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2.6 Processi idrici e termochimici

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TECHNICAL AND ECONOMIC ASPECTS OF BIOMASS GASIFICATION FOR ELECTRICITY GENERATION IN AGRICULTURE

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ABSTRACT

The paper reports on a protracted performance test run with a medium-power (33 kVA) gasificator - generating set to assess the technical and operating feasibility of this technology for farming purposes. A wood-fuelled gasifier feeding a generating set was laboratory-tested for three months and then installed in a Po-Valley cattle farm and operated under variable conditions.

A form was prepared for the operating personnel to record daily such key parameters as biomass characteristics and consumption; process effluents; power output and use; repairs and maintenance.

While the technical parameters indicate good efficiency and reliability, the economy of the plant, according to the Net Present Value method, shows that a positive economic balance is achieved only by cogeneration and with full utilization of output heat.

1. FOREWORD

A great deal of research has been carried out recently on the use of renewable energy sources. Among these, woodwaste gasification has attracted growing attention, and several attempts were made in Europe for the commercial production of gasification units essentially designed for electricity generation (Table 1).

Indeed, numerous analyses prove that the energy content of the mostly untapped stock of ligno-cellulosic byproducts is quite significant, while experimental tests have yielded positive indications on the technical aspects of this process.

Such positive indications are confirmed by the results reported here of a test campaign with a German-made Fritz-Werner plant (Fig. 1). However, although no significant technical problems occur, it appears from the economic aspects of the gasification process, which are analyzed in detail by the Net Present Value (NPV) method, that the available energy should be fully used to make this process competitive against conventional energy.

2. EXPERIMENTAL TESTS

The test campaign was subdivided into two stages: in the first, the trend of the main operational parameters (fuel and output gas characteristics, gasification efficiency, total conversion efficiency, etc.) was determined; in the second, the complete process cycle was evaluated from the viewpoint of energy and economy, taking into account all the parameters and relevant operations (byproduct recovery and conversion into electricity, coverage of energy demand, long-term global efficiency, economic impact on the farm organization, etc.).

2.1 First Stage

The first stage was conducted with 7 kinds of agricultural byproducts. The results are given in Table 2. It was found that:

- The heat value of the gas varies from 3600 to 5500 kJ/Nm^3 (even during the same test) according to its chemical composition, i.e., to the gasification process;
- Specific fuel consumption attains 1.2 -1.3 kg "as is" per kWh when the plant runs close to full load (33 kVA), and increases to 1.6-2.7 kg/kWh at lower loads. When accounting for the different energy content of the test fuels, the global conversion efficiency (byproduct-to-electricity) ranges between 0.08 at 20% rated load and 0.20 at 85% rated load.
- The efficiency of the gasification process proper ranges between 0.7 and 0.8; with all the tested fuels, the specific gas production went from 1.9 to 2.8 Nm$_3$/kg fuel at 20% (w.b.) moisture content and with a loss of 5-10% unburnt carbon in the ashes.
- Fuel size (optimum value: 50 - 150 cm^3) and moisture (optimum <20% w.b.) are critical for proper plant operation. Gasification of briquetted or extruded byproducts posed problems due to rapid clogging of the bag filters.

2.2 Second Stage

The second stage of the test campaign was run on a grain-and-cattle farm in the Po Valley, whose crop pattern, some 100 ha of useful farming area and 150 dairy cattle, with free stabling and adjacent milking parlour, are typical of northern Italian farming.

The farm's direct energy consumption was recorded and broken down by type of energy and user point location (Fig. 2). The stationary user points were classed into

four groups: residential, animal husbandry, workshops, grain drying; the heat and electricity demand of each of them was then determined (Table 3).
In particular, animal husbandry requires an average daily outlay of 120-150 kWh electricity depending on the season, 105-140 kWh heat and 30-40 kWh of mechanical energy for feeding and grooming operations carried out by tractor-powered implements.
Since the farm facilities are clustered in two groups some 100 m away from each other and with two independent meters for grid electricity, and since the animal farming facilities account for more than one-half (55%) of total electricity consumption, the gasification plant was installed to serve these facilities only (approx. 50,000 kWh/yr = 135 kWh/day).
Feeding surplus energy back to the national grid was not considered, as it is scarcely attractive economically (surplus energy is bought back at roughly half the selling price) and poses technical and administrative problems.
From a qualitative point of view, all dairy cattle farms show a similar electric load curve, with peaks in correspondence with the milking operations; besides milking, also plant washing and milk cooling are to be accounted for.
Fig. 3 was drawn up from a large number of daily readings; it shows the qualitative pattern of the farm's electricity demand by main user points. The greatest demand occurs twice a day, from 2AM to 7AM (average consumption 50 kWh) and from 4PM to 8PM (average 40 kWh). Later in the morning and in early afternoon instead, demand is very low (12-15 kWh), mostly for cattle feeding and grooming. Fodder grinding also takes place in the afternoon every 2-3 days and requires 12-15 kWh.
Based on the electric load demand pattern and since - as proved in the first stage - the efficiency of biomass-electricity conversion depends on the load factor, the plant was put on stream late in the afternoon, for the

second milking (start up at 4PM, or at 2PM on fodder grinding days; shut off at 8PM). The electric demand for night milking was not considered, since plant maintenance and preparation, the skills and contractual duties of available labour, as well as the high cost of night overtime work, make this solution unfeasible from an organization point of view.

Table 4 shows the results of the second stage.

Daily average consumption was 85 kg of wood. With a specific consumption of 2.2 kg/kWh electricity, the plant covered the afternoon peak demand (40-55 kWh); plant output thus attained 8-12 kW, or 30-40% of rated power.

Long-term operation further showed that a proper energy balance should also take into account the charcoal fed every 2-3 days to the outer area of the gasificaion reactor's throat and the fuel smouldering in the gasifier after shutting off the plant at night and before starting in the morning (unproductive consumption). This means that, under the operating conditions described, 2.5 to 2.6 kg wood are needed per kWh electricity, and the actual conversion efficiency drops to 9-10%. The impact of unproductive consumption on efficiency is exalted because of the short running time per day; longer runs would reduce this impact, but an upper limit is set by the need to top up the charcoal in the outer area of the reactor's throat every 6 - 10 running hours.

It can be concluded that, to generate the 1800 kWh/yr roughly needed to meet the stables' afternoon electricity demand, the farm should have available some 3.5 t/yr of wood byproducts and 0.8 t/yr charcoal and dispose of some 0.7 t/yr of ashes.

Concurrent with the technical data, the relevant cost items (labour and materials) were obtained. The plant is run by one man, made available part-time by the farm.

Start up is a matter of 3 minutes; however, every 10 hours of operation the man in charge has to spend some 20 min on maintenance and inspection before start up. Some 12 min after starting up the reactor (onset of the

gasification process), the generating set can be switched on to deliver electric energy.
Extraordinary maintenance involved minor replacements or repairs (water pump of the gas scrubber, hydraulic jacks of the reactor baffle, electric accumulators, control board) but chiefly cleaning operations (engine spark plugs, butterfly valve of the lighting-off torch, bag filters). All in all, start up is the most critical stage, when most serious technical mishaps occur (the most frequent being undoubtedly condensate build-up on the spark plugs).

5. ECONOMIC EVALUATION

The profitability of generating electricity by woodwaste gasification was evaluated by the present cash flow method, using the net present value (NPV) as index.
Specifically, the operating costs were broken down into ordinary costs (fuel, lubricant, charcoal and routine maintenance) and extra costs. The former are directly related to the plant's normal operation and should be pro-rated to the hours of operation; the latter are correlated to running time and consequent component wear (filter and reactor repairs, engine overhauling). The income (energy production value) is calculated from the price of grid electricity and amount of generated energy.
Under the test conditions and with the parameters recorded during both test stages, with a plant cost of Lit. 70M (equal to Lit. 2.5M per kWh) and assuming 10 years' useful life and 8% interest rate, Table 5 shows that, against ordinary costs of Lit. 4200 per h and yearly extra costs ranging from Lit. 0.3M minimum to Lit. 7.9M maximum, the energy production value is approx. Lit. 1400 per h (Lit. 2.1M per year). Because of the consequent negative income, the NPV equals some -Lit. 108M. In other words, in the case in question, the

plant's profitability is hampered by the widening cost/income gap (Fig. 4); the situation worsens for longer yearly running times (Fig. 5).

This decidedly unfavourable situation was analyzed in greater detail by calculating the cash-flow items at the moment of investment. It can be seen (Table 5) that the ordinary costs attain Lit. 46M and account for no less than 82% of total (ordinary + extra) costs. The present-value ordinary costs further break down into fuel cost (Lit. 15.8M, for 31% of total), maintenance material cost (Lit. 15.1M, for 29%), and labour cost (Lit. 11.3M, for 22%). The incidence of the extra costs (Lit. 9.4M) is of the order of 18%.

Now, both maintenance material cost and extra costs couldn't hardly be reduced, for technical reasons; therefore, the only items available to improve the economic balance are labour costs, the cost of fuel at plant inlet and the load factor. A load factor of 0.75 and labour costs variable from nil to Lit. 20,000 per h are assumed in Fig. 6. The situation slightly improves, but the cost/income gap still widens.

On the other hand (Fig. 7), if labour is made available by reorganizing the farm's work after installing the plant, and its cost can be assumed as nil, the situation improves with lower fuel costs, although the NPV is still negative.

In fact, when fuel costs drop below Lit. 15 per kg, the NPV is still lower than the initial investment (Lit. 70M) in absolute value; this means that the cash flow, although globally positive (the cost/income gap tends to close), does not determine a net profit sufficient to pay back the initial investment at the assumed interest rate.

This analysis therefore shows that, under these test conditions, cutting down on every possible cost item and increasing energy output does not make this output competitive against grid energy because of the large initial cost of the plant.

This cost is of the order of Lit 24,000 - 28,000 per kg, and seems to be excessive, even when accounting for the complex construction (90 - 120 kg/rated kW) and small market, when compared to that of a generating set of equal rating (Lit. 13,000-16,000 per kg; 28-32 kg/rated kW).

By assuming that the present investment cost can be reduced by 40% and that labour is available at no cost, the NPV pattern is that, still negative, of Fig. 8. The economic balance is in the black only for a cogeneration system, and when all the energy output is utilized (Fig. 9). In this last case, if the initial cost of a plant made on a semi-industrial scale is Lit. 2.5M per kW inclusive of cogeneration and fuel is available at salvage cost (Lit. 35-45 per kg), the NPV turns positive when the plant runs longer than 3600 yearly hours and labour cost is nil.

6. CONCLUSION

The conclusions to be drawn from this test campaign with the Fritz-Werner gasification plant are:

- All in all, the plant is technically sound and reliable, although not fully automatic: occasional supervision is needed and might cause organization problems on the farm;
- The main problem to be solved for practical applications is that the plant's output should match energy demand. Solving this problem is the more difficult, the less uniform the load curve.
- From an economic angle, the results are undoubtedly negative under the test conditions- which represent real conditions in northern Italian farms- and at the state of the art. An attractive solution, once plant costs have been reduced by semi-industrial production, is cogeneration. It should be emphasized however that the profitability was calculated on the basis of the

mere selling price of a kWh from the national grid; when the true cost of a kWh from the grid is higher than its selling price, (ENEL calculates the cost of a rural electrification system composed of 2 km of medium-voltage lines, a pole-mounted transformer and 2.5 km of low-voltage lines serving 5 to 15 users to be around Lit. 100M), electricity generation by gasification can be a sensible alternative.

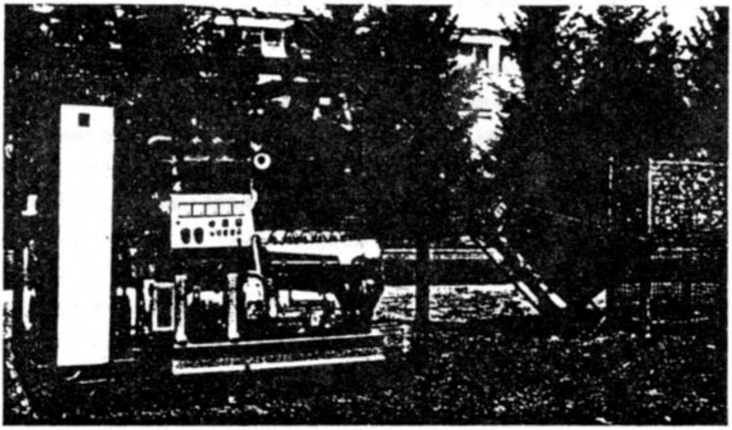

Fig. 1 - Down-draught gasifier for electricity production manufactured by Fritz-Werner; the electric generator rating power is 33 kVA

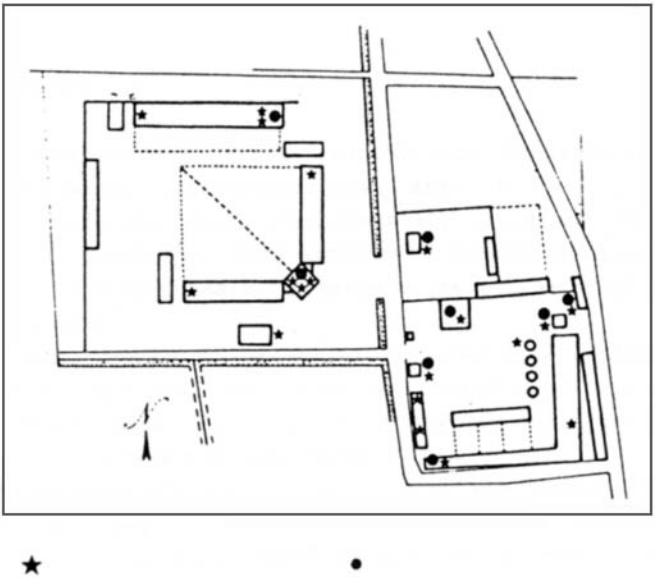

Fig. 2 - Dairy farm centre and energy user point layout

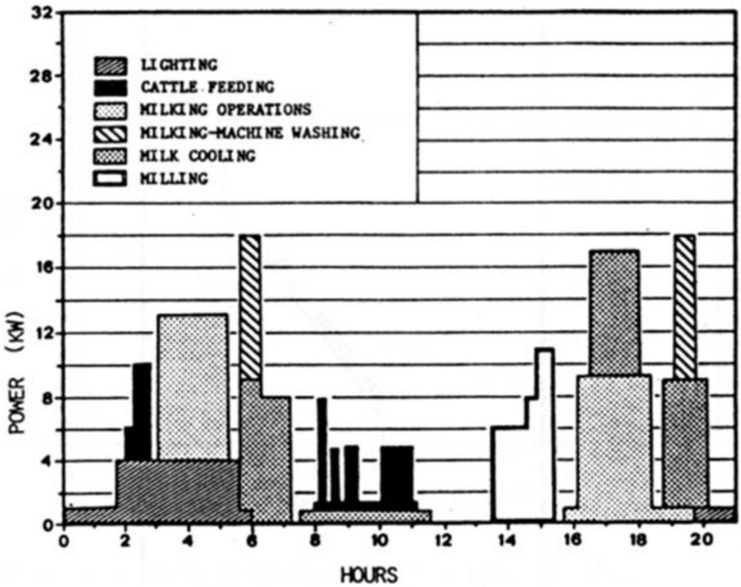

Fig. 3 - Daily electric power requirements by final user point

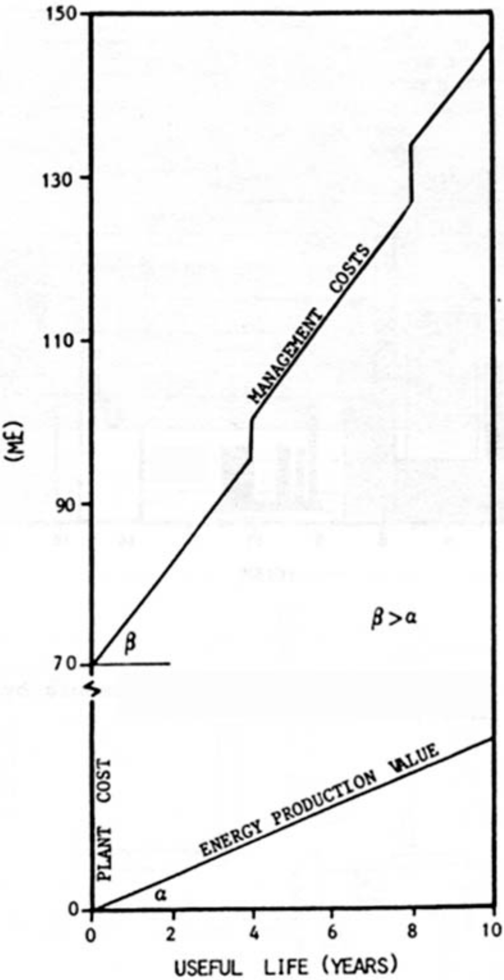

Fig. 4 - Cost-income diagram in the experimental conditions (plant cost: 70 MLit; fuel cost: 70 Lit/kg; manpower cost: 9000 Lit/h; load factor: 0.35; running time: 1500 h/year)

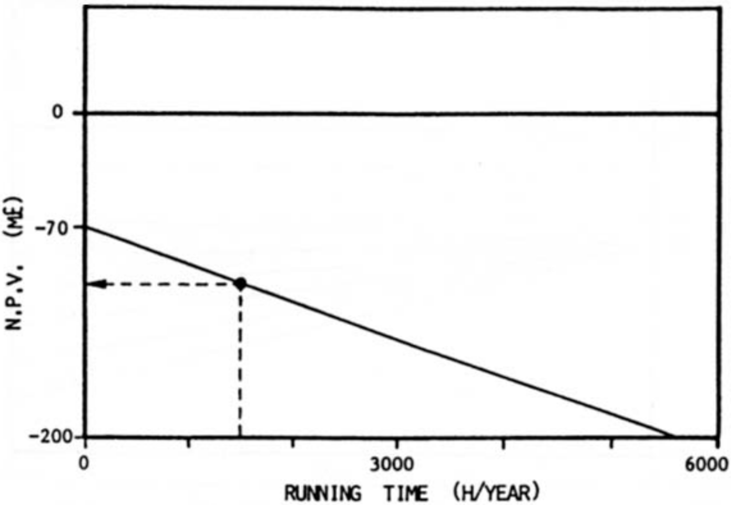

Fig. 5 - Plant NPV related to the running time in the experimental conditions

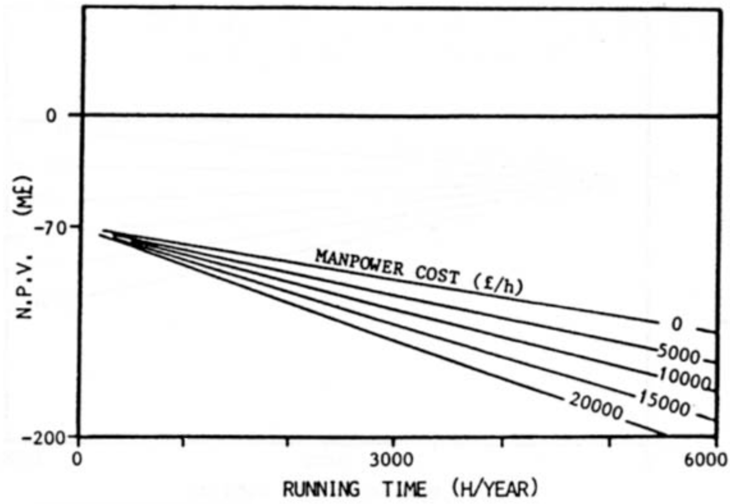

Fig. 6 - Plant NPV related to the running time for different manpower costs (plant cost: 70 MLit; fuel cost: 70 Lit/kg; load factor: 0.75

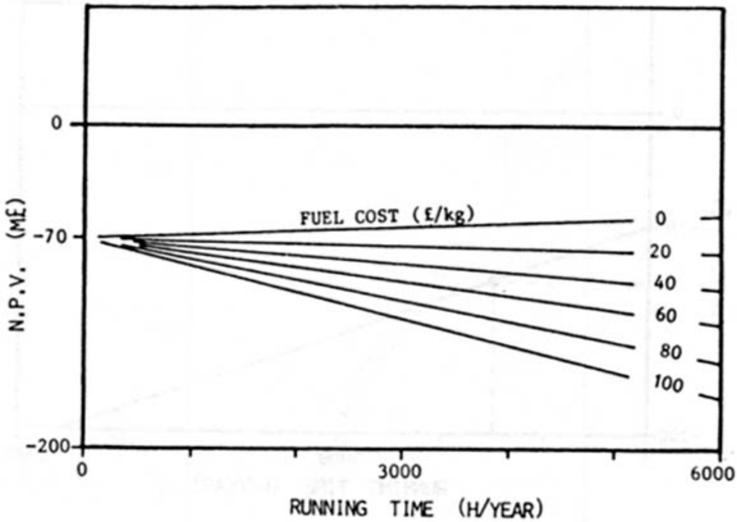

Fig. 7 - Plant NPV related to the running time for different fuel costs (plant cost: 70 MLit; manpower cost: 0 Lit/h; load factor: 0.75)

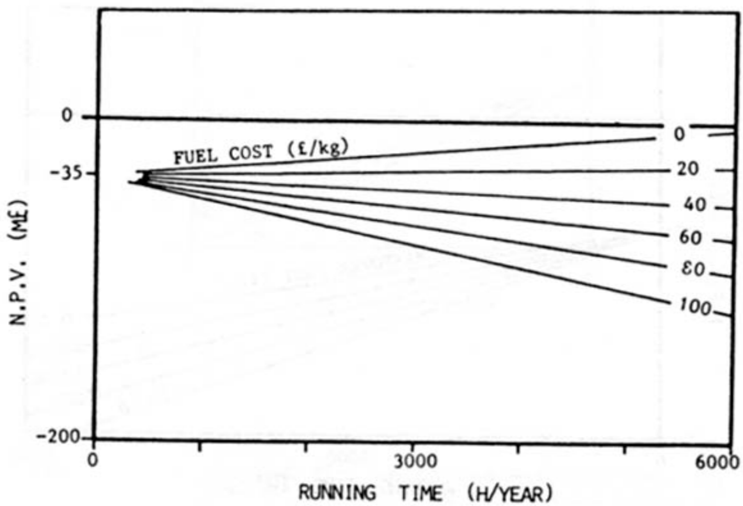

Fig. 8 - Plant NPV related to the running time for different fuel costs (plant cost: 35 MLit; manpower cost: 0 Lit/h; load factor: 0.75).

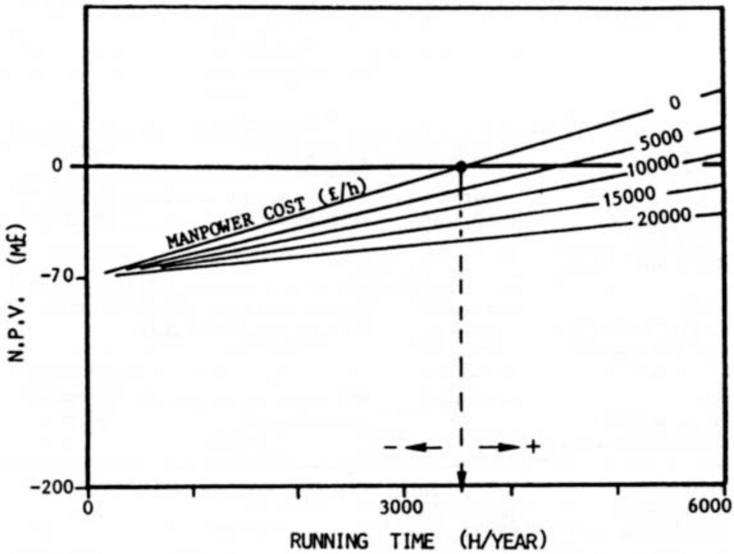

Fig. 9 - Plant NPV related to the running time for different manpower costs (plant cost including the co-generator device: 70 MLit; fuel cost: 40 Lit/kg; load factor: 0.75)

Table 1 - Gasification plants European manufacturers

ADDRESS	GASIFIER TYPE	UTILIZED FUEL	POWER
BECE Plesmanweg, 27 P.O. box 498 7600 Al Almelo (NL)	co-current and fluidized bed	charcoal, wood and agricultural waste, briquettes	2-15 kW 30-150 kW
B.E.S. Via Piani Madonna, 127 17017 Millesimo (I)	down-draught (twin feeding)	charcoal, wood chips, compres- sed fuels, agricultural waste	30-80 kW
CHEVET 40, Rue de Paris 77200 Croissy-Beaubourg (F)	down-draught	wood, cotton stalks, corn cobs, coconuts, waste	20-100 kW 25-200 kW
COPPEE-France 4, Rue Diderot 92156 Suresnes (F)	vertical reactor, gas recycling by Lacotte process	coke, coal, wood, charcoal	5-60 t/day
CREUSOT-LOIRE Division Energie 15, Rue Pasquier 75583 Paris Cedex 08 (F)	fixed kiln inclined (CEMAGREF lic.)	wood in logs (100 mm diameter and 300 mm lenght max), compressed fuel	1000 kW (av.)
DEL MONEGO P.zza Repubblica, 8 Milano (I)	down-draught	wood chips, agricultural waste corn cobs, sawdust briquettes	> 200 kW th.
K.H. DEUTZ Deutz-MülheimerStrasse Postfach 800509 5000 Köln 80 (D)	down-draft	any kind of lignocellulosic raw materials: wood, compressed agri- cultural waste	2 size: 100-200 kW
DUVANT B.P. 599 9, Rue H. Caffraux 59308 Valenciennes (F)	vertical with chamber using gas (Lacotte); horizontal with recycling gas (CREUSOT-LOIRE)	wood chips, coconut shells, waste, corn cobs wood chips, coconut shells and waste, compressed fuels	200-1200 kVA
E.E.E. P.O. Box 316 65, Eckboerstraat 570 Ah Oldenzaal (NL)	down-draught moving bed	every kind of organic waste products	2 sizes: 65-125 kW

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EVRARD 53, Av. Roi Albert 5520 Andenne (B)	down-draught, cracking device, water filtration system	all raw materials mineral fuels : anthracite, peat	20-120 kW
FRITZ WERNER Ind.Ausrüsteingen GmbH Postfach 1254 6222 Geisenheim (D)	down-draught	wood chips in size from 3 to 8 cm, moisture < 20%	7 sizes: 20-100 kW
GOHIN POULENC Cie 13, Av. du Dc. A. Netter 75580 Paris Cedex 12 (F)	down-draught	mineral coal, charcoal, compressed fuels with < 10% volatile matter and < 6% ash	5-220 kW
IMBERT Energietechnik 49, Bonner Strasse 5345 Weilerswist (D)	down-drought	all vegetable waste	50-1000 kW
LAMBIOTTE 290, Av. Brugmann 1180 Bruxelles (B)	cross-draft, down-draft	charcoal, wood and woody materials, compressed fuels	10-600 kW
PILLARD B.P. 56 13, Rue R. Teissère 13268 Marseille (F)	down-draught in sospension	wood chips, wood waste, plant shells, coconut waste, fruit stones chopped straw, bagasse, coffee and rice husk, sawdust, leaves	20-1500 kW 100-1500 kW
S.E.S. Via Bissolati, 57 00187 Roma (I)	down-draught	wood chips, hazelnut shells, agricutural wastes	15-30 kW
SPECIALIST ENGINES Ltd P.O. Box 2 Helston Cornwall TR13 8XB (UK)	horizontal flow down-draught	charcoal, carbonized coconut shells wood chips	10-25 kW 10 kW
TOUILLET 137, Route de Paris B.P. 419 86010 Poitiers Cedex (F)	down-draught	charcoal in size from 2 to 4 cm, wood logs, corn cobs, agricultural waste	20-120 kW
VYNCKE 224 Gentsesteenweg 8740 Harelbeke (B)	down-draught	wood chips, compressed fuels	20-120 kW

Table 2 - Main results obtained in the first gasifi-
cation tests

FUEL	HEAT VALUE (kWh/kg)	SPECIFIC GAS PRODUCTION (Nm3/kg fuel)	GASIFICATION EFFICIENCY	OUTPUT POWER (kW el.)	SPECIFIC FUEL CONSUMPTION (kg/kWh el.)	TOTAL EFFICIENCY
Woodworking residues	4.6	2.6	0.80	6	2.4	0.09
				15	1.2	0.18
Corn cobs	3.9	1.9	0.70	0	-	-
				6	2.7	0.09
				15	1.6	0.16
				24	1.3	0.19
Grape seeds briquetts	4.7	1.9	0.78	15	1.4	0.15
				24	1.2	0.17
Wood logs	3.7	2.3	0.74	6	2.6	0.10
				24	1.3	0.20
Wood chips	4.1	2.8	0.70	0	-	-
				6	2.4	0.10
				15	1.6	0.15
				24	1.2	0.20
Sawdust briquettes	4.7	2.5	0.68	0	-	-
				6	2.7	0.08
				15	1.5	0.14
				24	1.2	0.18
Pruning residues briquettes	4.1	2.7	0.67	15	1.6	0.16
				24	1.4	0.19

Table 3 - Farm thermal and electric energy requirements: monthly values are reported as range (minimum-maximum), yearly as total and index values

	MONTHLY REQUIREMENTS (kWh/month)		YEARLY REQUIREMENTS (kWh/year) (% totale)	
	THERMAL	ELECTRIC	THERMAL	ELECTRIC
Hauses	900-23700	2000-3050	104600 54	30200 33
Cattle breeding	3200-4200	3600-4700	45500 24	49800 55
Workshop	-	150-900	- 0	6350 7
Maize dryer	18700-23300	2000-2500	42000 22	4500 5
	TOTAL		192100 100	90900 100

Table 4 - Average daily values and results of running parameters concerning the Fritz Werner plant installed in the dairy farm

PARAMETERS		AVERAGE VALUE
Running time	(h)	4.4
Electricity production	(kWh)	40
Power output	(kW)	9.1
Load factor		0.32
Fuel consumption	(kg)	85
	(kg/h)	19.6
	(kg/kWh)	2.2
Starting time	(h)	0.20
Maintenance	(h/every 10 hours)	0.35
No productive consumption	(kg)	12
Charcoal consumption	(kg)	2.2
Ash production	(kg)	1.7
	(% fuel)	2.0
Total efficiency		0.10

Table 5 - Experimental conditions: input data, cash-flow and plant NPV

INPUT DATA

Plant cost	: 70 M£	Useful life	: 10 years
Engine cost	: 15 M£	N° of start per day	: 1
Filters cost	: 3 M£	Maximum output power	: 28 kW el.
Gasifier cost	: 5 M£	Load factor	: 0.35
Manpower cost	: 9000 £/h	Fuel consumption	: 20 kg/h
Fuel cost	: 70 £/kg	kWh grid price	: 140 £/kWh
Charcoal cost	: 800 £/kg	Interest rate	: 0.08
		Running time	: 1500 h/year

PRESENT VALUES AND CASH-FLOW (M£)

	PRESENT VALUES	CASH-FLOW YEARS 0	1	2	3	4	5	6	7	8	9	10
PLANT COST	70	70										
MANAGEMENT COSTS:												
A - Ordinary costs												
1) fuel	15.8 (31%)											
2) materials	15.1 (29%)											
3) manpower	11.3 (22%)											
total A	42.2 (82%)	0	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
B - Extra costs	9.4 (18%)	0	0.3	0.3	0.3	4.9	0.3	0.3	0.3	7.9	0.3	0
TOTAL (A+B)	51.6 (100%)		6.6	6.6	6.6	11.2	6.6	6.6	6.6	14.2	6.6	6.3
ENERGY PRODUCTION VALUE	14.1		2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
N.P.V.	-107.8	-70	-4.5	-4.5	-4.5	-9.1	-4.5	-4.5	-4.5	-12.2	-4.5	-4.3

Table 6 - Cash-flow and NPV concerning a gasification plant "semi-industrial" manufactured and equipped with a cogeneration system

INPUT DATA

Plant cost	:40+30 M£	Useful life	: 10 years
Engine cost	: 7 M£	N° of start per day	: 1
Filters cost	: 3 M£	Maximum output power	: 28 kW el.
Gasifier cost	: 5 M£	Load factor	: 0.75
Manpower cost	: 0 £/h	Fuel consumption	: 27.5 kg/h
Fuel cost	: 40 £/kg	kWh grid price	: 140 £/kWh
Charcoal cost	: 800 £/kg	Interest rate	: 0.08
Gasoil cost	: 700 £/kg	Running time	: 3600 h/year

PRESENT VALUES AND CASH-FLOW (M£)

	PRESENT VALUES	CASH-FLOW YEARS 0	1	2	3	4	5	6	7	8	9	10
PLANT COST	70	70										
MANAGEMENT COSTS:												
A - Ordinary costs												
1) fuel	27.5 (36%)											
2) materials	36.2 (47%)											
3) manpower	0.0 (0%)											
total A	63.7 (83%)	0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
B - Extra costs	13.1 (17%)	0	0.1	2.2	0.1	5.2	0.1	0.1	10.2	0.1	2.2	0
TOTAL (A+B)	76.8 (100%)		9.6	11.7	9.6	14.7	9.6	9.6	19.7	9.6	11.7	9.5
ENERGY PRODUCTION VALUE	147.6		22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
N.P.V.	0.8	-70	12.4	10.3	12.4	7.3	12.4	12.4	2.3	12.4	10.3	12.5