# Small scale heat and power from biomass

## Introduction

A comparison has been made between four options to produce power (electricity) and heat from biomass. These options are:

- Direct firing of biomass
- Flash pyrolysis - diesel engine
- Flash pyrolysis – Gas Turbine with steam generation
- Flash pyrolysis – Gas Turbine with steam turbine

In the paragraphs below, the starting points and assumptions are given followed by results of the calculations.

## Starting points and Assumptions

### *Biomass*

The calculations are based on the average composition of mixed, untreated wood (ECN, Phyllis Database).

As received properties:

| | |
|---|---|
| Moisture | : 18.7 % |
| Ash content | : 2.2 % |
| LHV | : 15 MJ/kg |

Dry ash free:

| | |
|---|---|
| LHV | : 18.8 MJ/kg |

Dry ash free composition:

| | |
|---|---|
| C | : 50.7 wt% |
| H | : 6.06 |
| O | : 42.8 |
| N | : 0.36 |
| S | : 0.06 |

### *Scale*

For the calculations, small scale, decentralized units will be considered having an electrical output of somewhere between 1 to 5 MWe.

## Calculations and Results

For all options, the heat and power production are calculated, based on an input of 1 t/hr of biomass (as received).

The produced heat will is classified in three ranges:

- Low grade heat, temperature < 60 °C. In most cases, this heat can be considered as “waste” heat;
- Medium grade heat, temperature between 70 and 100 °C. This heat may be used for heating or cooling (absorption cooling);
- High grade heat, steam at 2 bar(g) or higher. This heat may be used for (process) industry.

***Direct firing of biomass***

System description
The simplified process flow diagram is given in figure 1.

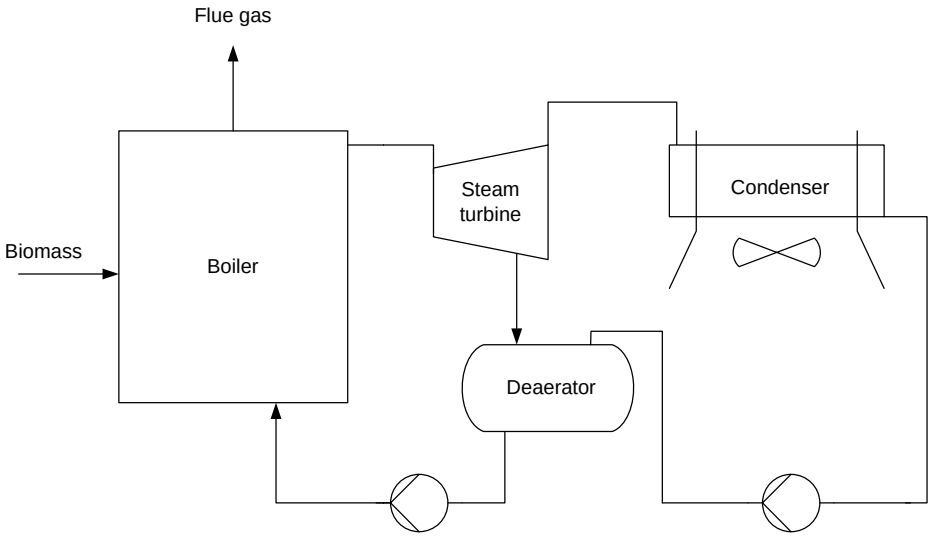


**Figure 1 Biomass direct fired**

Design parameters
The calculations have been based in the following main parameters:

- Steam pressure : 45 bara
- Steam temperature : 420 °C
- Condenser pressure : 0.2 bara
- Turbine efficiency : 70%
- Combustion air ratio : 1.3 (O2 conc. flue gas, 5.4 %, wet)
- Flue gas stack temperature : 160 °C

Results
The power and heat produced for a biomass feed of 1 t/hr are:

- E-power gross/net : 901 / 813 kWe
- Heat : 2.8 MWth, low grade heat

***Flash Pyrolysis***

In the comparison of the different options, the heat and power produced in the pyrolysis process is taken into account. Taking the 1 t/hr biomass as the starting point, the pyrolysis installation will produce the following:

- Pyrolysis oil : 0.57 t/hr
- Net heat : 0.5 MWth, high grade heat (steam)
- Net power : 87 kWe

The heat and electrical power required for drying of the biomass has been taken into account. The values are based on the Empyro installation to be built in the Netherlands.

***Flash pyrolysis – Diesel Engine***

System description
Pyrolysis oil (PO) is used as a fuel for a medium sized diesel engine (1 – 5 MWe).

Design parameters
The calculations are based on the following parameters:

- Heating value PO : 16.5 MJ/kg (LHV)
- Amount of PO : 0.57 t/hr (65 % yield)
- E-efficiency diesel : 43 %
- Heat efficiency : 43 %, medium (2/3) and high grade (1/3) heat

Results
The power and heat produced, starting with 1 t/hr of biomass, are:

- E-power diesel only / total : 1120 / 1207 kWe
- Heat diesel only : 0.37 high grade / 0.75 MWth, medium grade
- Heat total : 0.87 high grade / 0.75 MWth, medium grade

For clarity, these values are shown in figure 2.

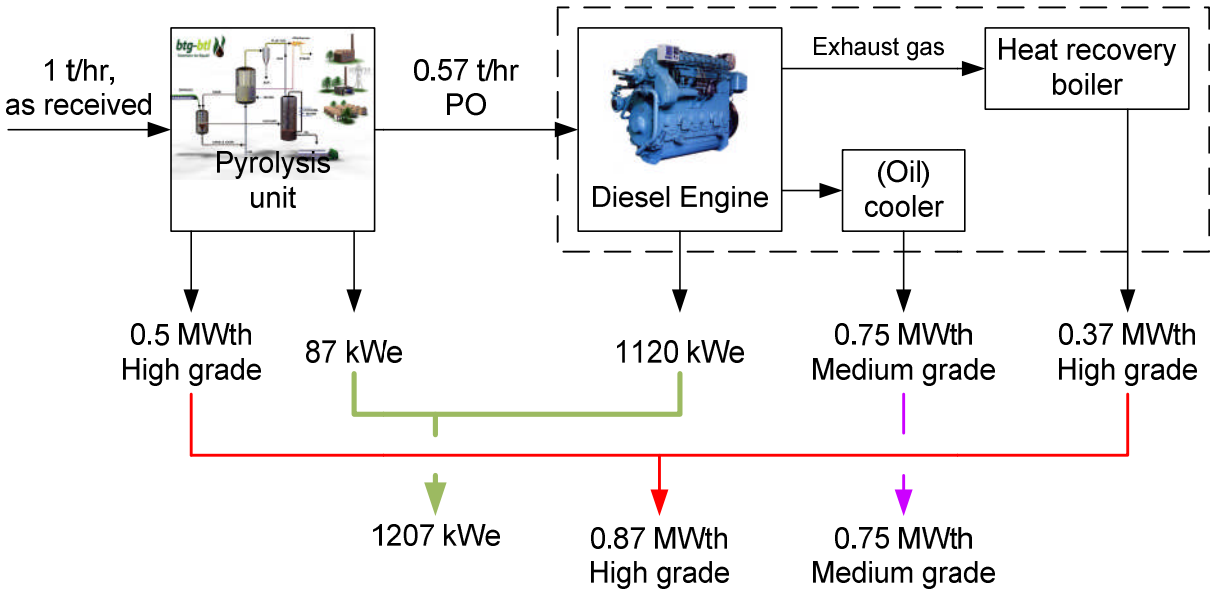


**Figure 2 Flash pyrolysis – diesel engine**

***Flash pyrolysis – Gas Turbine HRSG***

System description
Pyrolysis oil (PO) is used as a small gas turbine in combination with a heat recovery steam generator (HRSG).

Design parameters
The calculations are based on the performance data of an OPRA gas turbine (1.8 MWe) and the following parameters:

- Heating value PO : 16.5 MJ/kg (LHV)
- Amount of PO : 0.57 t/hr
- E-efficiency GT : 24 %
- Heat efficiency : 60 %, high grade heat

Results
The power and heat produced, starting with 1 t/hr of biomass, are:

- E-power GT only / total : 625 / 712 kWe
- Heat GT only / total : 1.56 / 2.06 MWth, high grade

***Flash pyrolysis – Gas Turbine and Steam Turbine***

System description
Pyrolysis oil (PO) is used as a small gas turbine in combination with a heat recovery steam generator (HRSG) and steam turbine. The steam system is identical to that of figure 1 with the exception that steam is generated in a HRSG behind the gas turbine.

Design parameters
The design parameters are equal to those used in the direct firing case and the gas turbine HRSG case.

Results
The power and heat produced, starting with 1 t/hr of biomass, are:

- E-power GT/ST only / total : 964 / 1051 kWe
- Heat GT/ST only : 1.18 MWth, low grade
- Heat total : 1.18 MWth low grade, 0.5 MWth, high grade

## Conclusions and Considerations

A summary of the calculations is given in the table below. For the calculation of the overall heat and power efficiency, the low grade heat has been excluded.

**Table 1 Summary results**

| | Unit | Grade | Direct fired | Diesel Engine | GT with steam | GT / ST |
|---|---|---|---|---|---|---|
| E | kW | | 813 | 1207 | 712 | 1051 |
| Heat | kW | high | | 869 | 2059 | 496 |
| | kW | medium | | 747 | | |
| | kW | low | 2792 | | | 1181 |
| E-efficiency | % | | **19.5%** | **29.0%** | **17.1%** | **25%** |
| H&P-eff | % | | **19.5%** | **67.8%** | **67%** | **37%** |

It can be seen that for the small scale considered, heat and power generation based on PO is an interesting option, especially when the produced heat can be utilized.
The PO based options either result in a higher net electrical efficiency and/or produce more valuable heat.

An advantage worth mentioning is the fact that PO based installations will have a much smaller footprint compared to a direct fired installation. Also the logistics will be easier as the PO can be stored and will take much less space due to its higher energy density.

A. Toussaint
BTG BioLiquids BV
E-mail : ardy.toussaint@btg-btl.com