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FBC design for low grade fuels: an experimental analyasis

B.Lonia and R.K.Bansal

Mechanical Engineering, JSSIET, Kauli, Patiala.

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ABSTRACT

This paper reviews the current situation with regard to generation of low grade fuels and their prospects of economic conversion into electrical power, the technologies presently available for this purpose, and the problems faced in such efforts. It emphasizes the need for an integrated approach to devise ways and means for generating electrical power from low grade fuels; keeping in mind the requirements of cleaner production and environmental protection so that the initiative leads to a total solution. The calorific value of such fuels varies between 550kcal/kg-1050 kcal/kg as compared to developed countries ie1550kcal/kg to 2050kcal/kg. The combination of various low grade fuels were prepared and tested, experimental analysis amply high light the usage of these fuels as a replacement of coal. There is a shimmering promise that the whole process of using low grade fuel i.e. too Agriwaste harvesting, collection, transport,economic processing and utilization of low grade fuel can be made technically and economically more viable in future. Thus, this paper highlights the value of low grade fuels as a prospective source of electric power and thus serving the remote areas in the form of stand- alone units giving a boost to decentralized power supply. This approach and option seems to be possible in view of its potential contribution to our economic and social development. No doubt, this initiative needs to be backed and perused rigorously for removing regional imbalances as well as strengthening National economy.

Introduction

India being agriculture based country, 70% of (share in GDP) its main income comes from agriculture sector. Any enhancement of income from this sector is based upon adequate supply of basic inputs in this Sector. Regular and adequate power supply is one such input. But the position of power supply in our country defies both these characteristics. A major portion of power produced being sent to the industrial and urban consumers, there is a perennial shortage of power in the agriculture sector. Consequently, there is an emergent need to produce more power, in order to fulfill the needs of this sector effectively. One way of accomplishing this is setting up captive or rural based small power generation plants. In these power plants, instead of water-head, diesel oil or coal, we can use agri-residue to produce electricity. The agriwaste, like rice straw, saw dust, sugarcane-trash, coir-pith, peanut shells, wheat stalks & straw, cottonseed, stalks and husk, soyabean stalks, maize stalks & cobs, bagasse, waste wood, sunflower seeds, shells, hulls, kernels and coconut husk can be fruitfully utilized in power generation. This stuff is otherwise a waste and liability and consumes a lot of effort on its disposal; in addition to being a fire hazard. Apart from the above, it causes serious air pollution in the form of smoke, unburnt suspended particles and unwanted addition of heat to atmosphere. Surely, agriwaste stuff at present is available in abundance and prospects of its utilization in producing energy are enormous. Agriwaste components can be procured at reasonably low rates from farmers who will thus be benefited economically, apart from being relieved of the responsibility of its disposal. Table-I exhibits the details of classification, location, different forms, production related data of various types of agriwaste.

Tele:
E-mail addresses: bal_lonia@gmail.com

Table 1. Availability of agricultural residues in India

Type of Residues	Energy Potential (MW)	Quantity of agriwaste required (million tonnes)	Available agriwaste in Northern Zone (million tonnes)
Agricultural residue	9500	90	350
Agro-Industrial Residue	5000	50	70
Energy Plantation	3500	1 (mha)	93 (mha)

Source: "biomass program in India; an overview" NP Singh, MNES, New Delhi

The various technologies preferred for higher production, efficient conversion and effective utilization of agri-residue/waste are:

- Agri-residue production
- Agri-residue briquette
- Agri-residue combustion
- Agri-residue gasification
- Agri-residue cogeneration

A vast amount of agri-residue is generated which amounts to nearly 405 million metric ton (mmt) annually. The breakup of different agri-waste is given in the Table No.2. On the basis of calorific value, the amount of agri-residue generated is roughly equivalent to about 260 metric ton of coal. Further, it is reported in literature that agri-waste/residue availability can be increased by 35% if the energy plantations are grown on even 10% of waste land in the country. The factors which influence the agri-waste utilization in generation of electric power include technological, environmental, economic, fiscal and managerial.

Table: 2agri residue estimates

Sr. No	Agri-residue	Percentage (%)	Quantity available in Northern Zone (million tonnes)
1.	Wheat straw	33.5 *	20.65 *
2.	Rice husk	12.0	8.16
3.	Cotton stalks	8.0	12.46
4.	Sugarcane Bagasse	32.0	12.88
5.	Ragi & Bajra straw	77.0	15.00
6.	Coconut & groundnut shells	6.7	8.00
7.	Maize	50.0	12.00

** These values depend upon the type & methods adopted. **(R & D requirements in Biomass Combustion and Gasification) O.P.Rao, CSIR, New Delhi.*

Fludisation Principle

When a gas is passed through a packed bed of solid particles the gas experiences some pressure drop across the bed. At low velocities, this pressure Drop is small and the particle system will be undisturbed. But as the gas velocities is increased steadily the pressure drop also increases till a point where the pressure drop across The bed equals The weight off the bed particles per area. At this stage the bed particles are in a suspended state and it is called minimum fludisation velocity. When the gas velocity is increased further, the bed becomes highly turbulent and rapid mixing of particles takes place. At this stage the bed of solids attain pseudo fluid properties.Figure 1 shows a quantity of solid particles contained in a vessel having a porous base through which the air supplied to the plenum chamber underneath the base can flow and then percolate upwards through the spaces surrounding the individual particles, the fluid can be gaseous or liquid.

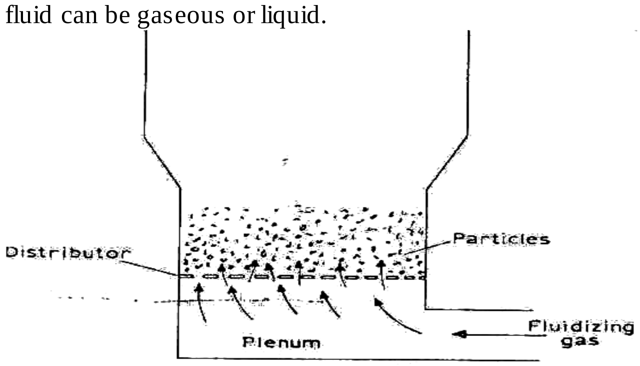


FIG. 1. Fluidised bed.

(i) The first striking feature of the quantity of the solid particles is the large surface area of the particles which is available for contact with the air flowing among them, the mean diameter particles of 100μm, contained in a vessel of $1m^3$ has a total surface area of the order of $3\times10^4 m^2$.

(ii)The second feature is that a bed of solids has a large heat capacity per unit volume. By virtue of this is that particulate solids can be used for heat storage and if they can be transported or made to flow from one location to another, they are the most effective carriers.

Phenomenon of fluidisation

If air is introduced into the bed of particles as shown in figure 1 through the porous base it is normally desirable that the gas be distributed uniformly into the bed. This requires porous base to be designed to achieve this. Different types of distributor plates are shown in figure 2. (a) Shows a simple drilled plate, having a number of closely spaced small holes of diameter smaller than the smallest particle to prevent the flow back of solids in the plenum. For uniformity of distribution, the pressure drop across the distributor has to be of sufficient magnitude to affect this. On the other hand the pressure drop should not be unnecessarily large because an excessive pressure drop is a penalty, which is paid for through increased running cost due to additional pumping power and also by increased capital cost. Figure 3 shows the pressure drop The flow rate is specified as a 'fludising velocity, U', which is:

$$U = \frac{\text{volume flow rate of gas}}{\text{Cross sectional area of bed containment}}$$

It is seen that as the fludising velocity increases the pressure drop, Δp_b, across the bed rises until the drag force exerted on the particle is just sufficient to just support the weight of the particle

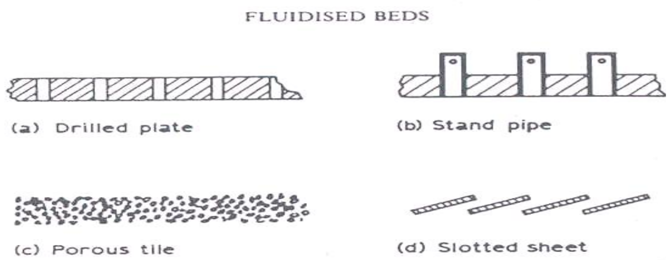


FIG. 2. Some types of distributor.

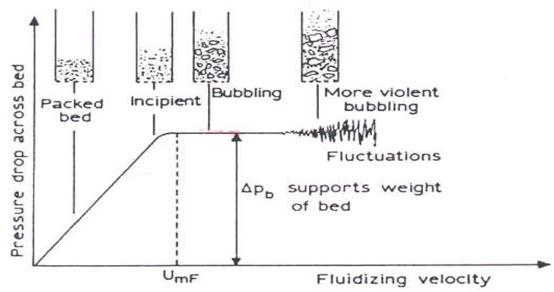


FIG. 3. Variation in pressure drop across bed with fluidising velocity

As the air flows through the bed increases beyond the minimum fluidizing velocity, the air tends to form cavities among the particles which look like bubbles of air and rise through the bed, carrying particles upwards. This bubbling action promotes the mixing of particles which in turn promotes uniformity of temperature throughout the bed.Figure 4 illustrates how the heat transfer coefficient at the bed – to – surface interface of the tube, immersed in a given fluidized bed changes with fluidizing velocity. It is seen that as the fluidizing velocity increases from zero, the heat transfer coefficient undergoes little change until the minimum fluidizing velocity is reached. The heat transfer then rises sharply with fluidizing velocity, reaches a maximum and then declines gradually. The values of heat transfer coefficient and the corresponding fluidizing velocity are affected by the mean size of the particles, the fluidizing gas properties, the location of the tube with in the bed and the bubbling pattern. The fluidizing velocity at which the heat transfer coefficient maximizes is in the region of about 1.3 to 3 times the minimum fluidizing velocity.

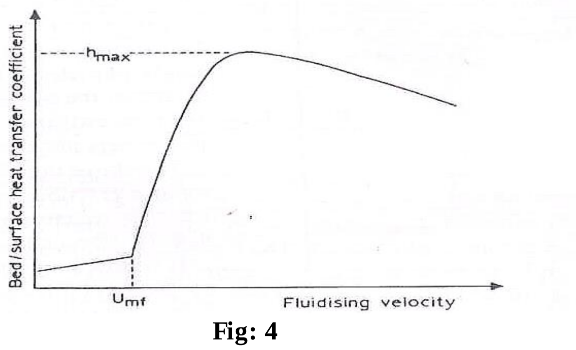


Fig: 4

For SI units the correlation for the maximum heat transfer coefficient in W/m^2K is:

$h_{max} = 35.8\rho_p^{0.2} \times K_f^{0.6} \times d_p^{-0.36}$

Where, ρ_p = particle density

K_f = thermal conductivity of fludising air

d_p = particle size

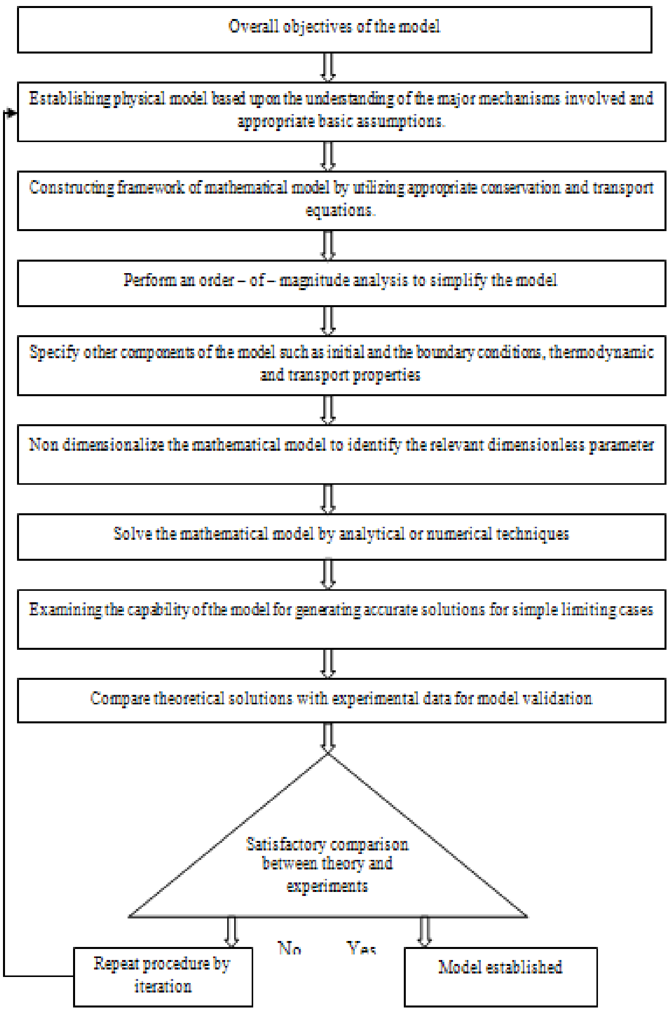
FBC for low grade fuels

A range of waste materials can be burned up in fluidized bed combustion system. Although waste materials

Include sewage sludge, slurries, lignite, municipal, agriwaste and industrial waste. Municipal and agriwaste is of special interest for power generation using FBC as it solves disposal problem as well as provide additional power. Municipal refuse is rapidly increasing with the high rate of population growth especially in developing countries like India, Pakistan and Srilanka. It is estimated that a typical urban area in India disposes 0.6 kg per man day and it is increasing at the rate of 1.3 % per year. But due to high density of population in India the refuse produced is quite large. (Nearly 3000 tons per day in Metro cities).

This refuse is disposed in the form of land filling. Land filling contributes least to air pollution problem but requires large and suitable land sites. Combustion of municipal refuse produces a significant amount of heat. (1 ton refuse = 70 gallons of oil). This heat can be easily recovered in FBC system by the gas, which can be further used for power generation.

The calorific value of Indian waste (350 – 550 K cal / kg) is very low compared with developed countries (1500 k cal/ kg); therefore self sustaining combustion reaction can't be maintained in FBC.



DESIGN PROCEDURE

Components/parts	Material/specification
Furnace, cyclone, economizer	Mild steel – 18 gage
Nozzles	Mild steel – tapered drilled
Tubing	Copper
Base plate	Mild steel
Piping	G.I
Insulation	Fireclay
Bed	Silica sand, dolomite
Rota meter	
Manometer	
Thermocouples	
Blower	3hp, air velocity = 30.5m/s, 2.2kW

Calculations and aassumptions for various parameters

Calculation of pipe length (copper)

Parameter	**Value**
Mass flow of gasses	0.5 kg/s
Air inlet temperature	50°C
Air outlet temperature	200°C
Water inlet temperature	20°C
Water outlet temperature	80°C
Tube material	copper
Tube bore	12mm
Tube outside diameter	15mm
Chosen particle	Silica sand
Particle size	427 µm
Minimum fludising velocity at 200°C	0.25 m/s
Physical Properties	
Particle density	2640 kg/m^3
Air mean specific heat	1.04 KJ/kgK
Air thermal conductivity at 200°C	3.87×10^{-2} W/mK
Air density at 1atm, 200°C	0.746kg/m^3
Air viscosity at 200°C	2.58×10^{-5}kg/ms
Water viscosity at 50°C	544×10^{-6}kg/ms
Water Prandtl number at 50°C	3.54
Water specific heat	4.18kJ/kgK
Water thermal conductivity	634×10^{-6}kW/mK
Copper thermal conductivity	380W/mK

The duties required from the heat exchanger and water flow rate are,

Duty = 0.5 × 1.04 × (200-50) = 78kW Water flow rate = 78 / 4.18 × (80-20)

=0.311kg/s

If this water flow is passed through a single tube, the water velocity will be,

Water velocity = $0.311 / (\pi/4 \times 0.012^2 \times 10^3)$ = 3.74m/s

We now proceed to estimate the heat transfer coefficient at the inner and the outer surface of the tube using the following empirical correlations. At the inner surface,

$Nu = 0.023 (Re)^{0.8}(Pr)^{0.4}$

Where, Nu = Nusselt number

Re = Reynolds number

Pr = Prandtl number

$Re = (\rho ud/\mu) = (10^3\times2.74\times0.012) / (544\times10^{-6}) = 60441.176$

$Nu = 0.023 (60441.176)^{0.8}(3.54)^{0.4} = 254.92$

At the inner surface, heat transfer coefficient, h

$h = Nuk/d = 254.92\times 643 \times 10^{-6} / 0.012 = 13.61 kW/m^2K$

At the outer surface, first checking that it is not outside its range of applicability [$Ar < 26000$ and $Re_{mf} < 12.5$]

$Ar = (427\times10^{-6})^3\times0.745\times2640\times9.81 / (2.58\times10^{-5})^2 = 2260$

$Re_{mf} = 0.745\times0.25\times427\times10^{-6} / (2.58\times10^{-5}) = 3.08$

Using equation $h_{max} = 35.8\rho_p^{0.2}\times K_f^{0.6}\times d_p^{-0.36}$

$H_{max} = 35.8 \times (2640^{0.2}) \times (3.87 \times 10^{-2})^{0.6} \times (427\times10^{-6})^{-0.36} = 402 W/m^2K$

70 % of this value gives the heat transfer coefficient at the outer surface of the tube.

$h_o = 281 W/m^2K$

Overall bed to liquid thermal resistance (1/ UA) is given by

$$\frac{1}{UA} = \frac{1}{hoAo} + \frac{1}{hiAi} + \frac{t}{kAm}$$

Where, $A_0 = \pi d_0 L$, $A_i = \pi diL$ and $A_m = 0.5\ \pi\ (d_0+d_i)\ L$

Hence (1/ UA) = $$\frac{1}{\pi L}\left[\frac{1}{0.281\times 0.015}+\frac{1}{13.61\times 0.012}+\frac{0.003}{0.380\times 0.027}\right]$$

= 243.6/πL K/kW

Logarithmic mean temperature difference (LMTD) is based on water inlet and outlet temperature and the assumption that the temperature of the bed of the fludised particle is that of the outlet temperature of the gas namely 200°C.

Thus, (LMTD) = $$\frac{(200-80)-(200-20)}{\ln\frac{200-80}{200-20}} = 148\ K$$

The overall thermal resistance = (LMTD) /duty

Equating (1/ UA) and overall thermal resistance, we get,

Tube length, L required = (243.6 × 78) / (148×π) = 4.087m

Furnace

We have made a furnace of mild steel (18 gage) sheet rolled to form a cylinder. The internal diameter of the cylinder is 16 inch and height is 36 inch. With the plenum at the base. The furnace contains four input windows for feeding fuel at a height of 5inch, 11inch, 17inch, and 22inch from the bottom of the furnace. These windows can be closed or opened as desired.

Distributor Plate

Distributor plate is used to distribute air equally intc the furnace and to form hydrodynamics. It is fabricated from mild steel (18 gage) sheet. Diameter of the distributor plate is 16 inch. With 14 nozzles 1 nozzle at the centre,5 nozzles at the radial distance of 4 inch and remaining 8 nozzles at a radial distance of 8 inch. This distributor plate is fitted at the distance of 2 inch from the bottom of the furnace and welded to the furnace to make a leak proof joint.

Plenum:

Plenum is used to collect the air from blower and to pass the air equally into the furnace through the nozzles in the distributor plate. The plenum is made a frustum of a cone of mild steel (18 gage) sheet. The height of the frustum is 8 inch, with 16 inch bigger diameter And 3 inch smaller diameter. Air is fed from the blower into the plenum with the three inch diameter GI pipe fitted at three inch diameter of the frustum.

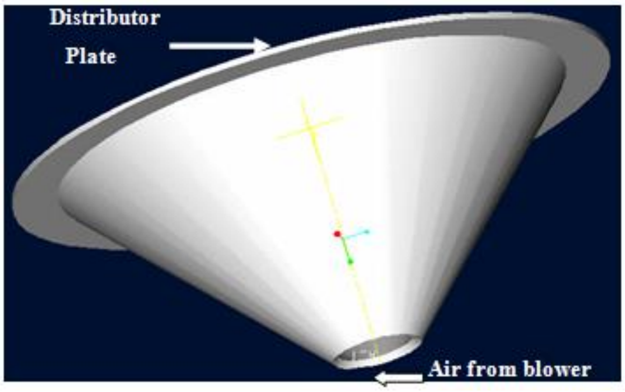
This plenum is welded at the extreme bottom of the furnace to form a leak proof space between the distributor plate and the cone.

Nozzles:

The nozzles are used to inject air at high pressure into the furnace and distribute equally the air into the furnace; these are also used to form hydrodynamics in the furnace. The nozzles are made from mild steel rod of diameter 19mm. this rod is tapered drilled with inlet port diameter 15mm and exit port diameter 3mm. the height of the nozzle is 2.5 inch. Each nozzle contains one exit port only.

Tubing:

The tubing made of copper is used for producing steam. The internal diameter is 12mm and outer diameter is 15mm. the length of the pipe taken is 512 inch (13m). With 46 inch forming the uppermost and the lowermost horizontal tube and 420 inches forming the middle vertical tubing. The inlet of water is from the lower most horizontal tubing to the vertical middle tubing and then to the uppermost horizontal tubing which exits steam out of the furnace.



Cyclone: The design of cyclone is shown in the figure below along with its working.

We have made a cyclone with an internal diameter of 7 inch and height 25 inch. The shape of cyclone is cylindrical at the top and conical at the bottom. The flue gases are allowed to enter tangentially into the cyclone.

Economiser: The water before feeding into the copper tubing is first preheated in economizer to elevate its temperature and hence increasing the overall efficiency of the system.

ASH SUMP: The ash and the dust remains in the flue gases settle in the ash sump. The flue gases are then exhausted into the atmosphere through ash sump.

Piping

These above explained components are then assembled together wit the help of GI pipes of variable diameters. The pipe fittings used are:

S.No	Parts	quantity	length	Specifications(diameter)
1	Elbows	2 3		3 inch 2 inch
2	Sockets	2 3		3 inch 2 inch
3	pipe length	2 1	5 ft 3 ft	3 inch, 2 inch 2 inch
4	Reducers	4		

The Environmental Prospective

The agri-residue plantations have various environmental & cost benefits. Ascertaining the environmental and social impact is quite a complex job because it must be considered in the context of alternative energy options. Globally, it can be possible to replace fossil fuels with agri-residue energy. The degree of benefit depends on the efficiency with which the agri-waste is converted to electricity. If the efficiency of conversion of agri-residue to electricity is similar to that for coal conversion, then the benefits are several e.g. Airborne pollutants such as toxic heavy metals, ozone-forming chemicals, and releases of sulphur dioxide that contribute to acid rain will be reduced.

- The ash and waste products from burning will, in most cases, begin to return to the soil.
- There will be a considerable reduction in net carbon dioxide emissions that contribute to the green house effect.

Local environmental and social benefits can be maximized when agri-residue replaces fossil fuels. These benefits include:

- Protection of water quality
- Prevention of erosion of soil
- Improvement of local micro climate through evaporative cooling and humidification

Reduction in use of agricultural chemicals

- Improvement of soil properties

- Protection of domesticated animals

Preparation of fuel for FBC: We have prepared fuel for burning in FBC using various agriwaste. These are as follows:

by mixing variable proportion of different agriwaste we prepared fuel inform of bricks of size 2×2×2 inch and 3×3×1 inch. Some fuel has also been prepared in pulverized form.

S. No.	Agriwaste	Calorific value (kCal/kg)
*1	Eucalyptus leaves	4800
*2	Eucalyptus saw dust	4400
*3	Saw dust (any)	4400
*4	Straw	3700
*5	Wood (hard)	4400
*6	Bagasse	4200
*7	Ground nutshell	4500
*8	Rice husk	3200
**9	Cattle dung (dry)	3700
**10	Wheat straw	2500
**11	Rice straw	2500
**12	Dung cake	2940

Conclusions and Recommendation:

It is concluded that the agriwaste holds good future on account of following:

- Increasing prices of fossil fuels.
- Foreseeable depletion of fossil fuels, particularly oil.
- Pollution from use of fossil fuels specially greenhouse gases.s
- Agriwaste is renewable.
- Agriwaste contains negligible sulphur.
- The efficiency of conversion of agriwaste can be sufficiently enhanced with the application of appropriate and advanced technologies.

Recommendations:

- Direct combustion is the dominant technology for harvesting energy from agirwaste but it is characterized by low efficiencies.
- Combustion of agriwaste depends upon firing methods i.e. grate firing, suspension firing, and fluidized-bed combustion. The selection of the most appropriate firing method depends upon the size of unit, condition of the fuel, and the energy product (steam). The grate-fired systems have been mostly used because of their flexibility. Fluidized bed combustion is best suitable because of its technical merits & is emerging as an alternative to grate-fired combustion.
- Finally, harvesting, collection, transport, and material processing affect agirwaste utilization technically and economically. Therefore, R & D in these areas is to be continued together with the conversion technologies.

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