Journal of Environmental Protection and Ecology 6, No 4, 936–944 (2005)

CLEAN ENERGY FROM BIOMASS. A CHALLENGE FOR THE FUTURE

N. SDRULA[a]*, L. GLEJARU[a], C. SDRULA[b]

[a]*S. C. IPROCHIM S. A., 19-21 M. Eminescu Street, Bucharest 1, Romania*
E-mail: nicolae.sdrula@iprochim.ro
[b]*EcoSepDesignCenter (ESDC)®, 16 N. Titulescu Street, Bucharest 1, Romania*
E-mail: costin_stefan@k.ro

Abstract. The problem of recovered fuels began to concern scientific people for a long time. The limitation of fossil fuels which are not renewable and also disturb the global CO_2 equilibrium imposes the orientation of people to the natural resources for energy like biomass and waste, geothermal, hydro, wind, solar, waves or other.The present paper is focused on waste or biomass processing in order to produce clean energy by saving the fossil resources and protecting the environment.

Keywords: clean energy, biomass, waste processing, pyrolysis.

AIMS AND BACKGROUND

Fast pyrolysis and gasification of biomass are processes which transform the raw materials into valuable components which can be used both as chemicals or fuels. The processes can be applied separately or consecutive depending on the final aim and the experience of the producer. The biomass waste is simply pyrolysed in case the bio-oil have to be the final product and gasification is accomplished when syn-gas is expected.

Renewable energy is of growing importance in satisfying environmental concerns over fossil fuel usage. Wood and other forms of biomass are some of the main renewable energy resources available and provide the only source of renewable liquid, gaseous and solid fuels. Wood and biomass can be used in a variety of ways to provide energy by[1]:

- direct combustion to provide heat for use in heating, for steam production and hence electricity generation;
- gasification to provide a fuel gas for combustion for heat, or in an engine or turbine for electricity generation;
- fast pyrolysis to provide a liquid fuel that can substitute for fuel oil and any static heating of electricity generation application. The liquid can also be used to produce a range of specialty and commodity chemicals.

---

* For correspondence.

Fast pyrolysis can directly produce a liquid fuel from biomass, which can be readily stored or transported.

FAST PYROLYSIS

Fast pyrolysis is a high temperature process in which biomass is rapidly heated in the absence of oxygen. Therefore, it is decomposes to generate mostly vapours and aerosols and same charcoal.

After cooling and condensation, a dark brown mobile liquid is formed which has a heating value about half that of conventional fuel oil. While it is related to the traditional pyrolysis processes for making charcoal, fast pyrolysis is an advanced process, which is carefully controlled to give high yields of liquid.

FEATURES

The essential features of a fast pyrolysis process are:

- very high heating and heat transfer rates, which usually requires a finely ground biomass feed;
- carefully controlled pyrolysis reaction temperature of around 500°C in the vapour phase, with short vapour resistance times of typically less than 2 s;
- rapid cooling of the pyrolysis vapours to give the bio-oil product.

The main product, bio-oil, is obtained in yields of up to 80% wt. on dry feed, together with by-product char and gas there are no waste streams. While a wide range of reactor configurations has been operated, fluid beds are the most popular configurations due to their easiness of operation and ready scale-up.

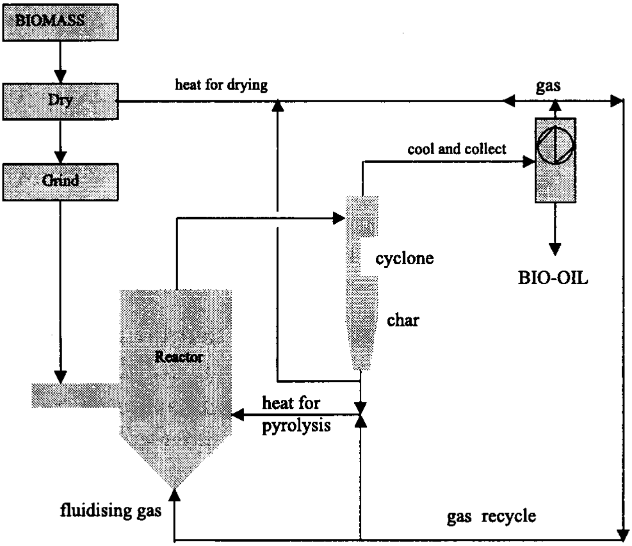

Fig. 1. Conceptual fluid bed fast pyrolysis process

A typical bubbling fluid bed configuration is depicted in Fig. 1 with utilisation of the by-product gas and char to provide the process heat. The figure includes the necessary steps of drying the feed to less than 10% water to minimise the water in the product liquid oil and grinding the feed to around 2 mm to give sufficiently small particles to ensure rapid reaction.

REACTORS

Fluid beds. Bubbling fluid beds have been selected for further development by several companies including Union Fenosa who have a 200 kg/h pilot unit in Spain, Dynamotive who have a 50 kg/h unit in Canada, based on a RTI design, and Wellman who are bubbling a 200 kg/h unit in the UK. Circulating fluid beds and transported bed reactors have been developed to commercial status and are used in the USA for food flavourings and related products in several plants of 1 to 2 t/h. A unit of 650 kg/h have been supplied by Ensyn to ENEL in Italy.

Ablative pyrolysis. Ablative pyrolysis is interesting as much larger particles sizes can be employed than in other systems and the process is limited by the rate of heat supply to the reactor rather than the rate of heat absorption by the pyrolysis biomass. Much of the pioneering work in ablative pyrolysis reactor has been carried out by NREL in their vortex reactor and by CNRS at Nancy. More recent developments have been carried out at Aston University. This fast pyrolysis route offers a more intensive and potentially compact reaction system.

Entrained flow reactor. Entrained flow fast pyrolysis was developed at Georgia Tech Research Institute and scaled up by Egemin. However, probably because of the difficulties that have been encountered in achieving good heat transfer from a gaseous heat carrier to solid biomass, the Egemin process is no longer operational or being further developed.

Rotating cone reactor. The rotating cone reactor, invented at the University of Twente and being developed by BTG, is recent development and effectively operates as a transported bed reactor, but with transport effected by centrifugal forces rather than gas. The 200 kg/h unit was built in Holland.

Vacuum pyrolysis. Vacuum pyrolysis is unique in that the rate of heating is very low compared to the other systems described above, but the effect (in terms of liquid product yield and quality) of fast pyrolysis is achieved by removing the vapours as soon as they are formed by operating under a vacuum.

PYROLYSIS LIQUID – BIO-OIL

Pyrolysis liquid is referred to by many names including pyrolysis liquid, pyrolysis oil, bio-oil, bio-crude-oil, bio-fuel-oil, wood liquids, wood oil, liquid smoke, wood distillates, pyroligneous tar, pyroligneous acid, and liquid wood. It is combustible and renewable, hence the use of the term 'bio' pyrolysis liquid has that of a conventional fuel oil – typically 16 ÷ 18 MJ/kg. The main characteristics are summarised in Table 1.

Table 1. Typical property and characteristics of wood derived pyrolysis oil

Physical properties		Typical value
Moisture content		15 ÷ 30%
pH		2.5
Specific gravity		1.20
Elemental analysis, dry basis	C	56.4%
	H	6.2%
	O (by difference)	37.3%
	N	0.1%
	ash	0.1%
HHV as produced (depends on moisture)		16 ÷ 19 MJ/kg
Viscosity (at 40°C and 25% water)		40 ÷ 100 cp
Solids (char)		0.5%
Distillation		max. 50% as liquid degrades
Characteristics		
– liquid fuel		
– easy substitution for conventional fuels in many static appliances – boilers, engines, turbines		
– heating value is about 40% that of fuel oil or diesel on a weight basis and 60% on a volume basis		
– does not mix with hydrocarbon fuels		
– not as stable as fossil fuels		

APPLICATIONS FOR BIO-OIL

Bio-oil can substitute for fuel oil or diesel in many static applications including boilers, furnaces, engines and turbines for electricity generation. The possibilities are summarised in Fig. 2. There are also a range of chemicals that can be extracted or derived including food flavourings, specialties, resins, agri-chemicals, fertilisers, and emissions control agents.

Upgrading bio-oil to transportation fuels is feasible but currently not economical.

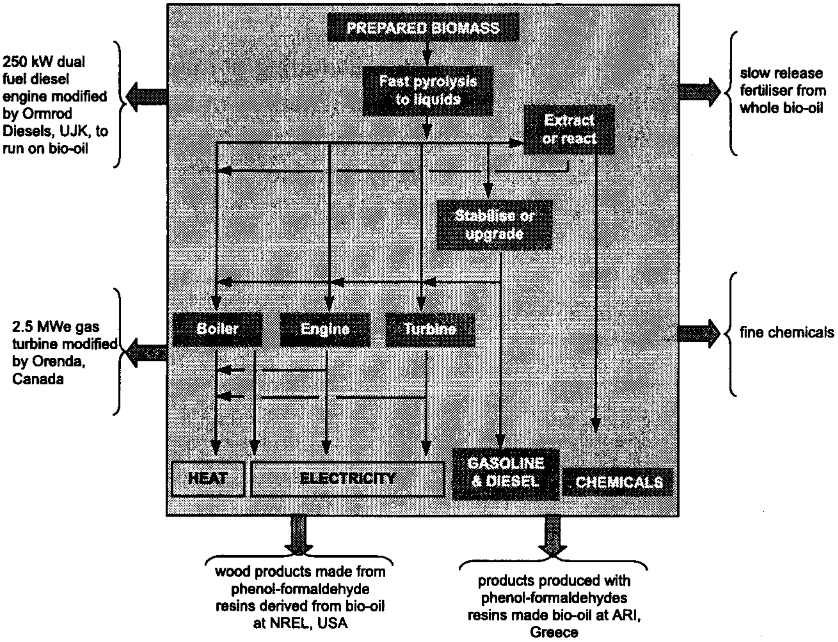

Fig. 2. Applications for bio-oil

ECOMONICS OF BIO-OIL

The projected cost of bio-oil is related to feed cost and size of unit. Detailed cost analysis has been carried out over a range of plant sizes and feed costs to give the results shown in Fig. 3. The cost includes all plant and processing from reception of wet whole tree chips through all necessary preparation and pyrolysis to storage of cold bio-oil.

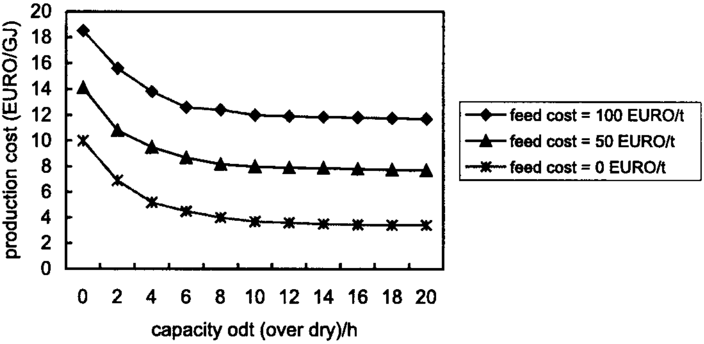

Fig. 3. Bio-oil production costs versus capacity at different feed costs

The data in Fig. 3 has been reduced to a simple equation shown below which can be used to estimate the cost of bio-oil for a range of feed costs and sizes with adjustments possible for plant efficiency and feed heating value.

$$\text{Bio-oil cost} = 8.87 \ \left(\text{wood capacity, dry t/h}\right)^{-0.3407} + \frac{\text{feed cost, ECU / dry t}}{0.625 \ \text{wood LHV, GJ/t}} \ \text{(EURO/GJ [LHV])}$$

The bio-oil cost is expressed in LHV terms and EURO costs. The bio-oil energy yield is assumed to be 62.5% and the wood higher heating value is taken as 19 GJ/t.

BIO-MASS GASIFICATION[2]

Generally, biomass gasification is a thermal conversion technology where a solid fuel is converted into a combustible gas. A limited supply of oxygen, air, steam or a combination serves as the oxidising agent. The product gas mainly consists of carbon monoxide, carbon dioxide, hydrogen, methane, water, nitrogen, but also contaminants like e.g. small char particles, ash and tars. After cleaning the gas makes is suitable for boiler, engine use, and turbine use to produce heat and power (CHP).

Process chemistry. The substance of a solid fuel is usually composed of the elements carbon, hydrogen and oxygen. In the gasifiers considered, the biomass is heated by combustion. Four different processes can be distinguished in gasification: drying, pyrolysis, oxidation and reduction.

The water gas shift reaction determines largely the final gas composition. The equilibrium constant (k_W) can be written as: $k_W = [CO_2]\,[H_2]\,/\,[CO]\,[H_2O]$. In practice, the equilibrium composition of the gas will only be reached in cases where the reaction rate and the time for reaction are sufficient. Below 700° the water-gas shift becomes so slow – without a catalyst – that the equilibrium is said to be ‘frozen’. The gas composition then remains unchanged. Methane equilibrium will only be reached at very high temperatures (> 1200°C).

Short process description. Gasifiers are already investigated for more than a century, and many different types have been developed. The main types of gasifiers are moving beds (co-current or counter current), fluid beds (dense or circulating) and entrained beds. For CHP applications in the small to medium size, BTG applies the co-current fixed bed, and the fluidised bed gasifier. In both cases, air is used as the oxidant, and the gasifier is operated at ambient pressure.

The typical gas composition data obtained from wood and charcoal co-current gasifiers operated on low to medium moisture content fuels (wood – 20%, charcoal – 7%) are presented in Table 2.

Table 2. Gas composition from gasification

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

For synthesis gas production BTG considers the pressurised, oxygen-blown entrained flow gasifier fed with bio-oil.

Gas conditioning. Dependent on the application, type of gasifier and contaminants in the fuel, a certain level of gas conditioning (cleaning/cooling) is required. The most frequent impurities are hydrocarbons (tar), dust (particulate), ammonia, sulphur, chloride, alkalis, etc., which need to be removed or converted. Dust is usually removed by cyclones and fabric filters. Ammonia, sulphur and chloride can be removed by scrubbers or by using additives. The most critical component to be handled, however, is tar. Cooling is required for: (i) combustion in gas engines, (ii) when filters are applied with a maximum allowable temperature, or (iii) when compressors are incorporated like with atmospheric IGCC.

Electricity production. For biomass-CHP gas engines, (micro-) turbines, and in the future possibly fuel cells can be applied as the prime mover. So far, BTG mainly possess operational experience with gas engine application.

Fixed-bed. The different fixed-bed reactor types are often characterised by the direction of the gasflow through the reactor (upward, downward or horizontal) or by the direction, respectively, of the solid flow and the gas stream (co-current, counter-current or cross-current). For specific feedstock, a co-current gasifier is used with the advantage that the tar content in the producer gas is low. Additional gas cleaning – prior to fuelling a prime mover – is avoided. Obviously, this will reduce the investment and operational costs.

Fluidised-bed. In a fluidised bed, gasifier air and biomass are mixed up in a hot bed of solid material (e.g. sand). Due to the intense mixing the different zones – drying, pyrolysis, oxidation, reduction – can not be distinguished; the temperature is uniform throughout the bed. Contrary to fixed bed gasifiers the air-biomass ratio can be changed and, therefore, the bed temperature can be controlled. The producer gas will always contain certain amounts of tar, which need to be removed.

In BTG's laboratory, a complete 'biomass-to-electricity' chain is available for testing. This chain includes the biomass feeding, a fluidised bed gasifier, catalytic tar removal, and gas cooling and gas engine+generator. Maximum capacity is about 25 kg of biomass per hour (100 – 150 kWh). A large number of different feedstocks have been tested in this installation as e.g. wood, energy crops and dried chickens manure.

Currently, a demonstration plant is erected based on this technology. In that particular case dried, chicken manure is used as the feedstock. The capacity is about 60 kWel.

Status of the technology. The technology is close to commercialisation and, therefore, BTG has informed the international community in detail about the status for many years, i.e. about the current installations and the current manufacturers. Over 90 installations and over 60 manufacturers are listed now indicating the large interest in biomass gasification.

Despite many R&D efforts for the last decades, commercial status is still not achieved for several technical and non-technical reasons. To promote the technology in general and to contribute to the Kyoto protocol, BTG initiated a European wide Network on Gasification, GasNet, in which 20 members from all European countries participate. Information on different aspects are exchanged and distributed through Internet at www.gasnet.uk.net and bi-annual newsletters. GasNet co-operates with PyNe (Pyrolysis Network) and the IEA Bioenergy Agreement, Task 33 on Thermal Conversion.

Applications. The fixed bed and fluidised bed gasifiers applied by BTG are mainly meant for the small and medium size. Fixed bed gasifiers are used in case of a well-defined feedstock; fluidised beds are more tolerant with respect to the feedstock.

The simplest application is the single production of heat for e.g. district heating. For CHP applications BTG used so far gas engines, but on the short – to medium term the use of (micro-) turbines might become interesting, and in the long term also fuel cells.

A further interesting addition to the CHP will be cooling, e.g.the application of ad- or absorption coolers.

Economics. Several economic studies have been made on biomass gasification regarding the feasibility and long-term prospects. The first demonstration projects are mostly far too expensive to become profitable. Investment figures of more than 5000 Euro/kW electric are not exceptional. However, it is expected that due to the learning curve, the investment costs can be reduced to approximately 2000 Euro/kW electric within the coming decade. Operational experience and value engineering are needed to achieve this goal.

Another aspect is the operational costs, in particularly the price of the feedstock. These can be expensive like short rotation coppice (SRC) or cheap (negative) like waste residues. Transportation, fuel handling and processing add to the cost of the feedstock. Furthermore, labour costs must be minimised through process control and automation. Practical experience is needed to determine the maintenance costs. Remuneration of electricity and heat can also be decisive in the overall economics.

CONCLUSIONS

There is still not a well-defined 'best' fast pyrolysis process and potential remains for further development and optimisation. The liquid bio-oil product has the considerable advantage of being storable and transportable as well as the potential to supply a number of valuable chemicals. Considerable work is required to characterise and standardise this liquid and develop a wider range of energy applications. Chemicals offer more interesting commercial opportunities and are likely to be focus of continuing R&D effort.

For the short- to medium term, biomass gasification can not compete with fossil fuel produced power. Therefore, comparison must be made to alternative renewable energy sources. Studies showed that biomass gasification could compete with other RES when capital costs can be reduced and favourable conditions are created. Both conditions are likely to happen.

REFERENCES

1. T. BRIDDGWATER: A Guide to Fast Pyrolysis of Biomass for Fuels and Chemicals. PyNe Newsletter, March, 1999, 1-6.
2. Ir. H. A. M. KNOEF: Biomass Gasification. BTG Biomass Technology Group BV 2002-2003, Last Modified. April, 2003.

Received 5 July 2004
Revised 12 September 2004