becomes clear that the gasifier programs that have adopted strategies for sustainability and long-term development have shown the best results. Donor agencies should concentrate on building local capability through training and transfer of technology rather than on simply providing expertise and equipment. Building local capacity is a slow process, but it is the only one that 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 also destined to have no future. The most effective gasification programs have resulted from the formation of strong and experienced local organizations that enable the training of local personnel in different aspects of the technology and the adaptation of the process 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 expansion in the use of biomass gasification. Any long-term program should probably start with setting up a national center of expertise.

Heat Gasifiers

The commercial potential for heat gasifiers is significant. The technical performance is generally proven and reliable. Heat gasifiers are economically attractive compared with conventional alternatives. In addition to their 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 dryers used in various industries. A complete evaluation of the market potential of heat gasifiers would require a separate study.

Annex: Criteria for Preliminary Project Identification

The experiences from World War II as well as from several more recent projects in developing countries demonstrate that under certain conditions, wood gas from biomass can substitute for petroleum fuels. However, this does not mean that biomass gasification is a technically, economically, ecologically, or socially feasible alternative to petroleum fuels under all circumstances.

Using the Checklist

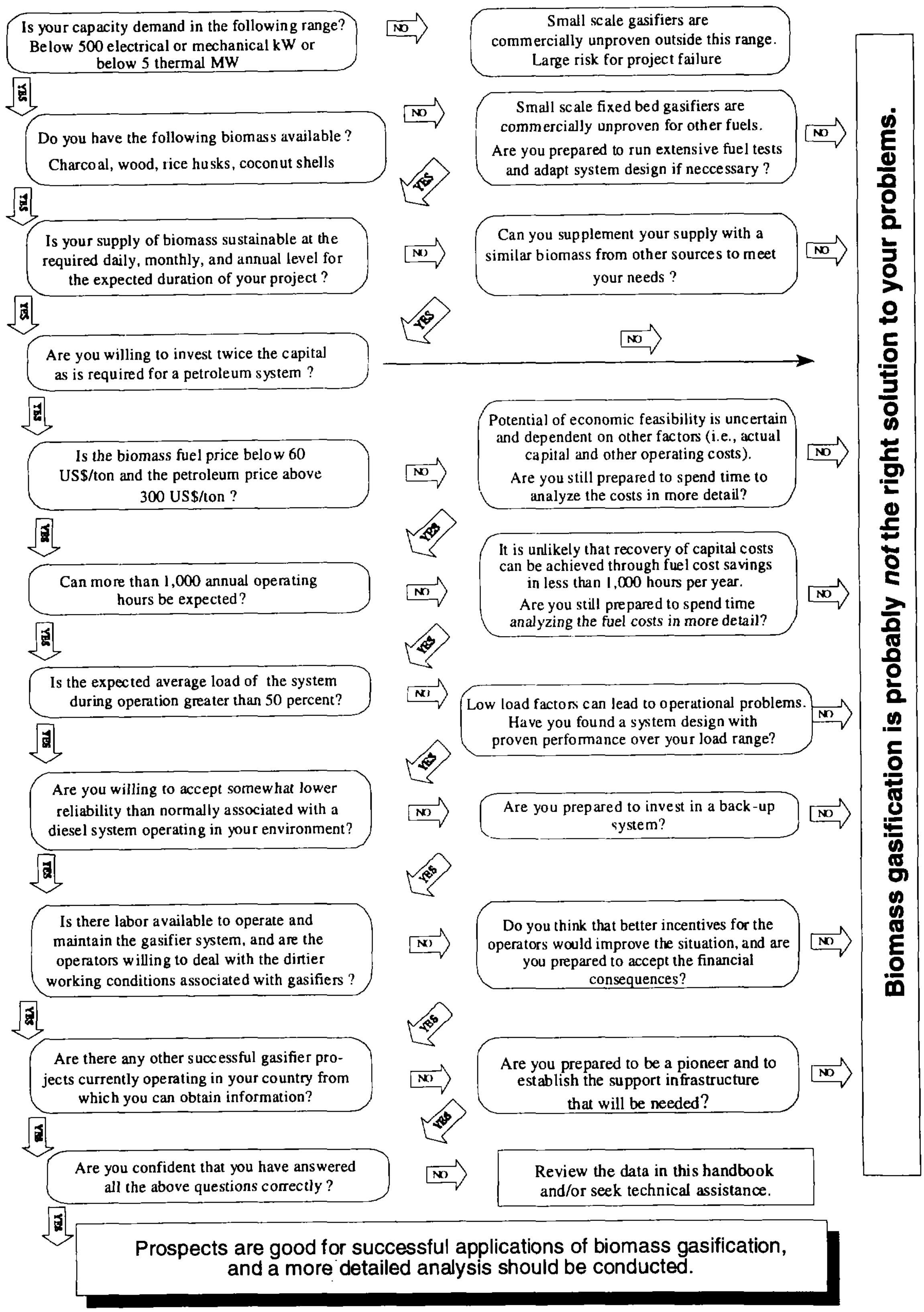
Reasonable assurance about the feasibility of a biomass gasifier installation can only be obtained after a careful technical and economic evaluation that takes into account site-specific requirements and conditions. For a first screening, however, a checklist (Figure A1.1) can be used to indicate whether biomass gasification is worth considering. If all questions on the list are answered positively, the evaluator can be reasonably sure of good prospects for a biomass gasification project. Any negative answer should prompt the evaluator to look for ways to eliminate the obstacles to a successful biomass gasification project or to examine alternative ways of meeting power requirements. The decision tree in Figure A1.1 is based on simple positive/negative answers to a number of questions. Some background information to these questions is given in the following paragraphs. This information is summarized in Table A1.1.

Capacity Range

The largest fixed-bed gasifier power plant reporting more-or-less reliable operation uses two wood gasifiers to fuel three wood-gas engines of 330 kW_{el} each. The BGMP was not able to monitor this plant, which is in a Mennonite community in Loma Plata, Paraguay. Single gasifier units in capacities above 500 kW_{el} are not commercially proven. Moreover, upscaling of fixed-bed power gasifiers above 500 kW_{el} may be difficult for technical and environmental reasons. Most recent biomass gasification experience stems from plants operating generators in the 10 to 100 kW_{el} range.

Probably the largest feasible capacity for fixed-bed heat gasifiers is in the range of 5 MW_{th}. Larger heat gasifiers are in operation, but the reactors are mostly of the fluidized-bed type, which is outside the scope of this report.

Figure A1.1 Decision Tree for Small-Scale Biomass Gasifier Projects



Biomass Fuels

Charcoal, many types of wood, rice husk, and coconut shells are the only fuels that can be considered as commercially proven in fixed-bed power gasifiers. Depending on the gas producer design and the form in which the fuel is available, preprocessing of the fuel may be required. The same fuels work well in fixed-bed heat gasifiers. However, indications are that the performance of these plants is less critical with respect to specific fuel characteristics, so that other biomass fuels (e.g., maize cobs, coffee husks, coconut husks, cotton gin trash) also may be considered in this application.

Sustainable Fuel Supply

For successful application of a biomass gasifier, a suitable quantity of biomass fuel must be available to fuel the installation during its lifetime. Table A1.1 gives biomass fuel consumption figures for plants operating on full power that were measured during the BGMP. In conjunction with actual power or heat demand figures, those data can be used to estimate the minimum necessary biomass supply.

Investment

The cost of an installation with a biomass gasifier compared with one using petroleum fuel will obviously depend on choice of equipment and supplier. Data from the BGMP show very large variations in specific costs (US$/kW). However, experience from recent units indicates that as a rule-of-thumb the installed cost of a gasifier power plant tends to be two to four times the cost of a similar installation operating on petroleum fuel and that the installed cost of a heat gasifier may be one and a half to two times the cost of an oil-fueled plant.

Local Conditions

The feasibility of small-scale biomass gasifiers hinges on the savings that can be gained by switching from relatively high-cost petroleum fuels to low-cost biomass fuels. A detailed and accurate financial feasibility study can only be carried out late in a project study, after the operating conditions have been determined and the equipment has been specified. In the early project identification phase, a first rough estimate is desirable; hence, the three listed items in the decision tree (i.e., fuel cost, operating hours, and load factor) address this issue. It should be borne in mind however, that the three factors are interrelated (i.e., a high number of annual operating hours or a high value of the load factor can compensate for too-low petroleum fuel costs on site or too-high processed biomass fuel costs.

Fuel Costs

Obviously the possibilities to regain the additional investment through savings on the fuel bill are highest when petroleum costs are high and biomass fuel costs are low.

Table A1.1 Background Information to the Checklist When Considering Biomass Gasification

Evaluation factor	*Power gasifiers (capacity range < 500 kW_{el})*	*Heat gasifiers (capacity range < 5.0 MW_{th})*
Biomass fuels	Charcoal Wood Rice husks Coconut shells	Wood Charcoal Rice husks Coconut shells Limited experience with a number of other biomass fuels
Fuel consumption	Wood: 1.3–1.4 kg/kW_{el} Charcoal: 0.7–0.9 kg/kW_{el}	Wood: 0.4 kg/kW_{th} Charcoal: 0.15–0.17 kg/kW_{th}
Investment	2–4 times the investment in petrol/oil-fueled plant	1.5–2.0 times the investment in oil-fueled plant
Local conditions		
Fuel cost	Petrol/diesel > 300 US$/tonne	Processed biomass fuel < 60 US$/tonne
Operating hours	> 1,000 hour per year	
Load factor	> 50	
Reliability	10–20 downtime caused by technical problems	Less than 5 downtime caused by technical problems
Labor	Motivated and skilled labor required	No special labor requirements
Other projects	Initial support needed	No special requirements

Note: kg = kilogram; kW_{el} = kilowatt electric; kW_{th} = kilowatt thermal; MW_{th} = megawatt thermal.

However, the data from the BGMP show that it is unlikely that biomass gasification will be financially feasible if the cost of petroleum fuel on site is less than about US$300/tonne and the cost of processed biomass fuel on site is more than about US$60/tonne.

Operating Hours

If the additional investment in a gasifier is to be recovered within a reasonable time, the unit must be operated frequently. After all, only in operation can comparative savings on fuel cost be realized. Consequently, the possibility of recovering the additional investment depends greatly on the operating time. Data from the BGMP indicate that recovery of the additional capital investment is unlikely when the gasifier is used for less then 1,000 hours per year.

Load Factor

The load factor of an energy system is defined as the ratio of the actual energy output and the nominal (maximum possible) power output. Low load factors in gasifier systems may have both economic and technical consequences. If the average load factor is low, reclaiming of the additional capital investment as compared to a conventional petrol- or oil-fueled system will become increasingly difficult. Also, certain type of power gasification systems (i.e., downdraft fixed-bed gasifiers) are technically not suitable for prolonged operation on low loads. Therefore, evaluation of the gasifier option only makes sense when the expected average load factor is above 50 percent.

Reliability

The data of the BGMP make it clear that gasifier power plants are less reliable than comparable petrol- or oil-fueled systems. On the one hand, this is caused by a lag in development that may well be remedied over time. On the other hand, the complexity of adding a gas producer to an engine is an intrinsic reason for lower reliability. The data indicate that at present the more developed small-scale biomass gasifier power plants are down for 10 to 20 percent of the time because of technical problems or scheduled maintenance. Heat gasifiers have fewer technical problems and consequently are more reliable.

Labor

Operating an installation with a biomass gasifier means additional fuel processing, fuel handling, and system service compared with using liquid fuel. In particular, the regular cleaning of gas filters can be a dirty and therefore less attractive job. Service intervals for biomass gasifier plants are shorter than for plants using liquid fuels, which means that the requirements on operator discipline are higher if operational disturbances are to be minimized. Operation itself also requires a higher time input, since high-tech control and safety systems that allow unattended operation are more difficult to justify financially for small-scale installations. Even with regular service, some operational disturbances—such as those that may be caused by irregularities in fuel properties—are likely to occur at irregular intervals. Such disturbances will demand intervention of higher skill and understanding of the process from the operator than is normally the case in liquid fuel operation. These skills can be transferred through proper training if the trainee has a reasonable level of diagnostic aptitude and ability.

The implication is that successful operation of a small-scale gasifier power installation calls for a more skilled, motivated, and disciplined operator than is normally needed for diesel engine operation. In addition, this operator must be willing to do dirty work. The BGMP has learned that such operators are sometimes difficult to find on sites and in situations where small-scale power gasifiers are financially feasible. Some plants would have performed much better had the operators shown more skill and dedication in their tasks. More specifically, the BGMP indicated that it is not easy to transform engine drivers into gasifier operators, especially without adequately adapting their salary to the new and more demanding tasks, introducing an incentive scheme based on fuel-cost savings, or both.

The above-mentioned labor problems were not encountered at heat gasifier plants, probably because operating a heat gasifier intrinsically calls for less skill, motivation, and discipline than are needed for running a power gasifier.

Other Projects

Since it is more complex to fuel an engine with producer gas than with liquid fossil fuel, it is very likely that advice and technical support will be needed in the initial phase of the project, which may last for a year. If other similar installations are operated in the neighborhood, the necessary support may be obtained from the users of these installations. In pioneer installations, however, support must be arranged either through the equipment manufacturer or through a technical consultant. This initial support must not be neglected or underestimated. Many if not most failures of biomass gasifier projects in developing countries can be attributed to lack of sufficient technical assistance.

Detailed Evaluation

If careful consideration of the questions in the checklist have led to the conclusion that there are good prospects for a successful application of the technology, a preliminary project design should be made.

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