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Fit4Micro

Deliverable 2.7

Final mass, energy and elemental balance input for value chain assessments 1

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Acronyms

GHG: greenhouse gases
LPG: liquified petrol gas
DHO: domestic heating oil
RED-III: renewable energy directive III
HPO: Hydrotreated Pyrolysis oil
FPBO: fast Pyrolysis bio-oil
SPO: Stabilized Pyrolysis Oil
PDU: Process development unit
LCA: Life cycle assessment

1. Introduction

In the Fit4Micro project the aim is to develop a highly efficient micro combined heat, cool and power system, working on renewable energy. With the fluctuating and seasonal availability of solar and wind energy, the use of bioenergy as dispatchable renewable energy source provides a solution to achieve the desired flexibility in system operation.

Buildings represent a hard-to-decarbonise sector in the European energy system. Around 40% of the final energy consumption and 36% of the emissions from energy in Europe is ascribed to the building sector[1]. Heating, cooling and hot water account for 79% of the total final energy use in EU households[2], of which 75% is still generated from fossil fuels. The energy demand in the European building sector is very diverse, including for example old city centers, traditional rural homes and newly constructed districts. The demand for heating, cooling and power is strongly affected by geographical location and season.

Development of a flexible energy system is important to achieve widespread implementation (and decarbonization) in the European building sector. The efficient use of resources is important to reduce costs and limit greenhouse gases (GHG) emissions. Applying a combined heating, cooling and power system is an essential strategy to achieve resource efficiency across use-cases. In addition, logistics of the energy supply are a crucial aspect. While electrical grid connections are available for most buildings, the total capacity of the grid can be insufficient in case of high demand, or during peak PV production hours. A natural gas grid connection is less common but does allow relatively easy introduction of renewable gas in buildings. Buildings where both the electricity supply is limited and a gas grid connection is unavailable are currently mostly heated by liquid and liquified fuels such as liquified petrol gas (LPG) or domestic heating oil (DHO), which are produced from crude oil. Heating with traditional biomass or wood pellets is a way to utilize renewable energy sources in the building sector, however local emissions of pollutants are an important concern, and the future demand for biomass for products and chemicals will push prices and limit availability.

1.1. Production of a commodity biofuel

Ideally, a renewable fuel should have a high energy density to limit storage volumes and optimize distribution. For flexible operation, either a gaseous or liquid form is preferred to rapidly control the combustion process. In terms of sustainability and availability, it is important that a wide and diverse feedstock base, preferably consisting of residues, can be utilized. In Fit4Micro, the ambition is to produce a liquid biofuel with high energy density from Renewable Energy Directive III (RED-III) compliant resources. These resources will be converted into a liquid biofuel suitable for domestic heating, cooling and power system through processing in two stages; i) fast pyrolysis and ii) hydrotreatment.

The final product obtained from processing is referred to as 'Hydrotreated Pyrolysis Oil', abbreviated to **HPO**.

1.2. Fast pyrolysis

In the first stage, the fast pyrolysis process, the solid residue is converted into a liquid bioenergy carrier referred to as 'Fast Pyrolysis Bio-Oil' or **FPBO** in short. Fast pyrolysis is a relatively simple process, involving the rapid heating of a feedstock in absence of oxygen. The product is a mixture of shorter fragments of the

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[1] European Commission, 2020. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives

[2] European Commission, 2016. Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)

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original feedstock. The fast pyrolysis process is self-sustaining and requires no external energy input, some surplus renewable energy is even available for local usage. Furthermore, no chemicals or other resources are required for processing. This results in relatively low operational costs, combined with the limited investment costs for the installation the fast pyrolysis process can be applied at a medium scale (~25 MW input). Construction of the pyrolysis plant near the feedstock avoids long distant transport of the biomass.

FPBO is a liquid bioenergy carrier with properties that differ from conventional, fossil derived, fuels. FPBO is a mixture of hundreds of different organic molecules and typically contains a significant (~25 wt.%) amount of water. The oxygen content is also high (~50 wt.%) and as a result the energy density is relatively low (typically $^{1}/_{3}{}^{rd}$ of the energy density of typical fossil fuels such as diesel or gasoline). FPBO can be applied for domestic heat generation directly, however the poor combustion properties and distinct odour make it less suitable for direct consumer usage.

The production of FPBO achieved TRL-9 in recent years, with several commercial scale pyrolysis installations in operation in Europe. Three installations apply the fast pyrolysis technology developed by BTG and commercialized by sister company BTG-Bioliquids BV, and are located in Hengelo (the Netherlands), Lieksa (Finland) and Gävle (Sweden)[3].

1.3. Hydrotreatment

Hydrotreatment involves the reaction of FPBO with hydrogen in the presence of a catalyst. Typically pressures up to 200 bar and temperatures up to 400 °C are applied. In the process, the oxygen content of the FPBO is decreased until ultimately a hydrocarbon fuel remains. Contrary to FPBO, this fuel (HPO) is fully miscible with conventional fuels and can be distilled to obtain various fractions which fall for example in the diesel or gasoline boiling point range. A full review on the hydrotreatment of pyrolysis oil was recently published by Han et al[4].

BTG developed an upgrading process involving two stages, first the FPBO is stabilized by reacting it with hydrogen gas over a proprietary catalyst to form Stabilized Pyrolysis Oil (SPO). The SPO is then further hydrogenated over a conventional hydrotreatment catalyst to form HPO. The product properties of the HPO can be controlled by adjusting the process conditions in the hydrogenation stage. A schematic representation of the upgrading process is presented in Fig. 1. The abbreviation HPO^- and HPO^+ are introduced to describe a lower, respectively higher, severity in the hydrotreatment process.

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[3] https://www.btg-bioliquids.com/

[4] Yinglei Han, Mortaza Gholizadeh, Chi-Cong Tran, Serge Kaliaguine, Chun-Zhu Li, Mariefel Olarte, Manuel Garcia-Perez, Hydrotreatment of pyrolysis bio-oil: A review. Fuel Processing Technology, Volume 195, 2019.

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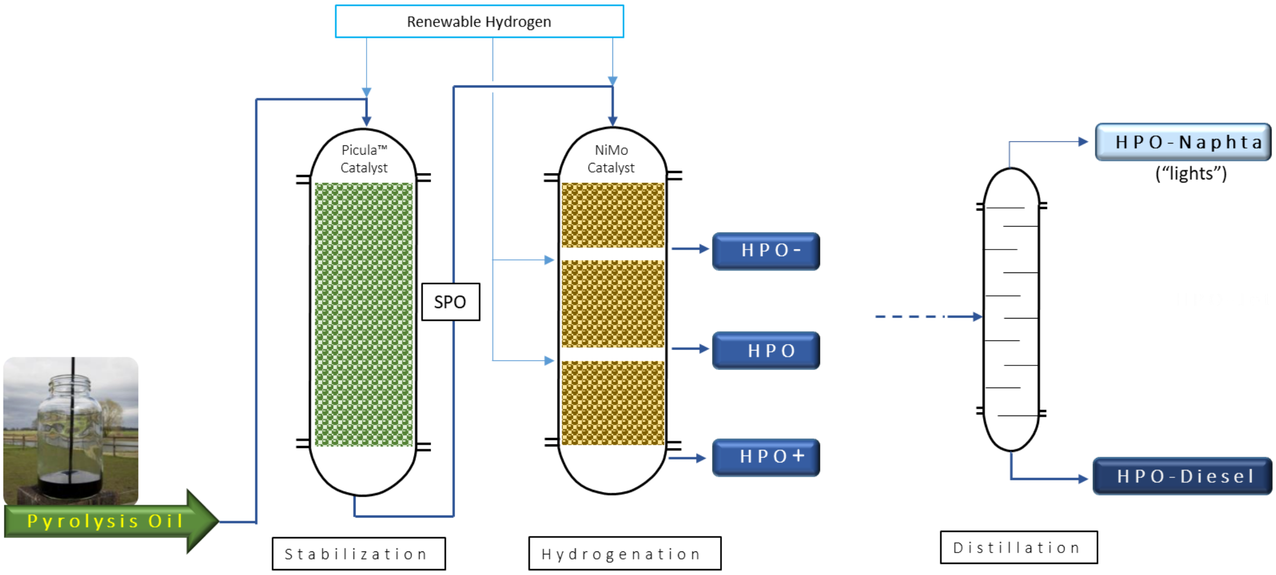

Figure 1: Schematic representation of the hydrotreatment process.

The hydrotreatment process is currently under development and a process development unit (PDU) with a capacity of 50 kg/day is available at BTG. For future implementation, a relatively large size of the hydrotreatment installation will be required to benefit from the economy-of-scale principle and reduce the fuel production costs. Likely, a hydrotreatment process will be fed with FPBO from 3-10 pyrolysis installations.

One of the goals in the Fit4Micro project is to obtain a HPO product with suitable quality for micro gas turbine usage, at the lowest possible operational costs. This is targeted by i) reducing the biomass feedstock costs by targeting residual streams and ii) limiting the hydrogen consumption in the hydrotreatment process. Experimental activities are employed within the project on both approaches. In this report, data is supplied on the mass, energy and carbon balances for the entire value chain as input for the (life cycle assessment) LCA work, also performed within the project (WP-6).

2. Scenario’s

As mentioned above, there is a difference in the capacity (scale of operation) for the pyrolysis process and the hydrotreatment installation. This feature allows on the one hand the flexibility of targeting different feedstocks in a decentralized installation near the origin of the feedstock, while on the other hand it allows for direct integration with current fossil-fuel industry on the back side of the value chain. Because the FPBO is a relatively uniform liquid bioenergy carrier, it is expected FPBO’s derived from different origins can be blended and co-processed in the same hydrotreatment installation to form the HPO.

For the Fit4Micro project, three different resources have been selected already in the proposal stage, i.e. Forest/Woody Residues (Bark), Contaminated Wood and Wheat Straw. Experimental research will be performed for each of these materials within the project to provide the data required for the value chain assessments performed in WP-6. In this current report, the experimental data is not yet available and estimate values will be supplied to allow a timely start of the value chain assessment work.

The overall concept for the biofuel supply considered in the Fit4Micro project is presented in Fig. 2. It must be noted here the HPO can also be considered for other applications, and possible by-products could be used in the micro gas turbine.

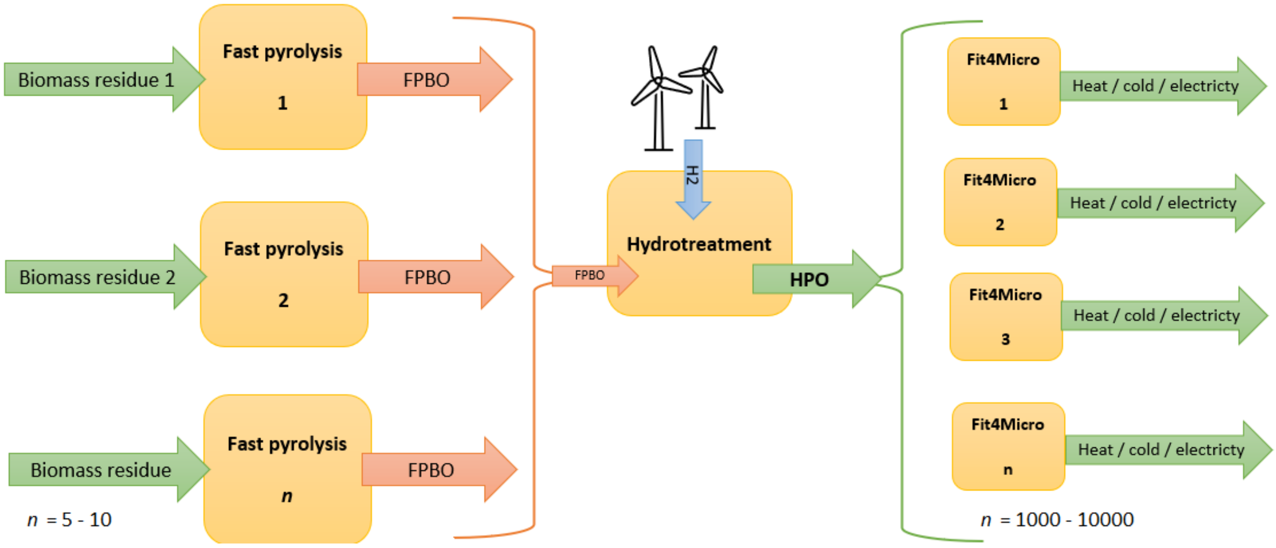

Figure 2: Concept of decentralized fast pyrolysis, centralized hydrotreatment and HPO utilization

3. Mass, energy and elemental balances

For the mass, energy and elemental balances, experimental data on the HPO production from three different feedstocks will be generated during the project. In this report, an initial estimate is given based on BTG's experience with the fast pyrolysis and hydrotreatment processes respectively. For both processes, a range will be supplied to stipulate the current uncertainty in the numbers.

3.1. Fast pyrolysis

The fast pyrolysis of biomass is optimized for the production of FPBO. For clean stem wood, the yield of FPBO can be up to 75 wt.%. Residual biomass materials typically achieve lower yields, ranging from 50-70 wt.%. During processing, by-products in the form of non-condensable gas and char are generated as well. In commercial scale pyrolysis plants these by-products are used for heat and power generation, to supply the energy need of the process. Excess energy is supplied in the form of heat (steam) to a neighboring factory and electricity (to the grid) in the pyrolysis plant located in Hengelo. For the pyrolysis plants in Lieksa and Gävle, there is limited excess energy as most energy is needed to dry the feedstock (sawdust) from 40-60 wt.% moisture back to 5 wt.% moisture used in the pyrolysis process.

The estimated mass (γ_m), energy (γ_E) and carbon (γ_C) balance for the three feedstocks in the fast pyrolysis process is presented in Table 1. Yields are defined according to the equations below the table

Table 1: Estimated mass, energy and elemental balance for the fast pyrolysis process.

Feedstock	Mass yield [γ_m]	Energy yield [γ_E]	Carbon yield [γ_C]
Woody/Forest Residue (Bark)	0.60 – 0.70	0.55 – 0.65	0.55 – 0.65
Contaminated wood (B-wood)	0.50 – 0.60	0.45 – 0.55	0.45 – 0.55
Wheat Straw	0.50 – 0.65	0.45 – 0.60	0.45 – 0.60

Mass yield:

$$\gamma_m = \frac{m_{FPBO}}{m_{BM}} \quad [-]$$

m_{FPBO} = mass of FPBO produced in the pyrolysis process (as received basis, including water) [g]

m_{BM} = mass of biomass fed to the pyrolysis process (as received basis, including water) [g]

Energy yield:

$$\gamma_E = \frac{m_{FPBO} \cdot LHV_{FPBO}}{m_{BM} \cdot LHV_{FPBO}} \quad [-]$$

LHV_{FPBO} = Lower Heating Value of the FPBO product (as received basis, including water) [J/g]

LHV_{BM} = Lower Heating value of the biomass feedstock (as received basis, including water) [J/g]

Carbon yield:

$$\gamma_C = \frac{m_{FPBO} \cdot C_{C,FPBO}}{m_{BM} \cdot C_{C,BM}} \quad [-]$$

$C_{C,FPBO}$ = Concentration of carbon in the FPBO [g/g]

$C_{C,BM}$ = Concentration of carbon in the biomass [g/g]

In addition to the main product, the FPBO, the fast pyrolysis process produces a solid (char) and gaseous by-product with fairly even distribution (i.e. for 0.7 w/w FPBO yield, approx.. 0.15 w/w char and 0.15 w/w gas can be expected). Combustion of by-products delivers the energy required to run the pyrolysis process, which is about 10% of the energy present in the biomass. This corresponds to 25-33% of the energy present in the by-products.

The remaining energy is available for external usage. In cases where relatively wet biomass (40-60 % w/w) is used, most of this energy is required for drying and there is no excess energy available for export. In cases where relatively dry biomass is used, most of this energy is available for export. The carbon from by-products is released in the flue gas as CO_2.

3.2. Hydrotreatment

The hydrotreatment process converts the FPBO into a hydrocarbon fuel. The process is currently under development and not yet commercially available. During the process development, the best results (in terms of carbon efficiency) are obtained when a two-stage process is applied. First the FPBO is stabilized to form SPO, in a second stage the SPO is converted to the HPO product. If desired, the HPO can be further purified for example by distillation.

In both hydrotreatment stages, a gaseous and aqueous byproduct is formed. These byproducts can be utilized to recover their energy content (combustion & anaerobic digestion respectively) or in case of the aqueous by-products the recovery of organic chemicals such as mono ethylene glycol or ethanol can be considered (after purification). Because of the uncertainties associated with the current technology readiness level, only the recovery of energy from these byproducts is considered here.

The information available so far is rather limited, yet there is no reason to believe the original biomass resource will affect the yields in the hydrotreatment process a lot. Therefore, generalized data is presented below, based on experience at BTG, which is applied to the forest residue, contaminated wood and wheat straw feedstocks similarly. Here it must be noted a 'worst case' assumption is used with respect to the hydrogen consumption (0.055 kg/kg FPBO). In the Fit4Micro project the target is to produce a low-severity HPO, which aims to reduce the hydrogen consumption to below 0.04 kg/kg FPBO.

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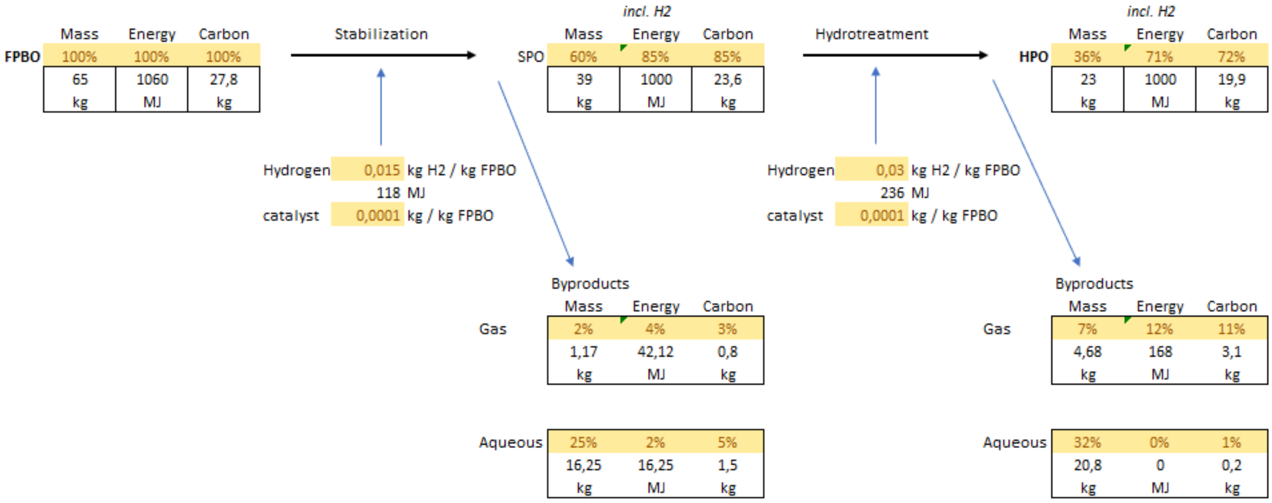

Figure 3: Mass (wet/as received basis), energy and carbon balance for the hydrotreatment process

4. Discussion & Conclusion

The data presented in this report is preliminary data, which is estimated based on experience with different biomass feedstocks. During the Fit4Micro project, the selected feedstocks will be converted to HPO to obtain information on the process performance.

The document will be updated in deliverable 2.8: Final mass, energy and elemental balance input for value chain assessments 2 due M44, which will include more information as work advances under task 2.6 and parallel tasks.

The work done in WP2 and WP3 of the project will give important information on the fuel quality required for the micro gas turbine. In case lower severity HPO can be applied, the hydrogen consumption will go down drastically, and overall mass, carbon and energy efficiency will improve compared to the estimated values.