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DEVELOPMENT OF AN INTEGRATED SMALL SCALE COMBINED HEAT AND POWER (CHP) BED GASIFICATION SYSTEM FUELLED BY STANDARD GASIFIER FUEL

FINAL REPORT

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1 EXECUTIVE SUMMARY

The aim of the project is to develop an economic, efficient and reliable total power/heat generation system using a fully automatized biomass fixed bed gasifier fuelled by standardized gasifier fuel (SGF) in combination with an engine/generator set in a commercial operating range of 100 - 2000 kW_{el}.

Seven main tasks were formulated in the project proposal:
In Task 1 *System Definition* an analysis of the different technical, economic, social and environmental boundary conditions that define the viability of small/medium scale CHP gasifier systems has been investigated. Task 2 *Fuel Pretreatment and Production* concentrated on the possibilities of producing a standard gasifier fuel (SGF) will be explored. Task 3 *Gasifier Development* focuses on developing a suitable gasifier reactor able to convert SGF in good quality producer gas. In Task 4 *Gas Cleaning* a suitable gas cleaning system was identified and tested. The raw producer gas quality should fulfil the requirements of the prime mover. In Task 5 *Unit Automation and Control* an automatic control system of the whole gasification system has been developed. Task 6 *Prime Mover* focused on the identification of a suitable prime mover for the treated producer gas. Finally, in Task 7 *Design of an Integrated System* a detailed design was made for a demonstration gasification system based on the developed components of the previous tasks.

This project has increased the state of the art of gasification systems and has identified the next 'steps' in the evolving gasification business. All deliverables have been covered. With the realisation of at least one demonstration plant the project outcome moved beyond its goal. Moreover, several **additional** activities were conducted to fulfil the objectives successfully, including:
- four duration tests
- construction of a 150 kWe gasifier
- interactive multimedia model on Internet
- waste water treatment tests
- development of an uniform test protocol.

Several spin-off activities were initiated based on this project which resulted in at least four project proposals while several others are under preparation. This report has identified the different exploitable results, the different routes for exploitation and the different sources if funding which will be accessed. Even as we write this report several of the results are being exploited in accordance with the plan.

The success of this project will ultimately be judged on its contribution to the demonstration of gasification systems and its contribution to the development of standards and guidelines for the gasifcation business.The nature of the partners business activities will guarantee the success of this exploitation.

2 OBJECTIVES OF THE PROJECT

The overall objective is to develop an economic, efficient and reliable total power/heat generation system using a fully automatized biomass fixed bed gasifier fuelled by standardized gasifier fuel (SGF) in combination with an engine/generator set in a commercial operating range of 100 - 2000 kW_{el}.

The project will concentrate on:

- an analysis of the different technical, economic, social and environmental boundary conditions that define the viability of small/medium scale CHP gasifier systems;
- identification and/or further development of a small scale automatic controlled gasifier/engine/generator unit for use with SGF;
- the identification and/or further development of a suitable gas cleaning system to be used with such gasifier;
- the identification of the most suitable type of prime mover to be used with such gasifier;
- the development of cheap and reliable automatic control systems for the CHP unit;
- the pilot scale testing of an integrated demonstration unit at 30-50 kW_e; and
- the design of a number demonstration projects in participating countries.

The development aims at the introduction of a standard gasification system to be worked with a standardized gasifier fuel (SGF) that is produced from different types of biomass. This development can be compared to the development of a standard engine to be run on a standard fuel produced from different types of crude oil, as has been done in the past for petrol and Diesel engines.

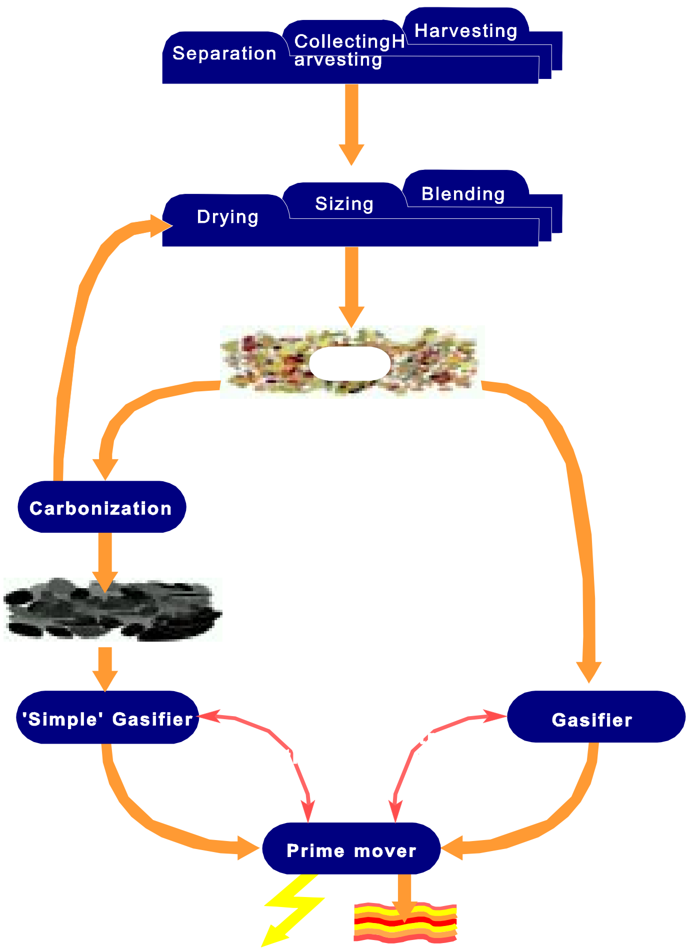
Since the early 90's the interest in relatively small-scale gasifier installations which reliably convert biomass and/or waste in electricity and/or heat is gradually growing. The motivation for this interest and for this programme are manifold:

- The technology developed by the project will encourage the use of set-aside land for the production of energy crops. Fertilizer, pesticide and herbicide inputs are much lower than for conventional food crops. While there may be some disadvantages in some cases (such as increased water demand), it is generally accepted that they are preferable from an environmental point of view than uncultivated land.
- Due to surpluses of agricultural production in the EU countries and rising EC subsidies there is an urgent need for new markets for agricultural products. Biomass fuel production (energy crops) for use in small and medium scale gasification systems may provide a new market of a size that is commensurate with the size of the problem, and therefore have an important positive effect on the solution of the present agricultural problems.
- In industrial and demolition activities biomass residues are produced. Often these residues must be removed and/or landfilled at considerable costs. Utilisation of these

biomass waste streams in nearby small-scale fixed bed gasification systems may be the more economic solution.

- Important positive effects of the utilisation of biomass for efficient energy production are the positive environmental effects. Especially the carbon neutral character (global warming) when fuelled with biomass from sustainably managed energy plantations, potentially high efficiences (through coupling with gas engines and in the long term gasturbines) and the low sulphur oxide emissions (acid rain), may be important factors in stimulating biomass energy production through combustion, gasification, etc.
- Equipment for small scale reliable and efficient biomass based electricity production may find a ready export market in decentralised energy systems in rural European areas and countries in development (Eastern Europe included).
- Job creation through the need for European manufacturing, assembling, suppliers of materials, equipment and services, especially foreseen for small and medium scale (new) industries, rural areas and export markets.

Figure 1: The biomass to energy chain analysed in this project



3 SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE PROJECT

This chapter comprises different technical sections covering the work performed and highlighting the main results achieved. At the start of the project task leaders were appointed to take care for carrying out the work and prepare a “task report”. Seven main tasks were defined in the Technical Annex and the findings are given below.

3.1 System Definition

Involved partners: FEE, BTG, EDON, INGE-H, COM, DKT, task leader FEE

3.1.1 Introduction

Over the years a considerable number of gasification systems for demonstration purposes have been financed worldwide. Two major reasons for this lack of success are technical problems and financial/economic problems. To overcome similar failures in future, the gasification system must be defined and specified in such a way that it meets the demands of existing energy markets. Because those market demands will probably be different in each country, a "system definition" phase is envisaged for each country, in which at least the following questions must be answered.

So, the objective of this task is to assess all conditions and limitations, i.e. technical, financial/economic, logistical, organisational and environmental which are relevant for the design and development of a **successful** small/medium scale CHP unit.

3.1.2 Findings

Within this task the following activities have been be executed:

- Who are the future users (farmers, industries, utilities, others), owners (private, lease, contract, etc.) and investors (utilities, private, waste processers, etc) of the CHP unit?
- What is the maximum acceptable kWh-price of the electricity delivered by such a unit? What does this requirement mean for the SGF fuel costs and the investment and operational costs of the CHP unit?
- Where (e.g. farm, industrial area, etc.) and under which circumstances (e.g. island operation, CHP, etc.) can such a unit operate economically?
- What should be the optimum capacity (kW_{el}) in relation to fuel logistics and organisation, fuel transport costs, specific capital costs and specific operational costs?
- What are the environmental requirements to be met by such small CHP units?

To get a complete overview on these items, a questionnaire was prepared and distributed among the involved partners. An additional questionnaire has been elaborated and send to all partners in a later stage aiming at cross-checking recent developments in the project partners’s countries.

In the course of the project several projects of biomass gasification in different stages of realisation were identified. A general review is given in Task 3. Due to the fast developments and changing policies regarding biomass utilization and energy generation it was already agreed in an early stage to extent the completion of this task till the end of the project.

Emphasis had been layed on market observation. In the course of this three years project, especially in at least Germany and the Netherlands an acceleration of applied R & D in gasification of biomass could be noted resulting in new test plants for different technologies. So far, no single installation has proven to operate reliably for more than 150 hours continuously.

Potential locations

Gasifiers in combination with Combined Heat and Power generators (CHP) can be installed in locations with a good potential of using the produced heat and which have an easy possibility of connecting to the public network of electricity distribution or, as an alternative, have a sufficient high continuous demand of electric power. Delivery of both heath and power against a reasonable price is necesary to make the exploitation of the gasifier financially interesting.
To determine potential locations it is of great importance to have access to information about the heat demand of different kinds of industries and other possible users of heat.
Energy distributing companies have good insight in the heat demand in their regions. In several locations, the bigger heat consumers use nowadays the heat from a CHP to fulfil their basic demand of heat. The peak in their heat demand they fulfil with an ordinary heater, normally powered with natural gas or an other conventional fuel.

Location requirements

A potential location has to fulfil a series of requirements, of which the following needs special attention.

- The basic heat demand should be sufficient and almost constant during the year. The installation can best deliver heat at a constant rate. Peaks in demand should be dealt with by an ordinary heater;
- Daily differences in heat demand can be regulated by a heat buffer, in the form of a water tank;
- The preparation of the biomass fuel will proceed noise; attention should be taken with local noise regulations; best it should be done in a specific preparation place, not necesarily connected with the power unit;
- The transport of the biomass fuel to the location will give noises; in some specific area’s this will not be welcome e.g. hospitals;
- The space needed for a biomass storage, gasifier and a CHP is more than the space for only a CHP on natural gas;
- The public electricity network should have sufficient capacity to make the connection;

- Transport of heat is very expensive, it needs a high investment per length pipeline and the loss of heat rises fast with longer distances. As result the power equipment should be located as near as possible to the heat demand inlet;
- Exhaust gases of a CHP should fulfil the local standards, which will be given in the community health and environmental regulations;
- The handling of biomass fuel can produce dust and odors; also given in the community health and environmental regulations;

Potential locations

Heat consumers can be differentiated in the following groups:

- Glasshouses;
- Hospitals, nursing- and rest homes;
- Sports halls and swimming pools;
- Obsolete existing biomass heating plants;
- Rural villages not connected to the grid;
- Retrofitting fossil fuel-fired heating plants;
- Process industry.

Glasshouses have a heat demand with a peak in wintertime, which is rather high. Their heat demand depends strongly on the weather and as result has an daily and a seasonal frequency. In summertime during the day the heat demand is very low to zero, but during night time there can be heat demand, although not very high.

Most glasshouses will have a basic need of heat during 4000 – 5000 hours on which the installation can be designed.

Hospitals and the alike, have heat demand for space heating and for hot water. Space heating demand is high in wintertime, hot water is needed all year round. The heat demand is strongly seasonal. For a typical hospital the basic heat demand is approximately 40% of the peak heat demand.

Sport halls and the alike need heat for space- and water heating. Especially the combination of sports halls and swimming pools (some of them being tropical) has a high heat demand. Heat demand is seasonal.

Process industry has heat demand for its processes. Their demand is more even year round as it does not depend on weather conditions. Specific types of these processes are dairy industry, food and feed industry and slaughter houses, but also papermills, textile industry and others with a high need of steam for processing and drying.

In summary, future users of biomass gasification systems will come from different market groups. Countries with a progressive to renewable energies policy**,** state-owned, big private and communal energy supplying enterprises might introduce biomass gasification systems for CHP. In countries where an abundant potential of residue-, waste- and demolition- wood is available main application is to be expected in commercial enterprises, in some communities and in agriculture.

Also in the medium term a stable and growing market for small scale biomass gasification is to be expected.

Number of potential locations

To a high degree the market potential of wood-gasification systems depends on future economical efficiency or the stimulation by legal regulations.

For **Denmark** could be reckoned that from the above-mentioned more than 100 heating plants and in numerous villages a substantial amount of gasification systems in the range of 0.5 to 2 MWel might be expected.

In **Germany**, economical efficiency might be reached in enterprises with sufficient waste-wood availability. For example, there are about 100 big saw-mills with a processing capacity of > 80.000 fm/a. Presuming, only half of the available residue- and waste-wood could be gasified (~ 14.000 m³/a = 30.000 MWh) every saw-mill could operate a gasification system with a capacity of 1 to 1,5 MWel during 5.000 to 7.000 hours a year.

In **Switzerland**, all big wood-processing companies and the whole wood energy branch have a strong interest in power generation by wood-gasification. Limiting factor, however, is the absence of district-heating grids with at least a continuous demand of 4.000 hrs/a or consumers with need of process heat.

In the **Netherlands**, the market potential is basically the obsolete CHP units installed. A high demand is there because of the absence of any limit for supplying power to the grid. Also heat may be freely delivered to local district-heating networks.

The number of CHP installations smaller than 1 MW electrical capacity in the Netherlands is about 4.000. The total number of CHP installations bigger than 1 MW is about 300. In the EDON region only, more than 300 CHP units are installed below 1 MWe which were installed in the last 10 years. Replacement of the first units is expected to start in the year 2000 which is a potential market for gasification units.

Health, safety and environmental aspects

The installation will be operated at underpressure; so no leakage to the environment can occur there. However, in the part operated on a small overpressure leakage can occur. Any leakage is detected by CO sensors installed in the building surrounding the installation and mobile sensors carried by any present operators.

The formation of any explosive or otherwise dangerous gasmixtures is prevented by ventilation of the building. The used equipment is explosion proof where possible. In the system many temperature sensors are installed to detect any unexpected or abnormal heat sources (fire). In the gas cleaning section an oxygen alarm is installed; this will stop the installation when oxygen is present in the producer gas.

A nitrogen system can be installed to purge the installation during start and/or stop procedures. It can also be used to stop the reactions inside the gasifier more quickly.
Heat isolation for conservation of heat as well as personal protection is used in the entire system.
Noise polution is prevented/reduced by taking aimed noise isolation measures.

Safety
During the pre-engineering phase the normally common sense is used for the engineering of the gasifier and the sections attached to the gasifier. Three different methods can be used for looking in a constructed way to the safety of the designed plant:
- a HAZard and OPerability study (HAZOP)
- determining the Fire and Explosion Index (FEI) and
- determining the Chemical Exposure Index (CEI).

Policy regarding energy production from biomass

There is no need for an analysis of national or European policy on bioenergy in the framework of this project, as abundant investigations are available elaborated on order of the European Commission.
A coherent programme on biomass doesn't exists as part of a comprehensive strategy on renewable energy, although in some regions or countries various programmes or plans for the promotion of bioenergy have been designed. Hence, national political conditions are rather different, partially pushing biomass utilization forward, partially obstacling the utilization.

Due to the White Paper on comprehensive strategy and action plan for the promotion of renewable energy sources in the European Union adopted by the European Commission by the end of the year 1997 aimed at doubling the the share of renewable energies in the total energy demand to 12 % by the year 2010 an accleration of elaboration of national and regional programmes is to be expected.

Technical risk analyses
The technical risks are relatively low since no major unproven components are involved in the designs. The consortia involved in the design and manufacturing of the gasifier installation have long-term experience in development and operating biomass gasifier plants. The main technical risks however are:
- the scaling-up of the designs
- the involvement of a rootsblower which could cause unexpected problems like condensate formation
- the involvement of a oil-based washing system
- the control of the gasflow through the system. The control valve must be able to operate the plant at a wide operational range, in particularly to determine the turn-down ratio

- the temperature levels at the gas cleaning section. These are quite narrow; to keep the temperature above the dewpoint and at the same time safeguard the fabric filters and rootsblower.

As long as the gasifier is operated with the specified fuel and according to the manual, the risks are within acceptable levels.

Permits

The building and use of installations is regulated by governmental legislation. Permits are needed and sometimes special research reports should be made before a permit can be given, mostly to prove that an installation can fulfil the prescriptions given by the permits.

Permits for the building and use of a biomass powered CHP installation are needed for different subjects:

- Building permit;
- Environmental permit/nuisance act;
- Permit to drain off sewage water.

The permits are combined in such a way that none of them is actuated until the others are given.

The building permit gives specification and prescriptions concerning the construction materials, available light inside the building and in working area's, measurements of doors and rooms, fire prevention and so on, and is meant to regulate safety and health for people working in or nearby the building.

The environmental permit gives specifications and prescriptions on a wide range of subjects concerning the environmental impact of the installation itself and of all the activities to operate the installation. Examples are prescriptions of the noise production of the installation and at 50 meter of the installation, the composition of the exhaust gases, the composition of the drainwater. On installations with danger for fire or explosions a safety plan should be prepared.

The permit to drain off sewage water is only required for installations with a more than normal impact on the quality of the local sewage water or installations which will drain off on directly on surface water.

The city council is the first administration to contact to start the procedures for obtaining permits. The time needed to obtain all the permits is minimal six months, but not unusual up to one year.

Financial Aspects

EDON/Hanze Milieu developed the Investment Decision Model (IDM), an economic evaluation model for biomass gasifier systems. This model has been used in the final stage of the project to perform the economic evaluation of demonstration projects.

In order to be economically effective for a manufacturing enterprise a CHP-plant on wood-gasification with a LCV-gas engine or turbine, the price for electricity in case of self-consumption has to be equal or below the tariff for power from the grid, in case of supplying to the grid costs are to be covered by remuneration. Costs for heat energy have to be also below the prices of competing heating systems of given local sites. Prices are influenced by:

- investment costs (real estate, plant, construction, size of the plant, technology, capital),
- variable costs (fuel and other operational costs, labour, remuneration for electricity and heat, load, planification, permits, depreciation, inflation, waste treatment, demolition of the plant after end of operation)
- subsidies.

Generalized factors determining the economics of gasifiers include:

- sufficient availability of fuel for which a price for disposal or landfilling has to be paid (negative fuel price) or a more or less cost-free fuel,
- utilization of highly homogenuous fuel, like SGF, as an important factor for an undisturbed and continuous operation.
- self-supply of energy (as a rule, in almost all countries tariffs to be paid are higher than feed-in tariffs),
- sale of generated heat as high as possible,
- high uninterrupted energy production,
- automatic and almost unmanned operation.

For economic evaluation of a wood-gas CHP, total costs equal capital costs plus operational costs. Total costs and profit have to balanced by remuneration for power generation and sold heat. Specific power and heat prices for energetic utilization of biomass must be compared with the prices for electricity and district-heating.

The energy prices valid in different countries are elaborated in the Task 1 report "System Definition". Prices for electricity in **Denmark** and in the **Netherlands** are lower than in **Germany** whereas, in **Denmark** prices for the primary energy carrier natural gas and heating oil are substantially higher than in **Germany**. Also heat prices should not be higher than for fossile fuels. In **Denmark**, prices are in the average at 53 ECU/MWh, in **Germany** between 37 and 50 ECU/MWh, in Switzerland between 20 and 52 ECU/MWh.

Avoided costs of landfilling are reflected by the disposal price to be paid for delivering waste- and demolition wood to the gasification plant. This disposal price is of course lower than the price for landfilling. As negative costs they improve the balance of variable costs. This is the main reason to prefer gasification of waste- and demolition-wood.

In the detailed financial analyses of SGF-based gasification it became clear that the high production costs of SGF (calculated at 40 EUR/ton, see paragraph 3.2) is prohibitive for operating gasifier units. The delivered price at the gasifier unit should be close to zero meaning that the raw feedstock price should be in the order of minus 40 EUR/ton which is not tremendous available.

Detailed financial evaluation of two gasifier systems designed for demonstration can be found in the two separate reports. A summary of the financial viability is given in paragraph 3.7.

3.2 SGF Production

Involved partners: BTG, RUG, INGE-H, COM, FEE, DKT, task leader BTG

3.2.1 Introduction

Two different ways of utilizing the SGF in small/medium scale gasifiers will be investigated in detail (see figure 1):

1. SGF briquettes from different biomass raw materials will be tested as such in a number of fixed bed gasifiers available at the participants; and
2. SGF will first be carbonized and those carbonized briquettes will be tested as fuel in a very simple and cheap fixed bed charcoal gasifier. This route may be attractive when the pyrolysis gas that is produced during carbonisation can be used to fuel the drying of blended feedstock prior to briquetting. Therefore an evaluation and testing of suitable briquette carbonisation technologies is part of this task.

This task should result in the specification and production of a standard biomass gasifier fuel for different applications and for different types of biomass raw materials.

3.2.2 Findings

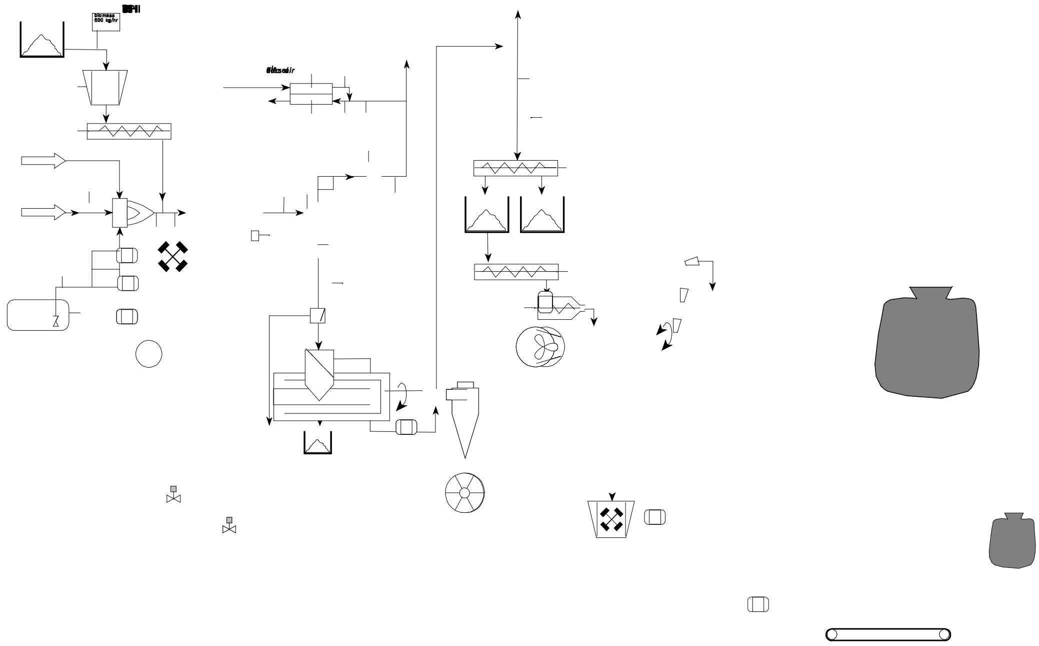
The following fuel-related tasks were executed:

- Analysis of fuel specifications for different types of fixed bed gasifiers;
- Production of batches of suitable SGF on the basis of different biomass raw materials;
- Testing of those SGF briquettes in different existing types of fixed bed gasifiers;
- Evaluation of the suitability for use of SGF briquettes in different types of fixed bed gasifiers;
- Identification the type of fixed bed gasifier that performs best with SGF briquettes;
- Evaluation of suitable carbonization technologies for SGF briquettes;
- Carbonization tests and production of carbonized SGF briquettes;
- Testing of carbonized SGF briquettes in a cheap and simple charcoal gasifier;
- Evaluation of drying technologies and the use of pyrolytic gas for drying the biomass feedstock;
- Technical, economic and environmental comparison of the two possible routes for power production through fixed bed gasification of SGF briquettes.

Different biomass raw materials were tested for SGF production. An experimental facility was designed in Almelo for SGF production. A proces flow sheet is shown in Figure 2. Experiments were conducted to determine the moisture and ash content of the various fractions and the residence time distribution in the rotary drier. Good quality briquettes were made with several mixtures of materials like thinning wood, straw and miscanthus. Each of the briquette types requires an almost unique set of control parameters of the briquetting screw: feeding rate, screw rotational speed, die temperature and others. The briquette quality is also determined by material characteristics like particle size, morphology, composition and state of decomposition. To determine the quality of the briquettes, crush and break tests were conducted as well as carbonisation tests. Good quality briquettes were tested for their suitability in fixed bed gasifier and carbonization. Carbonized briquettes were also subsequently gasified. Finally, an conomic analysis of the process was made for carbonized and uncarbonized SGF fuel.

In total six reports were prepared within this important task, i.e.
1. Evaluation of suitability of SGF
2. Evaluation of carbonisation technologies
3. Carbonisation of biomass briquettes (RUG)
4. Evaluation of drying technologies
5. Evaluation of the two routes
6. End-of-task report

Figure 2: Process flow sheet of the SGF production facility in Almelo, the Netherlands



In order to determine the suitability of SGF as a gasifier feedstock, it was decided to conduct gasification tests in various existing fixed bed gasifier systems. With respect to the content of the tests, it was agreed upon the following issues:

- The test should be a duration test of 150 hours. Reason for this is that the project aims at the development of a continuously operating CHP gasification system. Only duration tests can help to determine whether a gasifier system meets to the requirements of such a system.
- The duration test will be conducted at four different types of fixed bed gasifier systems (downdraft, two-stage, crossdraft, open-top).
- The test will be conducted via a uniform test protocol. This enables comparison of gasification characteristics and gives a good insight in the gasification properties of SGF in different systems.
- Based on the duration tests, possible improvements to each gasifier system will be identified. Promising SGF gasification systems suitable for further development within the project will be selected.

The results of the duration tests with the different gasifier systems are reported separately by the involved partners FEE/COM, DKT, INGE-H and BTG while a summary is given in the synthesis report.

A uniform test protocol was established in order to enable a good comparison between the different systems. The protocol incorporates the following items:

- 130 hours operation at full load conditions;
- 20 hours test period of reduced load (e.g. at 50%);
- SGF briquettes as fuel;
- determination of all operational parameters (pressure, temperature, gas composition, gasflows, fuel consumption, power production, condensate/ash production;
- tar and dust determination according to one standard method.

Table 1 shows a summary of the overall performance for three gasifiers. The test with the open-top gasifier failed although in a later stage of the project, this gasifier could also be operated on SGF briquettes. Table 2 shows the average gas composition data and Table 3 the tar and particulate matter content in the gas at different process conditions.

Only the downdraft gasifier incorporated a gasengine, so therefore more results are generated from this plant.

Table 1:	Overall performance results, based on the survey sheets delivered by the three partners collaborating in this project						
		Downdraft gasifier		**Two Stage Gasifier**		**Cross-draft gasifier**	
Parameter	**Unity**	**Value**		**Value**		**Value**	
		Full load	*Half load*	*Full load*	*Half load*	*Full load*	*Half load*
Measured parameters							
Primary air flow	Nm^3/hr	45	30	46		50..60	30..35
Producer gas flow (at stp)	Nm^3/hr	75	50	67.1		52.5	34.1
Secondairy air flow	Nm^3/hr	70	50	-		-	-
Calculated parameters							
Fuel consumption	kg/hr	28.5	21.4	20		18.3	12.8
Spec. fuel consumption	kg/kWh_e	1.12	1.61	-		-	-
Spec. gas flow	Nm^3/kg	2.61	2.32	2.97		2.87	2.66
Spec. gasification veloc.	kg/m^2hr	1256	943	-		-	-
LHV producer gas	MJ/Nm^3	4.99	4.99	5.29		3.98	3.865
Hot gas efficiency	%	91.5	81.2	100.92		90.7	81.6
Cold gas efficiency	%	72.5	56.6	90.53		63	62
Engine efficiency	%	25.7	23	-		-	-
Overall efficiency	%	18.7	13	-	-	-	-

[1] It should be noted that for the DTU-gasifier does the amount of energy used to heat the pyrolysis zone and to make superheated steam of 600 °C is not taken into account.

[2] If the energy balance is calculated in uniform way, the hot gas efficiency amounts 83.7%

[3] If the energy balance is calculated in uniform way, the cold gas efficiency amounts 76%

Table 2: Producer gas composition for the three different gasifiers.

	Concentration [vol %]			
	Downdraft gasifier	**Cross draft gasifier**		**Two stage**
	Full load Average	Full load Average	Half load Average	Full load Average
H_2	17.3	13.7	12.3	30.1
O_2	1.14	0.1	0.2	0.09
N_2	47.8	57.6	59	37.9
CH_4	0.93	0.3	0.8	0.74
CO	22.11	19.1	18	14
CO_2	10.73	9.2	10.4	17.2
	100	100	100	100
LHV MJ/Nm^3	5	4	3.9	5.3

Table 3: Particulate and tar measurements

		Downdraft			**Cross draft**			**Two stage**
Sample nr.		**1**	**2**	**4**	**1**	**2**	**3**	**1**
Load capacity		full	full	half	full	full	half	full
Sampling time	hr	2.5	4	4	1.3	1	1	2
Particulate [mg/Nm^3]	**raw gas**	517	666	749	1046	1894	4719	492
	clean gas	70	103	296				
Heavy tar [mg/Nm^3]	**raw gas**	384	173	135	1820	418	1796	327
	clean gas	478	226	160				
PAH's [mg/Nm^3]	**raw gas**	305	299	408	19.6	92.4	57.3	56
	clean gas	277	273	32				
Phenols [mg/Nm^3]	**raw gas**	n.a.	0.54	1.30	17.3	324.3	685	0.48
	clean gas	0.40	0.74	0.49				

Based on the duration tests results, the downdraft gasifier and the cross-draft gasifier were selected as most promising systems for further investigation within the project because:
- both gasifier systems have more than 1000 hrs running time with different fuels;
- both gasifiers with the results from the 150 hour test came closer to commercial stage of SGF-gasification;
- official permissions to drive the plants with a wood fuel are existent.

Based on the long-term tests several technical improvements were formulated:
Crossdraft gasifier

Changes at the gasifier system:

- Enlargement of the gasifier outlet diameter to lower the gas velocity and therefore lower the dust content in the gas;
- Revamping the ash discharge system to be able to adapt on different ash contents of the fuel and therefore reach a higher burn out of the fuel;
- Investigate modifications for re-directing producer gas to lower the tar content because of longer residence time of the gas in the oxidation zone;
- Installation of a new fuel level indicator to maintain a constant fuel level;
- Separation of the air flow to the reactor and the air flow to the combustion chamber to improve the gasifier efficiency.

Changes at the peripherals:
- Design and construction of a gas treatment section (cleaning and cooling) to meet the gas quality requirements of an engine. Preferably, the gas treatment should be a dry gas cleaning system thereby avoiding water treatment;
- Installation of analytic devices to control the off-gas parameters and the producer gas composition.

Downdraft gasifier

Changes at the gasifier system:
- Investigate the influence of the throat design on tar production;
- Investigate the influence of adding steam to the gasifier for improving the hydrogen content;
- Investigate the influence of activating the ash grid on process performance;
- Improving the fuel feeding system for automatic operation.

Changes at the gas cleaning system:
- Revamping of the construction of the cyclone and baffle filter due to the fact that SGF generates smaller ash particles than wood pieces;
- Installation of automatic ash discharge from the cyclone and bag house filter;
- Installation of an automatic cleaning device for the fabric filters inside the bag house filter. The cleaning device (mechanical, back flushing) should be activated and controlled by the pressure drop over the bag house filter.
- Installation of a coal bed filter behind the fabric filter as a safeguard for the engine;

Changes at the engine system:
- Optimisation of the engine operation (ignition timing, vacuum safety device, automatic secondary air control based on lambda measurement);
- Installation of heat recovery system to complete the CHP-unit;
- Installation of an electronic flare ignition system to monitor the gas quality;
- Determination of exhaust gas composition under various conditions.

Changes on the monitoring and automatisation system:

- Prevent all pressure tubes from entering water;
- Control the temperature downstream the gasifier and upstream the bag house filter by for example adjustment of the primary air intake. Too high temperatures at the gasifier exit indicates that the gasifier operates in a combustion mode, while too high temperatures at the inlet of the bag house filter may damage the fabric filters.
- Install new venturi gas flow meters for accurate determination of the mass and energy balance. During the duration test, the gas flow was calculated from the primary air consumption and the nitrogen balance.
- Visualising pressure, pressure difference and temperature signals for taking the right measures in case of any disturbance. During the duration test, all parameters and data were stored on a PC which was located in a separate room. So, the operators could not see any figure while working at the gasifier spot.
- Expanding the monitoring system for on-line history graphics

The actual modifications were made within task 3 (see paragraph 3.3). Two additional duration tests were conducted to determine the results of the modifications. For the downdraft gasifier this test was conducted after all automization work was completed.

The experimental work on SGF pre-treatment and production plant proved that different types of SGF-briquettes, based on different biomass material (red wood, thinning wood, straw and miscanthus), could be produced. No major technical constraints or limitations were encountered. In addition, these SGF-briquettes could be successfully carbonised. The most critical issue is fine-tuning of the operational conditions of the briquetting extrusion press. More research is needed to understand the physical phenomena of this process and find the optimal conditions for each material.

Centralised production costs of uncarbonised SGF-briquettes were determined at about 42 EUR/tonne. Production and gasification of uncarbonised SGF is only feasible when applying specific waste streams like contaminated wood or other residual materials which have a strong negative purchase price. Gasification of uncarbonised SGF under base case conditions results in a required feed-in tariff of 16.3 EUR ct/kWh. To get down to reasonable electricity sales prices of 7 to 10 EUR ct/kWh, an SGF fuel price in the range of -25 to +5 EUR/tonne is required. This corresponds to a raw material price between -45 and -25 EUR/tonne.

The production and gasification of carbonised SGF, is less attractive than the first route. The relatively cheap charcoal gasification system does not counterbalance the high base case production costs of 195 EUR/tonne. A electricity sales price of 20.6 EUR ct/kWh is required. To reach a required feed-in tariff between 7 and 10 EUR ct/kWh, the production costs of carbonised SGF have to decrease to -40-0 EUR/tonne, corresponding to raw material prices of -45 to -65 EUR/tonne.

Prospects

- The production costs of SGF needs to decline to make this pretreatment step attractive. This could be achieved by a value engineering study, and make use of cheap production facilities in developing countries and/or import cheap production equipment. Note: Briquetting facilities based on the Ekoblok procede are being constructed in China and Indonesia.
- Charcaol is nowadays considered as an appropriate fuel for power production. Even import from the Baltic States is seriously examined. This will undoubtfully lower the market price of charcoal in future, thereby making the carbonisation route more attractive.
- The SGF concept has shown that mixed biomass materials can be used as feedstock for gasifiers. This means that undefined raw materials for which no market exists yet can be useful converted into an energy carrier. Change in policy structures can stimulate the SGF concept.
- An attractive alternative for SGF briquettes is wood chips. Wood chips are easy available at (still) reasonable prices. Pelletizing might be another option but it si doubtful whether this can be used as fuel in high thermal conversion processes like a downdraft gasifier. Experiences so far with several pelletized materials showed that those pellets tends to desintegrate at high temperatures.

3.3 Development of fixed-bed gasifier

Involved partners: COM, BTG, FEE, task leader COM

3.3.1 Introduction

Different types of fixed bed gasifiers can be considered for small scale applications. All types of gasifiers have their specific advantages and disadvantages. None of these gasifiers meet the requirements to be set for automatic, reliable and flexible operation of gasifiers. Therefore, this task focusses on selecting the most promising type of gasifier and feeding system for the conditions formulated under system definition, and construction, installation, testing and evaluation of the selected fixed bed gasifier and feeding devices fuelled by SGF.

3.3.2 Findings

The major results of the work conducted is outlined below. More information is available from the end-of-task report.

The actual work concentrated on two main items:

- Inventory of existing small scale fixed bed gasifier at Europe
- Further development of promising existing technologies.

To identify suitable gasifiers for SGF, two actions were planned and conducted:

- Mailing of a questionnaire to collect data on different sections of a gasifier installation, (see Figure 3). Within task 1 also a questionnaire was prepared, based on which a preselection was made of interesting gasifier installations.
- Select suitable and different type of gasifiers available at project partners.

Conclusions of the inventory can be summarized as follows:

- All considered gasifiers and gasifier-systems where not reaching the commercial stage in the years 1996/97. Most of the gasifiers where in the stage of a pilot- or demonstration-plant.
- Only few experiences of using synthetic wood pellets as a fuel are available. Most of the tests where made with wood chips or other biomass.
- Nearly no gasifier system is known to perform long term tests via more than 1000 hrs. without any maintenance or interruption - therefore also not in a combination with a motor engine.

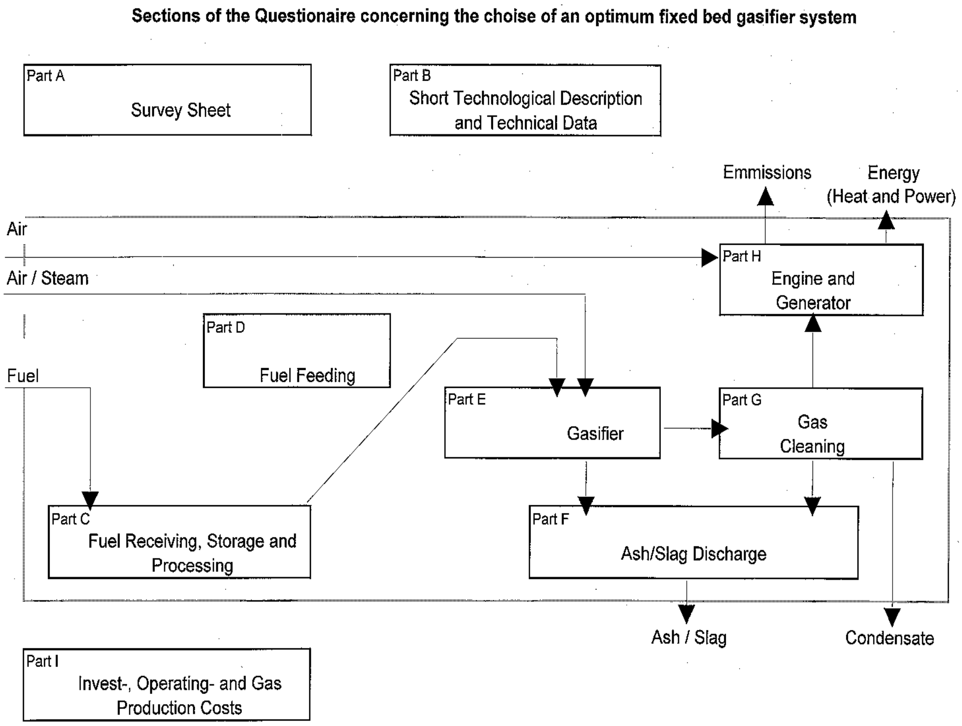


Figure 3: Different sections of a gasifier installation

- All known gasifiers are based on known designs. A complete new type of fixed bed gasifiers will probably not be developed in the next years.
- Subject of further development has to be the complete process line from the

<u>fuel</u> via <u>gasifier</u> via <u>gas cleaning</u> to the <u>power engine.</u>
Only the complete system and its interconnections is the basis for the commercial stage.

- The basic problem for further processing of the producer gases in a power engine is the content of high molecular hydrocarbons. The generation and possible ways of degeneration of hydrocarbons with regard to wood gasification is not completely examined today.
- Uniform and standard like methods of measurement of tar and dust where not available at the beginning of our project. Analytic values that are given in the inventory are not completely comparable because of different and partly unknown methods of sampling and analysis.

Analyses and evaluation of technical improvements

To analyse the technical improvements, first the basic situation needed to be defined. This was established within task 2 by conducting a duration test of 150 hours. Based on the long-term tests several technical improvements were formulated (see previous paragraph). The following actual improvements were realized on both systems.

Cross-draft gasifier:

- enlargement of the gas outlet diameter to lower the gas velocity at this point and therefore come to lower dust emissions from the gasifier (dust should fall down to the ash chamber);
- improvement of inside gas leading devices to reach a longer gas residence time inside the hot oxidation zone;
- separation of gasification air and secondary air for the burning chamber to come to a real and in this case higher thermal efficiency;
- installation of a new level indicator to reach a stable fuel level inside the gasifier;
- improvement of the ash discharge device.

After realisation of those improvements further short tests with different fuels and one 50 hour test with SGF was performed in November 1997. The representative test results compared with the 150 hour test can be summarized as follows:

		150 hr. test (1/97)	50 hr. test (11/97)
dust content	[mg/m³ i.N.]	1465	1195
tar content	[mg/m³ i.N.]	1120	855
phenols	[mg/m³ i.N.]	324	251
heating value	[kJ/ m³ i.N.]	3999	>4000

Down-draft gasifier

Based on the results of the duration test and identified technical improvements listed in the previous paragraph, several modifications were implemented. The following listing gives a complete overview of realised modifications, changes in operational procedures and the results of these changes:

- SGF briquettes were sized differently to investigate the allowable fuel size range. It appeared that the fuel size is most critically towards the throat diameter. Too large SGF results in not-complete carbonized material below the throat sectional area resulting in higher tar levels. There is almost no practical limitation regarding the smallest allowable size of SGF.
- The throat diameter was decreased to investigate the influence on tar production and fuel size. This was realised by inserting a metal throat from the top which could be changed easily. The influence on tar production was not significant. Since the metal material could not withstand the high gasification temperatures, this metal throat was removed and further test were conducted with the original throat design.
- The feeding system was improved by adding a fuel hopper, an infra-red controlled device to monitor if fuel is present on the belt conveyor and automatic control system. The angle of the hopper walls and of the belt conveyor appeared to be critical. Additional tests showed that the feeding system worked perfectly.

- The ash removal system, incl. removal frequency was adjusted. The ash grid was activated automatically when the pressure drop across the gasifier exceeds a pre-set value.
- A simple fuel level indicator was installed before the duration test was installed for controlling the fuel level in the gasifier. This device worked perfectly after its instalment.
- The baffle filter was improved for higher collection efficiency of particles. This device serves also as a spark arrestor for the downstream bag house filter.
- The fabric filter material was replaced with another material which can accept higher temperatures (max. up to 300 degrees C) and is more easy to clean. During the duration tests, back flushing was applied for filter cleaning. This method appeared to be cumbersome and expensive. With the new material mechanical cleaning is possible by means of a vibrating motor.
- A lambda sensor was installed in the engine exhaust to control the secondary air-valve. The oxygen level in the exhaust can be controlled at a pre-set value.
- A new gas/air mixing device was installed before the engine to improve the gas-air mixing. Moreover, the ignition timing of the engine was slightly adjusted for smooth operation. No back-fires happened afterwards.
- An oxygen sensor was installed in the main gas-line to monitor mal-functioning of the installation. For safety reasons, the plant can be shut-down at any pre-set value of the oxygen.
- The monitoring system was installed before the duration test and further improved afterwards for optimal operation of the whole plant from fuel feeding to electricity production.

After these modifications and the completion of all automatic control devices by TNO an additional duration test of three days was conducted. All main parameters were determined like at the first duration test. The findings of this additional duration test have been reported separately.

Although no major differences were found in temperature and pressure levels as well as the tar and dust content, the system operated more stable and all controls worked perfectly. Table 5 shows a comparison of main test results between the two duration tests. The most important finding was that the whole gasifier plant can **operate unmanned** which is one of the main targets of this project.

Table 5: Main results of the two duration tests

	First	Second	Unit
Average wood consumption	28.5	24.12	kg/h
Average air consumption	30	35.1	Nm^3/h
Average gasflow (w.b.)	75	71.0	Nm^3/h

Moisture content (w.b.)	12.5	12.5	%
Average load level	20	19.9	kW_e
Specific wood consumption	1.12	1.21	kg/kWh_e
Gas production	2.6	2.7	m^3/kg wood
Condensate production	?	0.04	l/kWh_e
Heating value wood	17.2	17.2	MJ/kg
Cold-gas efficiency	72.5	73.5	%
Engine efficiency	25.7	24.9	%
Overall efficiency	18.7	18.3	%

Further steps in the development of the gasifiers

Cross-draft gasifier

The long-term experience with the “VA130“ gasifier and the positive results of the technical improvements formed the basis for the development of the “VA300" and “VA1000" gasifiers. The realisation of this concept „VA300“ started in the end of 1998 and is now in the following stage:

- Feasibility study; basic design and detail design is ready for all units;
- Construction planning is ready;
- All permissions to drive the plant are given;
- Built up is prepared in a own plant side of VER near Dresden/ Germany;
- Start up with the first test runs at the end of 1999.

For the „VA1000“ a feasibility study is being prepared focussing on the following problems:

- chemical and thermodynamic modelling of the gasification process with the goal to increase overall efficiency;
- upscaling of the gasifier;
- high-performance flue gas treatment on the basis of industrial experience;
- input and output balance;
- complete automatisation;
- layout plan and safety concept.

Down-draft gasifier

Based on the results of this project two major new developments have been initiated to develop the current downdraft gasifier concept further and reach the stage of commercialisation.

In a Value Engineering Study, a design has been made for a 150 kWe gasifier installation based on the downdraft design with the main aim to operate the plant automatically and to reduce the capital cost investment to about 2000 ECU/kW electric, ex factory. Meanwhile the plant has been constructed and at present, the plant is being tested for about 500 hours in total. The test programme consists of three main parts:

- Operating the gasifier daily for approximately 8 hours during one week to determine the behaviour of the internal lining for thermal stresses.
- Operating the gasifier for approximately 100 hours continuous during the next week;
- Operating the gasifier for 200 hours continuously.

In a second project, a 400 kWe gasifier is being engineered at present. The plant will consist of a downdraft type gasifier, a thermal catalytic tar cracking reactor (reverse flow) and dry gas cleaning. After the engineering phase is completed in May 1999, the construction phase will start. It is expected that the first test with this gasifier will start by the end of 1999.

This 400 kWe unit will be scaled-up to 1 Mwe unit within the same engineering phase. Construction of the 1 MWe plant is pending based on financing.

The current 25 kWe pilot plant gasifier will remain available for additional tests for this specific and other projects. Two gas cleaning devices are planned so far for the pilot unit:

- Testing the Corona tar cracking reactor which is being developed within another Joule project;
- Testing the rotational particle separator (RPS) as tar and dust removal unit at high and low temperature. In this case, the gas cleaning system consist of two RPS units and a heat recovery system which makes it very simple.

3.4 Gas cleaning

Involved partners: INGE-H, BTG, RUG, COM, task leader INGE-H

3.4.1 Introduction

One major problem with combustion of producer gas in internal combustion engines is the gas quality, i.e. gas composition, calorific value, dust and tar content, impurities. Particularly the dust and tar content is important. Dust can be removed by cyclones, baghouse filters, ceramic filters, electrostatic filters, etc. Tar can be removed physically ("scrubbers") and/or chemically (thermal or catalytic cracking). In this task the most suitable gas cleaning device for use with the SGF gasifier/prime mover/generator unit will be identified based on technical, economic and environmental aspects.

3.4.2 Findings

Different gas cleaning technologies for small scale biomass gasifiers were evaluated and most suitable technologies selected for further testing. The testing work on three different gas cleaning devices (baghouse filter, the rotating particulate separator (RPS) and an activated carbon filter) has been completed.

Based on actual performance data from state-of-the-art cocurrent fixed bed gasifiers and the postulated gas quality for IC engines, gas cleaning systems should reach collection efficiencies of approximately 90% for both particles and heavy tars. However, there is a considerable uncertainty as to which level the contaminants can be accepted in the producer gas fed to the engine.

The most promising wet and dry gas cleaning systems have been evaluated for small scale and atmospheric cocurrent biomass gasifiers in a previous report. In this investigation, the following gas cleaning components are thoroughly tested under actual gasification conditions:

- Sand bed filter
- Wash tower
- Fabric filter
- Rotational particle separator
- Fixed bed tar adsorber.

The particle size distribution from two different fixed bed gasifiers has been found to be bimodal with submicron particle masses from 60 to 210 mg/Nm^3. All gas cleaning systems must have a certain collection efficiency for submicron particles since the acceptable particle content for satisfactory IC engine operation has been postulated as <50 mg/Nm^3.

The sand bed filter has been found as the most attractive gas cleaning system tested so far due to the high mean collection efficiencies for particles and tars of 86% and 73% respectively. A wash tower showed comparable particle collection as the sand bed filter, but the collection of organic contaminants was much lower. The low tar collection can possibly be attributed to the high operation temperature of the wash tower.

The investigated dry gas cleaning systems (fabric filter and the rotational particle separator RPS) exhibit comparable particle collection efficiencies as the sand bed filter. However much lower collection efficiencies for tar components were observed. The collection efficiency for heavy tars are in the range of 0% to 50% for the fabric filter and 30% to 60% in the RPS. Moreover, the heavy tar levels in the clean gas of the fabric filters can often be higher than in the raw gas. Dry gas cleaning systems require secondary measures (such as a fixed bed tar adsorber) to reduce the tar components to comparable levels as in the sand bed filter.

With a fixed bed-tar adsorber using lignite coke as a sorbent, a complete collection of PAH compounds has been observed at 80¡C and at ambient temperature. However, the estimated heavy tar collection at 80¡C is only approximately 50%.

All known fixed bed gasifier / IC engine systems generate condensates which must be treated before discharging them into the public waste water net. Hence, some test runs with the following waste water treatment systems has been made:

- UV induced wet oxidation with H_2O_2
- Catalytic wet oxidation with H_2O_2
- Adsorption on carbonaceous sorbents

The decontamination of the waste waters generated from state-of-the-art cocurrent gasifiers has mainly been made with UV induced wet oxidation and with adsorption on various coke sorbents. Both technologies have shown excellent results. Preliminary experiments have been made with catalytic wet oxidation. However, the investigated catalyst exhibited a low activity.

Based on the experimental data, an economic assessment has been made for a 1000 kW fixed bed gasifier with various combinations of gas cleaning and waste water treatment systems. The operating costs for gas cleaning and waste water treatment using state-of-the-art technology and a cost optimized disposal option vary between 0.035 and 0.08 ECU/kWhC,. However, the maximum acceptable operating costs for gas cleaning and waste water treatment from fixed bed gasifier / IC engine systems have been calculated as 0.050 ECU/kWh_{el}.

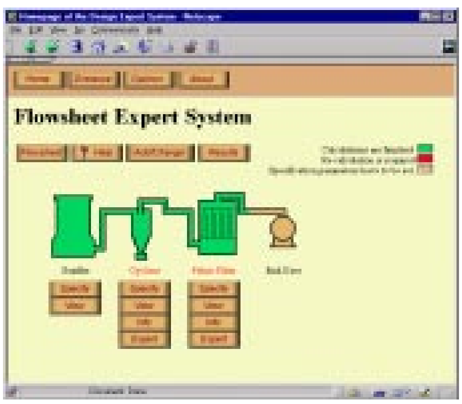
If all solid residues such as the tar loaden coke from a tar adsorber or the spent coke from the waste water treatment must be disposed as hazardous waste (instead of reusing it as an extra fuel in the gasifier), the operating costs of an integrated gas cleaning system will increase by 0.02 ECU/kWh_{el}, for the tar adsorber coke disposal and by 0.035 ECU/kWh_{el}, for the waste water coke disposal respectively. Hence, the cost for the disposal of the solid residues generated in the gas cleaning or waste water treatment has a high impact on the total operating costs of the gas cleaning and waste water treatment system.

The cost of waste water treatment are comparable to the cost for the gas cleaning as long as the phenol content in the' producer gas does not exceed approximately 100 mg/Nm^3.
Substantial efforts and improvements are necessary in gas cleaning and waste water treatment to reduce the operating costs and hence to make small scale biomass gasification based power gene rating systems more attractive. Improvements are required both for the collection of particles and tar components as well as for the operating costs.

Besides an evaluation study on gas cleaning devices and experimental work on the most promising technologies, an expert model for the evaluation of gas cleaning systems was prepared and published on an internet web-site. The expert system is programmed as a client/server application that is available on Internet at http://btg.ct.utwente.nl:8888/. Authorised users can access the expert system with an Internet browser.

The expert system contains five gas cleaning devices: a cyclone, a fabric filter, a ceramic filter, a venturi scrubber and a catalytic cracker. These devices are available through a flowsheeting package and an information package.

The flowsheeting package is a flexible means of comparing different gas cleaning systems. Up to five cleaning devices can be used. A user can carry out computations with the expert system using his own set of operation conditions (gas composition, temperature, pressure etc.). The effect of changing conditions can easily be investigated. With the flowsheeting package the user can get a fast insight in the characteristics of the chosen gas cleaning configuration.The information package contains a large amount of information, tips, experience data, literature references and hyperlinks to other interesting sites. This information is ordered per cleaning device. Hyperlinking with other Internet sites can be very valuable. An economic evaluation tool has been proposed, but not fully implemented. Vendor's data and quotations should to collected first.



3.4.3 Gas cleaning requirements

Gas engines

Application of wood gas in IC engines can give rise to a number of practical engine problems, which are mainly related to contaminations in the gas, such as tars, dust, soot and ash. However, there is little practical experience in testing the effect of tars in producer gas fueled engines. The very limited information available in this area are presented in this section.

In Table 6 values are given on the measured tar concentrations at the engine inlet manifold of six different gasifier/engine combinations. The table also provides acceptable and preferable tar concentrations usually quoted by engine manufacturers as guaranteeing normal operation and lifetime. From the engine oil analysis (engine oil metal content) it becomes clear that the presence of large tar quantities is extremely harmful to the engine. This is due to deposition of tarry “coke” on vital parts (valves, pistons) of the engine. It is therefore extremely important that the wood gas tar content is sufficiently low. Evidently, not all (commercial) gasifier/gas cleaning combinations are able to guarantee acceptable values. Tar and dust deposits on engine parts were also shown.

Table 6: Data on factors affecting life span of producer gas engines

Gasifier	Dust content mg/Nm^3	Tar content mg/Nm^3	Metal amount in engine oil
1	120-150	120-150	low
2	40-80	100-400	low
3	<5	<10	low
4	10-30	500-700	Medium
5	250-300	3000-4000	High
6	<100	1000-2000	High
Acceptable	<50	<100	
Preferable	<5	<50	

An assessment the engine wear and lifetime of some of the generator sets was made in the small scale biomass gasifier monitoring programme. Most of the lubricating oil analysis indicated reasonable to considerable engine wear. However, the effect could not be attributed solely to tar content. Particulates both in the producer gas and the ambient dust drawn in by the secondary air were blamed.

Parikh et al. described the effect of tar in engine applications where it could lead to rapid deterioration of lubricating oil and consequent abrasive and corrosive wear of the engine. In addition, deposit formation on combustion chamber walls, inlet passages, nozzle tip, valves, piston rings and grooves are not new to the users of producer gas for fueling I.C. engines. Piston ring sticking caused by deposits increases the blowby, i.e. flow of tarry gases past the piston to lubricationg oil sump, which deteriorates lube oil and results in corrosive and abrassive wear. Deposit formation on valves can result in abrupt stoppage of engine. Parikh also studied the effect of tars and particulates on the wear and maintenance of biomass-based producer-gas engine . They found that wear was higher by an order of magnitude and lubricating oils deteriorated faster than in the case of diesel operation.

In the 150 h duration test of the downdraft gasifier, tests of the resulting lubricating oil of the six cylinder water cooled Ford gas engine showed that:

- The viscosity of the oil increased about 10%;
- The amount of soot increased about 600%;
- The amount of iron, aluminium and copper increased from 0-1 to 80-180 mg/kg;
- The amount of silicon, tin and chrome increased from 0-1 to 20-50 mg/kg.

According to Hansen et al. a standard for tar based on engine operating experience can not be given currently by the engine manufacturers. There is insufficient as well as negative experience the manufacturers had with wood gas. A comparison of the engines with respect to tar content is not possible at the present status of development. To avoid deposition of tar components in engine inlet system, a small super heating of the mixture could be applied. Unfortunately, this will have an adverse effect on engine volumetric and thermal efficiency.

Ramackers and Heynis explained the effect of tar in gas engines. A high content of tar in the gas can cause problems because the tar will condense on the intake valve and ultimately squeeze off the engine. It can also clog up in the gas air mixer due to the change of pressure and temperature. Under normal engine running conditions, a certain concentration of tar is no real problem for the engine. The main problem with the tar occurs after stopping the engine. When the engine is cooling down, the tar can form a thick layer, not only in the intake manifold but also on the valve stem, etc. When the engine is restarted after a long period of cooling down, it could be impossible for the valve to go down on its valve stem. It is even sometimes possible that the piston touches the valve, resulting in bent valve stems, bent tappet rods or even damaged pistons, bent piston rods, etc.

Gas turbine

The main contaminants that can be carried over from the gasifier into the gas turbine were classified into three main categories, which with their main effects are:

- Tar which causes deposition and burn out (combustion efficiency);
- Particulates (char and ash): hot corrosion, erosion, and burn out;
- Alkali: hot corrosion.

The impact of these contaminants on both industrial and aircraft gas turbines has been discussed by Moses et al. (1993). The following problem areas were highlighted:

- Tars are a considerable part of the producer gas and thus, if not burnt out, they can contribute significantly to combustion inefficiency. But the lower flame temperatures in the combustion of low calorific value gases will make it more difficult for these compounds to completely burn out;

- Tar could condense out in critical areas such as valves, manifold, injectors which therefore, should be preheated before charging;
- The amount of allowable tar will depend on the machine and the firing temperature. Data and/or models of the burning times of char and tar at reduced flame temperatures are needed to establish upper limits on size and concentration;
- Other problems of tar that are more acute in liquid biomass fuels because of the higher concentration and the liquid phase of the fuel can occur especially where tar aerosols are formed. In the combustion chamber, if the tars are not burnt out in time. They will impinge on the walls or blades and form deposits, which will distort the flow. The tar may actually pyrolyse to form cenospheres, i.e., small particles of char, which can cause turbine blade erosion and exhaust particulates. Tar burn out will be more of a problem in aeroderivative combustors than industrial combustors because of the shorter residence time.

Tar components have a high potential risk to clog the fuel nozzle, and because of slow burning time, deposits on combustor walls should in general be avoided. The acceptable tar level entering the gas turbine combustion system will depend on the degree of producer gas superheating. If no superheating is applied, the acceptable tar level will be < 30 mg/Nm^3. If superheating is applied, a tar level up to more than 200 mg/Nm^3 will be acceptable. By conducting dew point calculations for a typical producer gas quality with different tar components, a prediction can be made of the dew points for a specific producer gas after a throttling process. It can be found that during the acceleration of the mixture, condensation will occur which can be avoided by reheating of the mixture.

Practical experience with gas turbines operating on producer gas

Although, gas turbines operating on coal derived producer gas have already accumulated many hours of operation and are almost fully available commercially, there is only limited experience with gas turbines operating on biomass derived producer gas.

In Sweden, a pressurized fluidised bed gasification plant was integrated with a 6 MW EGT Tornado gas turbine. So far the plant has not accumulated proper operation time yet. The plant was originally expected to start operation in 1993. In October 1995 when a test run with the gas turbine was conducted, a fire occurred resulting in considerable damage to the gas turbine. The fire occurred because of a leaking gas oil pipe. As far as is known, the gas turbine has not been operational since.

Due to the problems faced in determining gas cleaning requirements for prime movers it was decided to organize a meeting on this item. Together with the problem of determining tar content in producer gas, these topics were put on the agenda by INGE-H of the IEA meeting in Zurich, October 1997. A proposal was prepared for a concerted action to develop such standard tar measuring protocol.

In total this task on gas cleaning produced the following three reports:
1. Evaluation of gas cleaning technologies for small scale biomass gasifiers
2. Gas cleaning and waste water treatment for small scale biomass gasifiers
3. The design of a multimedia expert system for the evaluation of gas cleaning technologies.

3.5 Unit automation and control

Involved partners: TNO, BTG, COM, HYP, task leader TNO

3.5.1 Introduction

One of the main reasons for failures of demonstration projects has been the lack of low-cost automation systems and control. Therefore, in this task an automatic small scale fixed bed gasifier control system has been developed on the basis of cheap and reliable hard and software (sensors, activators, logical components), that has recently be come available as a spin-off of engine management in the automotive industry. In addition to controlling the system, the controller will be linked to a PC where Control and Data Acquisition system will be used to monitor the system and to record data for systems analysis. A modem link will be established with the developers so that remote data collection and analysis can be done.

3.5.2 Findings

The pilot downdraft gasifier was installed with all necessary monitoring equipment to determine the technical performance and establish mass and energy balances. The load level could be varied from 0 to 25 kWe by six steps. The hardware installed includes temperature sensors, pressure sensors, a level indicator and oxygen sensors in the cold producer gas and in the exhaust gas. The control system has been implemented in a software package called DasyLab, which has both data aquisition and control functions. The core of the program is formed by four items:

- safe guard (pressure drop/oxygen control producer gas);
- auto-fuel;
- ash removal;
- engine oxygen control.

The Control & Instrumentation diagram of the downdraft pilot gasifier is shown in Figure 4. Figure 5 shows the user interface which is explained in detail in the user manual.

In November 1998, the second duration test of three-days was carried out in order to evaluate the performance of the control system. It was tried to run fully automatically after starting the process manually. During the test several process parameters were recorded. Details can be found in the end-of-task report. Only the main results are given in this section.

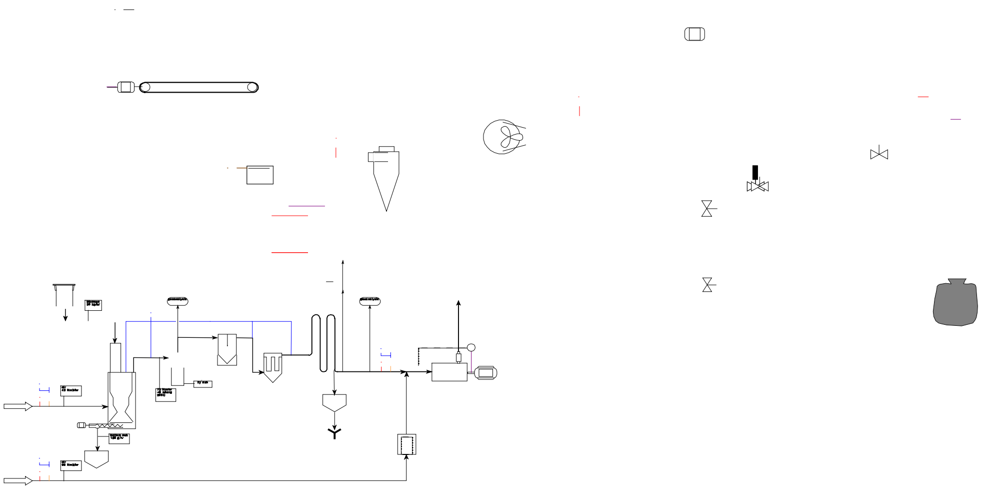


Figure 4: Control & instrumentation diagram of the downdraft pilot gasifier

Test results of the automatic fuel supply system showed that the fuel supply system has enough capacity to fill the gasifier during operation. In Figure 6 test results of the grid move automation system are shown. In this plot the pressure drop over the gasifier and the bag filter as well as the grid shake control are plotted as a function of time. It can be seen that pressure drop over the bag filter increases gradually. Pressure drop over the gasifier, however, rises quickly. Each time the pressure drop over the gasifier exceeds 18 cm water column the grid is moved to and fro. After that, the pressure drop over the gasifier drops almost immediately.

The results of the secondary air valve control are shown in Figure 7. The desired oxygen concentration in the exhaust gas is set at 0.2 %. The sudden changes of air valve position are mainly caused by refuelling actions because additional air enters the gasifier via the fuelling valves. During the measurements the bag filter was back flushed. This is seen as big disturbances in the oxygen concentration. After the back flush procedure the oxygen concentration is rapidly controlled to the desired value again.

Figure 7 clearly shows the advantage of automatic control. If the air valve position was not changed during the time period shown in this figure the engine would have stalled. In the past, when no automatic control was applied, the valve was adjusted manually when the operator detected unstable engine running. However, it was not clear in what direction must be adjusted. Automatic control on the basis of oxygen concentration in the exhaust gas appears to be very effective.

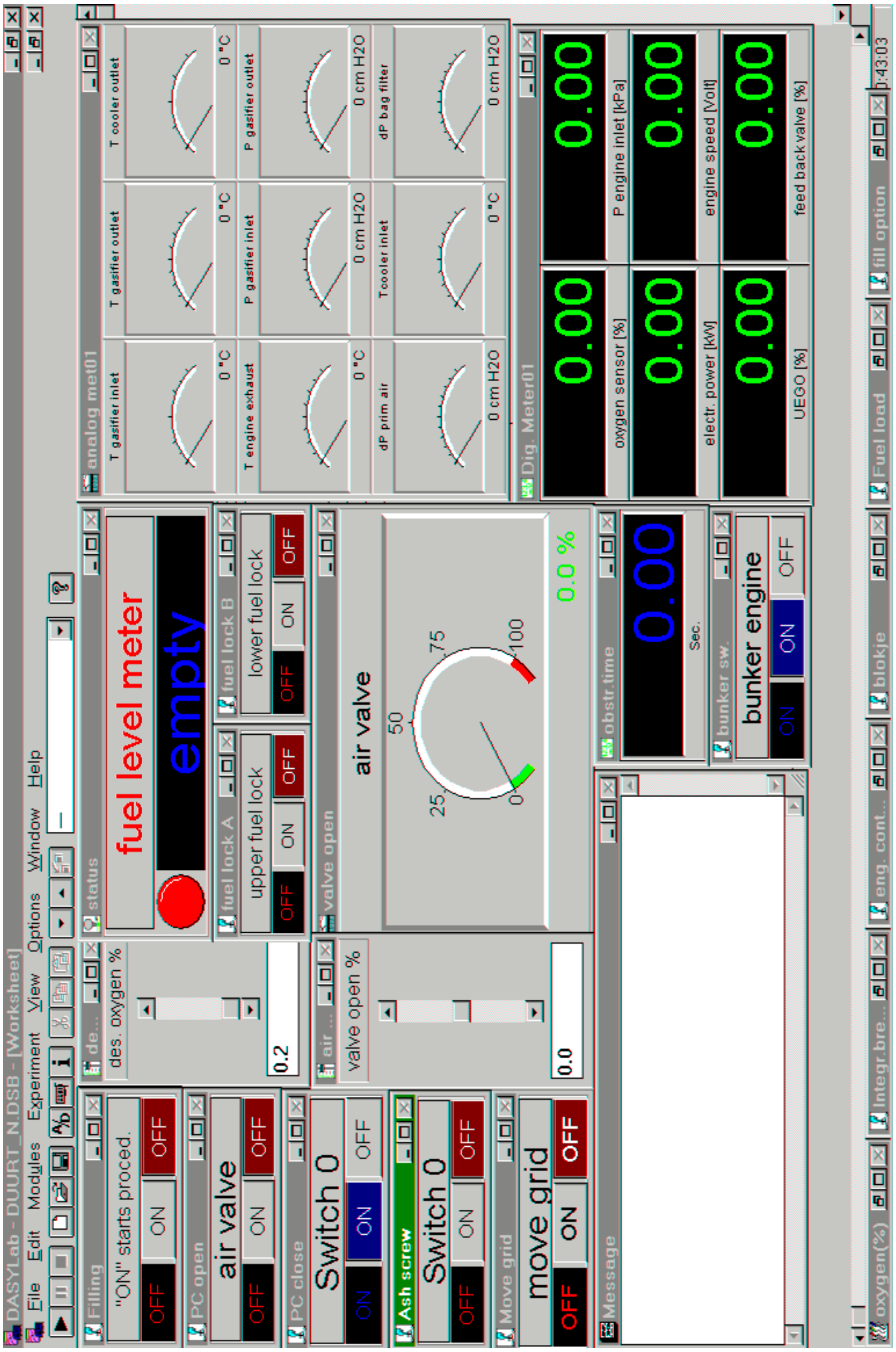


Figure 6: Results of the grid move automation system

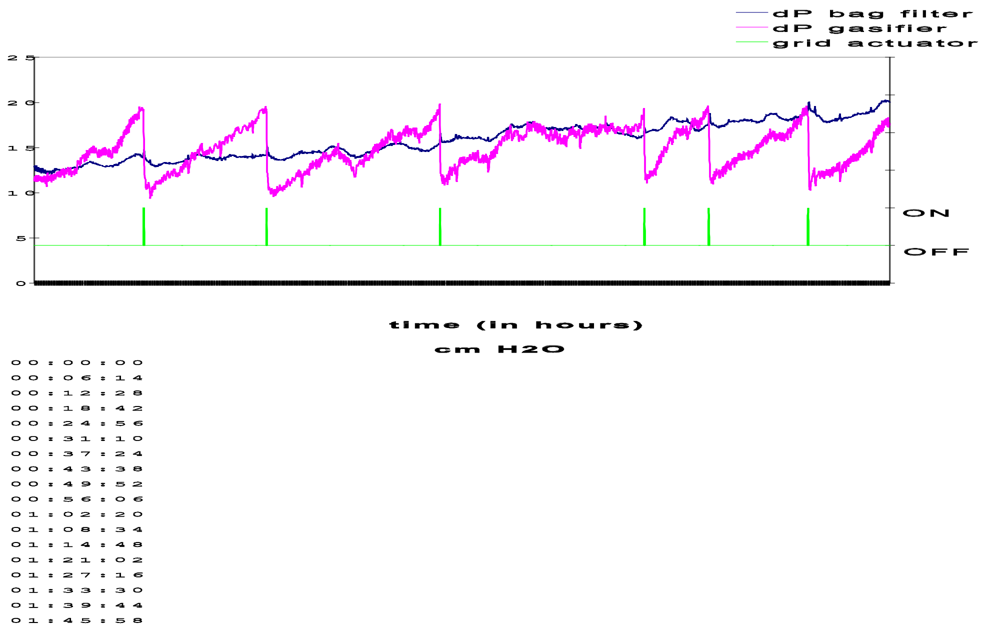
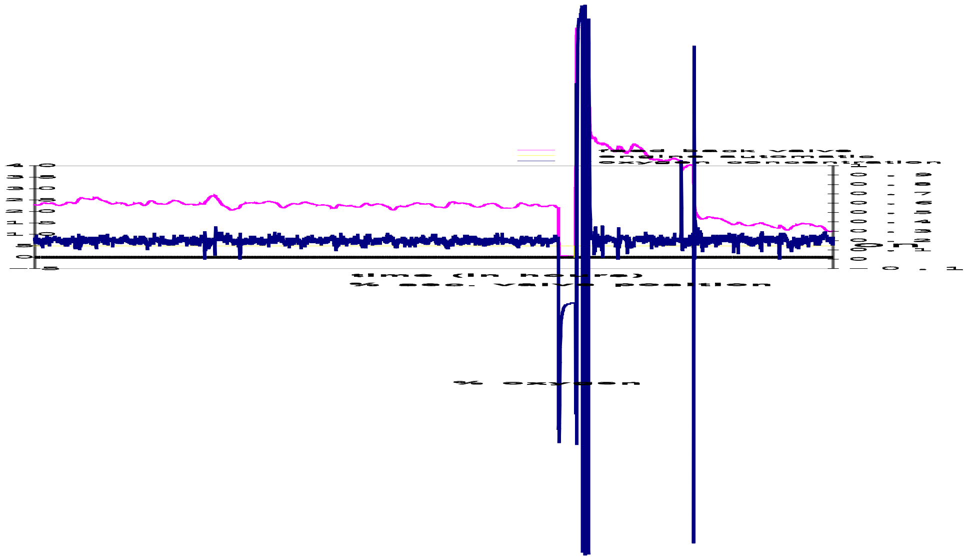


Figure 7: Result of the secondary air valve control



It can be concluded that the automation system successfully controls different tasks of the pilot gasification plant. The tasks that are automatically controlled cover:

- Supply of briquettes to the gasifier
- Ash removal
- Control of grid shaking
- Control of secondary air flow
- Monitoring of
  - pressure drop over gasifier
  - pressure drop over bag-filter

- temperature inlet bag-filter
- temperature cooler outlet
- oxygen concentration in producer gas and generating alarm if limits are exceeded

The role of Hyperion has been changed in the course of the project. Originally, their role was to develop a monitoring system for the gasifier installation. However, because of the duration test, which was added to the project workplan, this task was mainly carried out by BTG and German partners.

Hyperion’s role changed from the design of control systems to the commercial exploitation of the results. Hyperion has a broad experience in advising enterprises on strategy's for optimal use of R&D results for innovation and new commercial developments. Because a report on exploitation of project results must be prepared after completion of the R&D work (according to the General Conditions of the contract, see Annex 2 of the contract) all partners agreed with this change in the role of Hyperion. Also the scientific officer of the European Commission agreed with this change which has been described in a revised Technical Annex, which is the Annex 1 of the contract.

3.6 Prime Movers and Generators

Involved partners: DKT, BTG, EDON, TNO, FEE, COM, task leader DKT

3.6.1 Introduction

In this task the most suitable prime mover - generator will be identified to be used with the small scale fixed bed gasifier. Advantages and disadvantages of different prime movers will be investigated and possible problems of grid coupling addressed.

3.6.2 Findings

Gas Turbine or Engine

A review of gas turbines and reciprocating engines are presented. Recuperated gas turbines with efficiencies very close to 30 % will be available in the size from 50 kW to 1000 kW. Reciprocating engines are available with efficiencies from 30 to 38 % in the size from 50 to 1000 kW.

Conversion of a prime mover to wood gas operation is possible with minor modifications to the fuel handling system. Considering gas turbines a wood gas with high hydrogen content is preferred. Further more it's preferable to operate the gasification unit under pressure to reduce wood gas down stream compression when gas turbines is applied.

Producer gas quality is essential for reliable prime mover operation. It seems hard to fulfil prime mover producers fuel quality requirement for maximum allowable tar content, see also previous paragraph. It's not possible at the present to evaluate the relevants and importance of the very strict specifications of tar content in the gas put down by the engine manufactures.

Determination of the specifications of a dedicated prime mover for the SGF gasifier has been analysed. In the discussions with engine manufacturers it is clear that they can supply an engine for the product gas we have but that no guaranteees are given on the performance. All issues related to engine modifcations to this typical producer gas are known. The specifications are determined by the product gas generated and the engine manufacturer who desires a 'tar-free' gas. There are basically two type of engines:

1. cheap, robust, low-efficient, low-speed natural aspirated engines
2. expensive, modern, high-speed, turbocharged, lean-burn engines.

The first type of engines are more proven for producer gas. Such engine is applied in several gasification plants in f.i. China.

The second type of engines is considered as more appropriate due to the higher efficiencies. However, there is no experience with these engines on producer gas. Therefore the (financial) risk is higher. A third option is the use of second hand engines

So, basically, all type of engines can be used. Therefore, determine the specifications of an engine can only be treated in a general way. You can mention all issues regarding possible adaptations etc. but not exact determine which engine should be used. In the discussions with engine suppliers like Jenbacher, Waukesha and Caterpillar, they are willing to supply an engine, but no guarantees as said.

Some important parameters on gas quality specifications are listed in Table 7.

Table 7: Gas quality specifications

	Gasturbine	Engine
Electrical efficiency	25 - 30%	30 - 38%
Gas quality	High H_2 content in gas is preferable	ok
Particulates in gas	< 4 mg/m^3	<1-5 mg/m^3
Tar in gas	< 10 mg/m^3 (no limits with superheating of gas , >250 ^{o}C)	0 ? (superheating is not relevant for engines)

Emission of NO_X is expected to be lower than the emission produced by natural gas but CO emission will properly be higher.

The natural next step will be to carry out a long term duration test of a prime mover (reciprocating engine) with wood gas.

The interest from produces of gas turbines and reciprocating engines in converting for wood gas operation is very modest. Therefore it's very difficult to get seriously discussions with engine producers.

Generator

The most suitable generator for wood gas co-generation in the range 100 kWe up to 2500 kWe with wood gas engines is the brushless synchronous generator conformable to IEC 34-1.

For parallel operation with the local grid these generators are quite simple, robust and economical. The serial fabricated industrial standard generators have a long lifetime. The standard generators are cheap and reliable.

In comparison with a natural gas engine, a wood gas engine shows a shorter combustion and therefor a stronger torque pulsation on the shaft of the prime mover. These are the normal torque pulsations forced by the pistons of the engine. A second phenomenon is the possible misfiring and disturbed combustion caused by poor fuel mixtures. In the Netherlands there is good experience with natural gas engine co-generating stability with biogas from sewage. Nevertheless it can be necessary to pay attention by calculating the mechanical and electrical power swinging stability caused by unrest and resonance by system amplification of the oscillations. With wood gas engines one can expect the same electrotechnical experience as for the natural gas applications. Therefore it is logical to choose the same standard industrial synchronous generators.

For gas engines and gas turbines co-generation power from 1 MWe and higher, special terms do exist for power controlling and frequency supporting in case the grid will be out of balance and strongly disturbed.

Recommendation:
Due to the higher electrical efficiency of engines, and the problems associated with compression of fuel gas, we recommend the use of engines.

For the smallest engines (50-150kW) we recommend a stoichiometric naturally aspirating engine. For bigger units we recommend a lean-burn engine with turbo-charger.

It is recommended to increase the research especially in the following fields:

- The acceptable dust level in the producer gas (compare dust level that enters a producer gas engine with dust level that slips through the air filter of a conventional engine).
- The importance of the tar content and the acceptable levels, focusing on measuring the tar droplets and the condensation potential instead of gaseous tar components, because droplets are the real problem.
- Application of turbocharging on producer gas engines.

3.7 Design of an integrated demonstration system

Involved partners: all

3.7.1 Introduction

The aim of this task is to prepare a design package for a combined heat and power gasifier demonstration system in the capacity range of 100- 2000 kWe. Based on the previous tasks, an integrated demonstration gasification unit had to be designed within this final task. A financial assessment has been made for both units as well as identification of project location, application (input-output) and financing support structure policy. The final sub-task was to prepare a project proposal (incl. design, basic engineering and financing) for demonstration systems for a specific location and application in each of the participating countries. To avoid the need to prepare five proposals, it was agreed to use a sensitivity analyses to determine the market potential in each participating country.

3.7.2 Findings

For the crossdraft and downdraft gasifier, a scaled-up version was designed as a demonstration plant. Results of the previous task on the main system components were used in the design as far as appropriate, i.e. due to the difference in design of both gasifier reactors, the gas cleaning section is different. For both gasifiers full details on the designs are available in two separate documents:

1. Design of integrated demonstration systems; Subtask: Cross-current gasifier of the VER Verwertung und Entsorgung von Reststoffen GmbH.
2. Preliminary design package for a combined heat and power fixed bed gasifier system.

Because of the detailed information these documents are highly confidential.

The main components of both systems are summarized in Table 8.

Table 8: Main components of both gasifiers

	Crossdraft	Downdraft
Capacity (kW fuel input)	559	1000
Fuel supply	conveyor, lock hopper	conveyor , lock hopper
Reactor	crossdraft	downdraft
Gas cleaning	cyclone air-cooler oil washing system	cyclone baffle filter baghouse filter
Gasengine	Deutz, natural aspirated	Hongyan, natural aspirated
Automation	fully	fully

Summarized technical data are listen in Table 9.

Table 9: Main technical data

Performance item	downdraft	crossdraft	unit
Capacity	232	103	kW_{el}
Actual gas flow	588	317	Nm^3/hr
Gasifier cold efficiency	80%	66	%
Fuel intake	209	111	kg/hr
Net thermal input	1000	559	kW_{th}
Gross electric efficiency	23.2	27.6	%
Gas heating value	4100	4180	KJ/Nm^3

3.7.3 Potential locations

To determine potential locations it is of great importance to have access to information about the heat demand of different kinds of industries and other possible users of heat. Energy distributing companies have good insight in the heat demand in their regions. In several locations, the bigger heat consumers use nowadays the heat from a CHP to fulfil their basic demand of heat. Gasifiers in combination with Combined Heat and Power generators (CHP) can be installed in those cases. Delivery of both heath and power against a reasonable price is necesary to make the exploitation of the gasifier financially interesting.

A potential location has to fulfil a series of requirements, of which the main items are:

- The basic heat demand should be sufficient and almost constant during the year;
- Daily differences in heat demand can be regulated by a heat buffer;
- Attention should be taken with local noise regulations regarding fuel preparation and transport;
- Sufficient space for biomass storage, gasifier and the CHP unit;
- The capacity of public electricity network should be sufficient;
- The installation should be located as near as possible to the heat demand since transport of heat is expensive;
- Exhaust gases of a CHP should fulfil the local standards, which will be given in the community health and environmental regulations;
- The handling of biomass fuel can produce dust and odors; also given in the community health and environmental regulations.

Heat consumers can be differentiated in the following groups:

- Glasshouses;
- Hospitals, nursing- and rest homes;
- Sports halls and swimming pools;
- Obsolete existing biomass heating plants;
- Rural villages not connected to the grid;

- Retrofitting fossil fuel-fired heating plants;
- Process industry.

Future users of biomass gasification systems will come from different market groups. Countries with a progressive to renewable energies policy (Netherlands, Germany, Denmark), state-owned, big private and communal energy supplying enterprises might introduce biomass gasification systems for CHP. In countries where an abundant potential of residue-, waste- and demolition-wood is available (Denmark, Germany) main application is to be expected in commercial enterprises, in some communities and in agriculture. Also in the medium term a stable and growing market for small scale biomass gasification is to be expected. At the moment in all coountries involved in this project, at least one gasifier is in operation while several others are planned.

Many investigations are available on national and/or European policy regarding bioenergy production/utilization. However, a coherent programme on biomass doesn't exists as part of a comprehensive strategy on renewable energy, although in some regions or countries various programmes or plans for the promotion of bioenergy have been designed. Hence, national political conditions are rather different, partially pushing biomass utilization forward, partially obstacling the utilization.

Due to the White Paper adopted by the European Commission by the end of the year 1997 aimed at doubling the the share of renewable energies in the total energy demand to 12 % by the year 2010, an accleration of elaboration of national and regional programmes is to be expected.

The building and use of installations is regulated by governmental legislation. Permits are needed and sometimes special research reports should be made before a permit can be given, mostly to prove that an installation can fulfil the prescriptions given by the permits. Permits for the building and use of a biomass powered CHP installation are needed for different subjects:

- Building permit;
- Environmental permit/nuisance act;
- Permit to drain off sewage water.

The city council is the first administration to contact to start the procedures for obtaining permits. The time needed to obtain all the permits is minimal six months, but not unusual up to one year.

3.7.4 Financial viability

In order to be economically effective the price for electricity in case of self-consumption has to be equal or below the tariff for power from the grid, in case of supplying to the grid costs are to be covered by remuneration. Costs for heat energy have to be also below the prices of competing heating systems of given local sites.

Prices are influenced by:

- investment costs (real estate, plant, construction, size of the plant, technology, capital),
- variable costs (fuel and other operational costs, labour, remuneration for electricity and heat, load, planification, permits, depreciation, inflation, waste treatment, demolition of the plant after end of operation)
- subsidies.

Generalized factors determining the economics of gasifiers include:

- sufficient availability of fuel for which a price for disposal or landfilling has to be paid (negative fuel price) or a more or less cost-free fuel,
- utilization of highly homogenuous fuel, like SGF, as an important factor for an undisturbed and continuous operation.
- self-supply of energy (as a rule, in almost all countries tariffs to be paid are higher than feed-in tariffs),
- sale of generated heat as high as possible,
- high uninterrupted energy production,
- automatic and almost unmanned operation.

In the end-of-task report of this task 7 an economic evaluation is made of a 1 MW fuel input CHP wood gasifier installation for a client were the biomass raw material price and the feed-in tariffs are known. The internal rate of return (IRR), net present value (NPV) and the payback period (PBP) has been calculated. A sensitivity analyses was performed to determine the conditions under which a demonstration plant becomes feasible. Parameters investigated are fuel price, electricity and heat sales price, investment costs, and labor costs. For the base the following parameters were used:

Table 10: General data for the base case

Base currency	ECU	
Investment	2500	ECU/kWe
Labor input	13	manmonth/year
Fuel price	0	ECU/ton
Net electrical efficiency	23.2	%
Sales price		
- electricity	0.068	ECU/kWh
- heat	3.62	ECU/GJ
Operating hours per year	7469	
Discount factor	10%	
Interest rate	6%	
Inflation	4%	
Depreciation method	Linear	
Construction period	1	years
Rated net output	232	kWe
	464	kWth
Project lifetime	15	years

The results are shown on the next two pages. The calculated IRR of almost 8% justifies a project in this case. Based on the graphs the viability of any project can be analysed when the investment costs, feed-in prices, fuel prices are known.

For demonstrations of one or both gasifiers it is desired to set-up a consortium with at least a technology supplier and an end-user. Financial support is desired to cover the risks in such project.

3.7.5 Project proposals and spin-offs

Separate proposals have been prepared for demonstration of the crossdraft and the downdraft gasifier. Within the 5th framework of the European Commission two proposals were submitted as a follow-up of this project. The first one is a 400 kWe demonstration plant at a horticulture company in the Netherlands. This unit will incorporate a thermal catalytic tar cracker which was developed within another Joule project. A consortium is arranged and the pre-engineering completed. A modern, high-speed, turbocharged engine from Jenbacher will be applied. Construction of the plant is planned for October 1999.

In the course of this project a 150 kWe scaled-up version of the downdraft gasifier has been realized. This design incorporates a robust, low-speed engine made in China and components developed within this project like the automation system and controls. The system is currently tested and will be installed in a commercial setting in October 1999. The project is supported by Shell International Renewables and Novem.

As mentioned under 2.4, a meeting was organized in Zurich on gas quality specifications and tolerances of engines towards impurities. A separate project was started to develop a standard tar measuring protocol. Several partners in this part took part in the other project. Based on this spin-off activity a project proposal has been prepared and submitted to the fifth framework programme of the European Commission. Within this concerted action, several partners of this project are involved.

Another spin-off is a project on the inventory of gasifier installations and manufacturers. This project will result in a worldwide overview of installations and manufacturers. Information will be distributed on a internet web-page: www.gasifiers.org. This project is financed by the Thermie programme of the European Commission. This "internet" project is approved as a direct positive result on the multimedia model on the evaluation of gas cleaning systems which is also available on internet.

Two other 'internet' projects are under preparation. One on setting up a gasification network and one on the evaluation of complete gasifier installations as a follow-up of the multimedia model on the evaluation of gas cleaning systems. Details can be found in the end-of-task report.

4 COMPARISON OF PLANNED ACTIVITIES AND ACTUAL WORK

The project consists of the following seven tasks, each consisting of a number of work packages or sub-tasks:
Task 1: System definition
Task 2: Fuel (pre)treatment and fuel production
Task 3: Fixed bed gasifier development and (automatic) feeding
Task 4: Gas cleaning
Task 5: Unit automation and control
Task 6: Prime movers and generators
Task 7: Design of integrated demonstration systems.

Although during the project faced a number of serious problems endangering the accomplishment of the objectives, all deliverables have been covered. The aim of the project was to complete the design of a demonstration plant which will be part of demonstration project proposals. With the realisation of at least one commercial demonstration plant, the project outcome has moved beyond that goal. Moreover, several additional activities were conducted to fulfil the objectives successfully, including:

- duration tests
- construction of 150 kW gasifier
- expert system on Internet
- waste water treatment tests
- development of an uniform test protocol.

Although a 150 hours duration test was not originally planned, it effected a major push forward to the development of the CHP gasifier system. Also the development of an uniform test protocol, including for tar and particulate determination is internationally reckoned.

Instead of five separate proposals, a sensitivity analyses was used to determine the market potential in each participating country.

Some alternations were implemented compared to the original workplan:

- The changing role of Hyperion as mentioned in paragraph 3.5
- The withdrawal of one industrial partner of which the project tasks were taken over by two other project partners
- The technical annex with the workplan was revised twice during the project as a result of the above two items.

The main technical deliverables are:

1. Experimental briquetting plant able to produce briquettes from different types of biomass raw materials.
2. Carbonisation plant at laboratory scale able to produce carbonised SGF and pyrolysis gas/oil.

3. Four different types of gasifiers able to operate on SGF.
4. Automatic control system.

The following reports are available:

1 Duration performance test of a LQV-Gasifier on SGF (Feb. 1997)
2 Duration test SGF, DTU two-stage gasifier (Jan. 1997)
3 Duration test report, Application of SGF in the KARA gasifier system (July 1997)
4 Final report on Task 1 *System Definition* (April 1999)
5 Evaluation of drying technologies for drying biomass feedstock for SGF production (May 1998)
6 Evaluation of carbonization technologies (March 1999)
7 Evaluation of the suitability of SGF in different fixed bed gasifier designs (Nov. 1988)
8 Evaluation of gasifying carbonized and uncarbonized SGF (March 1999)
9 Carbonization of biomass briquettes (July 1997)
10 The design of a multimedia expert system for the evaluation of gas cleaning technologies (August 1998)
11 Manual for the multimedia expert system to evaluate gas cleaning systems (August 1998)
12 Final report on task 2 *Fuel pretreatment and SGF production* (April 1999)
13 Final report on task 3 *Fixed bed gasifier development* (March 1999)
14 Final report on task 4 *Evaluation of gas cleaning technologies for small scale biomass gasifiers* (July 1997)
15 Final report on task 4 *Gas cleaning and waste water treatment for small scale biomass gasifiers* (Sept. 1998)
16 Final report on task 5 *Development of a control system for automatic gasifier operation* (April 1999)
17 User Manual Process control system of fixed bed gasifier system in Almelo (Feb. 1999)
18 Duration test report on automated wood gasification (Jan. 1999)
19 Final report on task 6 *Prime Mover for SGF producer gas operation* (Dec. 1998)
20 Preliminary design package for a combined heat and power fixed bed gasifier system.
21 Design of integrated demonstration systems; Subtask: Cross-current gasifier of the VER Verwertung und Entsorgung von Reststoffen GmbH.
22 Final report on task 7 *Design of integrated demonstration systems*
23 Six reports on progress meetings, mid-term assessment report, three annual reports
24 Final report (July 1999)
26 Technology Implementation Plan (May 1999).

5. CONCLUSIONS

Gasification is an evolving business and the technology is not yet commercially mature. Like all new business its commercial maturity must consider technical issues, financial issues, legal issues, environmental legislation and its potential social impact. This project has increased the state of the art of gasification systems and has identified the next ‘steps’ in the evolving gasification business.

With the completion of this report all deliverables have been covered.. The aim of the project was to design a demonstration CHP gasifier plant. With the realisation of at least one demonstration plant the project outcome moved beyond its goal. Moreover, several **additional** activities were conducted to fulfil the objectives successfully, including:

- four duration tests
- construction of a 150 kWe gasifier
- interactive multimedia model on Internet
- waste water treatment tests
- development of an uniform test protocol.

Several spin-off activities were initiated based on this project which resulted in at least four project proposals while several others are under preparation. This report has identified the different exploitable results, the different routes for exploitation and the different sources if funding which will be accessed. Even as we write this report several of the results are being exploited in accordance with the plan.

The success of this project will ultimately be judged on its contribution to the demonstration of gasification systems and its contribution to the development of standards and guidelines for the gasifcation business.The nature of the partners business activities will guarantee the success of this exploitation.5.0.1