Processing concept for the production of biomass fuel from mixed municipal solid waste

H. Giani*, A. Feil*, K. Hornsby* A. Clausen*, AND T. Pretz*

** I.A.R., Department of Processing and Recycling, RWTH Aachen*

University – Wuellnerstr 2, 52062 Aachen, Germany

giani@ifa.rwth-aachen.de

Abstract: The Material Advanced Recovery Sustainable Systems (MARSS), funded by the EU Life Plus Programme, is a demonstration project that combines both biological and mechanical processing of mixed rubbish, known as municipal solid waste (MSW), with the main goal to recover a biomass fuel suitable for use in renewable biomass power plants from MSW after it has been subjected to biological drying. The new MARSS plant will be constructed as part of an existing Mechanical Biological Treatment (MBT) plant in Mertesdorf, Germany. On basis of a detailed characterization programme of the input Material, a broad sorting campaign was carried out on technical lab scale. The testing campaign results indicate that the majority of the biodegradable fraction is concentrated in the < 40 mm fraction. According to these results, it is possible to enrich the biogenic material by sieving at 40 mm. Moreover about 45 % of the energy content of the 0-40 mm fraction is smaller 10 mm with a fossil carbon content less than 2 %. Therefore it is possible to remove the fossil carbon material by sieving activities. By additional further steps, it is possible e.g. to increase the heating value of the grain-size category 4-11.5 mm up to 13.300 kJ/kg. Based on the results of the sorting campaign, the concept for the demonstration plant was developed and the mass and volume flows within the process were calculated.

Keywords: biomass fuel, municipal solid waste, mechanical biological treatment, Landfill Directive, biodegradable municipal solid waste, sieving, density separation

1. Introduction

Concerns about climate change and the effects of waste management on the environment are becoming more important in recent times. The objective of the EU Landfill Directive of April 26 1999, is “to provide for measures, procedures and guidance to prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect, as well as any resulting risk to human health, from landfilling of waste, during the whole life-cycle of the landfill” (EU, 1999, Art. 1,1).

Through landfilling and treatment of waste, several greenhouse gases (GHGs) occur which contribute with the greenhouse effect. Landfilled biodegradable municipal solid waste (BMW) undergoes digestion processes that produce GHG in particularly methane (rd. 50 % by volume) and CO_2 (epa, 1991). According to the United Nations Framework Convention on Climate Change (UNFCCC), methane has a 21 times higher global warming potential than CO_2 when considering a time horizon of 100 years (Houghton et al., 1996). Because of that the EU Landfill Directive underlines the importance of reducing BMW being landfilled as it is considered the main source of climate harming gas emissions in the form of methane (EC, 2012). According to Article 5,2 c, the EU Landfill Directive demands the avoidance of BMW being landfilled by at least 65 % (by mass) in comparison to the production of biodegradable waste in 1995 (EU, 1999, Art. 5,2 c). However, the European Environment Agency (EEA) states that several European countries do not yet meet the requirements (EEA, 2013). Many of these countries have rather just started deciding on whether or how to set up their waste management system.

In practice, a wide range of different systems exist in these countries:

1. Separate collection, e. g. of bio waste and paper waste
2. Incineration of mixed municipal solid waste (MMSW)
3. Biological Treatment (MBT) of MMSW
    - Biological degradation (aerobic/anaerobic)
    - Biological drying

All these systems have advantages and disadvantages, which are discussed in detail in the publication “Production of biomass fuel from mixed municipal solid waste by MBT“, (Clausen et al., 2013). The acceptance of these individual systems varies from region to region as well as different stakeholder groups within the EU.

In order to provide an alternative to the above mentioned waste management systems, the Life+ demonstration project MARSS (Material Advanced Recovery Sustainable Systems) was designed. The primary objective of MARSS is to test a new waste processing technology using step-wise innovations. The consortium of five partners from Germany, Italy and Spain (coming from industry and academia together with a medium-sized enterprise (SME)) have developed a joint project to build, test and monitor a demonstration plant in Germany to determine the most effective way to separate the biologic material from MMSW into a refined renewable biomass fuel commonly known as Refuse Recovered Biomass Fuel (RRBF) and reuse it as a source for energy production. The goal is to produce an RRBF that reach the market demands for purity together with a high calorific value, and complies with the demands of the EU Landfill Directive Art. 5 and Art. 6. If the processing is successful, greenhouse gas (GHG) emissions will be reduced by the substitution of fossil fuels as well as by avoiding biodegradable substances being landfilled and hence resulting in further reductions of emissions.

The new demo plant will be built in Mertesdorf, near Trier, Germany, working alongside the existing MBT plant which employs the Herhof Stabilat Process®. In this process, the MMSW is stabilized through aerobic biological treatment steps to produce high calorific refused derived fuels (RDFs). The capacity of the MBT plant is drying and processing about 220,000 tonnes per year of MMSW coming from 532,000 inhabitants in and around the Trier region. Through the biological drying process the average water content of about 40 % of the input material, is reduced by about 30 %, which results in a total mass loss of at least 35 % (Clausen et al., 2013).

The project aims to provide a full demonstration activity and to close the cycle from untreated MSW to the production of final sustainable biomass fuel to be used as a carbon neutral heat and fuel recovery. This project will also demonstrate CO_2 in a quantifiable way, through the monitoring actions how such a process supports and enhances environmental protection through the reduction of harmful residues (gas and solids) from incineration plants, landfill as well as other impacts such as absolute loss of valuable resources such as NF metals. Final testing in commercial heat and power plants working with a range of different energy recovery technologies will be carried out to verify the quality and performance of the recovered biomass fuel.

The MARSS demonstration plant will receive a separate stream of about 10 Mg/h out of the dried MSW input material from the MBT plant where the organic materials will be cleaned and enriched by mechanical separation steps. Due to the fact that the majority of biogenic material is found in the fraction < 40 mm, only this material will be investigated regarding suitability to be used as a RRBF.

2. Materials and methods

The aim is to produce a high calorific RRBF product (in the range of about 12,000 kJ/kg) through the removing of inert and fossil-based fraction but at the same time to reach a high percentage mass output.

The following questions need to be answered in order to reach these conditions:

- What technical processes are necessary in order to reach the above stated goal
- Can the enrichment of biogenic materials take place solely through sieve classification used to separate out the inert or fossil-based fractions or are other cleaning steps necessary?

These questions can only be answered through detailed knowledge of the material and gravimetric composition of the input materials. Therefore, the Department of Processing and Recycling (I.A.R.) started a comprehensive test campaign to analyse the < 40 mm input material and to determine the potential of producing a RRBF (Clausen et al., 2013). The size and number of the samples taken follow the guidelines LAGA PN98 (Guideline for the procedure of physical, chemical and biological analysis regarding recycling/disposal of waste) (Laga, 2001).

The most important results of the test campaign were used as a basis for the plant concept and are presented.

Figure 1 shows the average material composition of the dried MMSW < 40 mm and the distribution of the materials into fuel groups according to the investigation work of mixed samples carried out by Clausen et al. (2013).

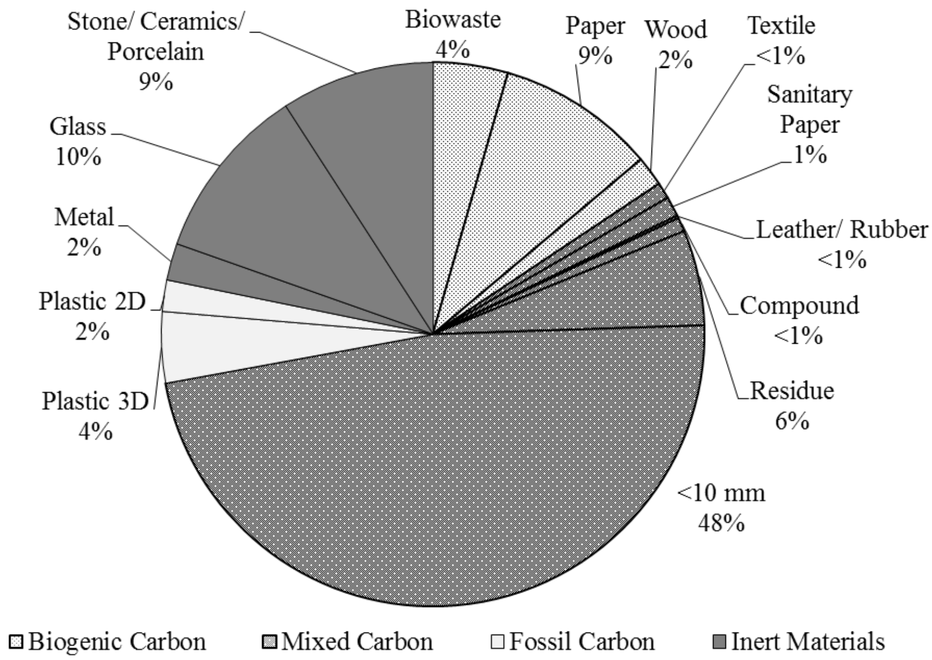

Figure 1: Relative composition according to material groups and fuel groups (Clausen et al., 2013)

The materials were distributed into three main groups on the basis of their composition namely "biogenic carbon", "fossil carbon" and "inert materials". In addition, fractions that could not clearly be identified as biogenic or as fossil carbon (e. g. sanitary paper) were put into a 4th group labelled as "mixed carbon".

The biogenic carbon fuel group (15 %) is the fraction that is further enriched to produce the RRBF. The inert materials group (21 %) must be separated out of the stream as it reduces the overall heating value and increases the ash content of the RRBF. The fossil carbon group (6 %) must also be separated out as it results in a negative CO_2 balance and therefore cannot be considered as sustainable. Particles with a size of 0-10 mm, which make up just under 50 % of the material investigated, were not dealt with in the first material characterisation testing programme. This fraction was therefore classified as part of the “mixed carbon” group. However, based on the high mass content, this fraction of 0-10 mm plays a significant role in the production of RRBF.

Figure 2 shows the water content, ignition loss and the heating value (dry (d) and with water (ar)) of the different material groups and size of particles. The water content influences the mass balance as well as the heating value (ar) (DIN 51900, 2000). The ignition loss indicates the amount of organic dry matter that the material contains, which is an indicator for the applicability of a material as a fuel (DIN 18128, 2002).

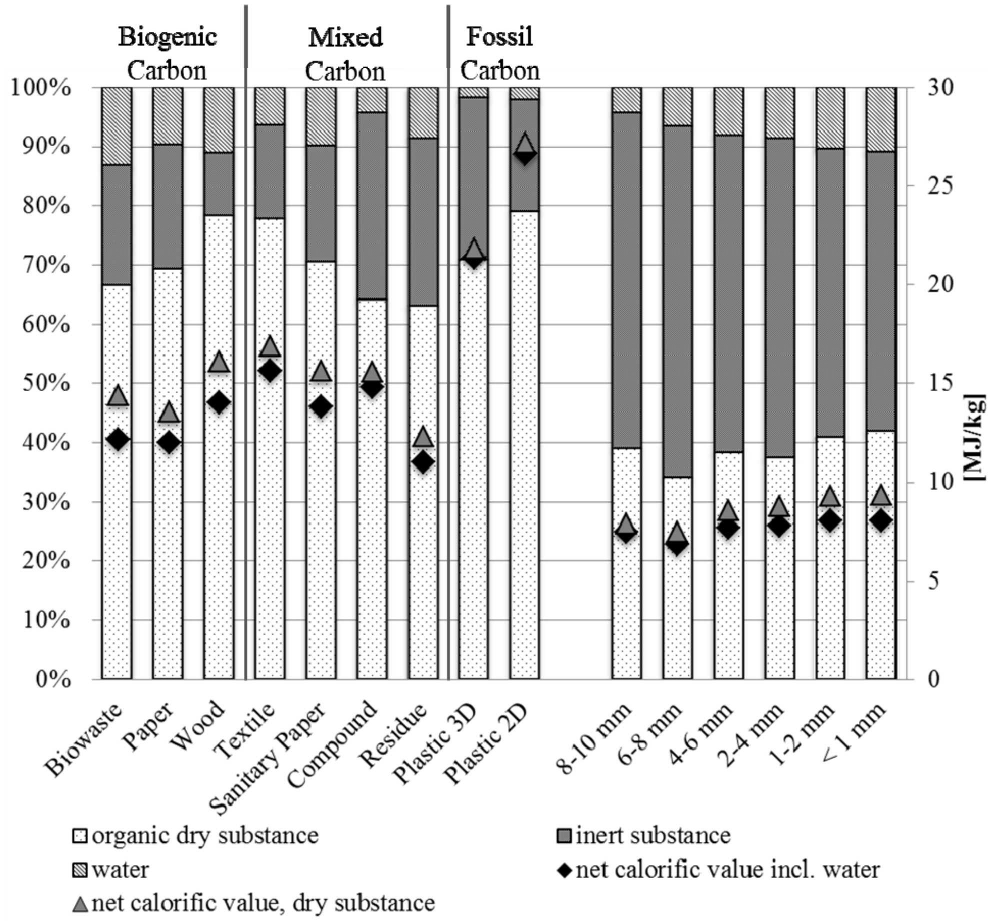

Figure 2: Relative composition of the material fractions in terms of water, organic dry substance and inert substance (primary y-axis) combined with the specific net calorific value (d and ar) (secondary y-axis). (Clausen et al., 2013)

It is clear that the biogenic carbon has a heating value (ar) of about 12-14,000 kJ/kg with a water content of about 10-11 %, and has an organic content of about 70-80 %. The heating value of the particle size of 0-10mm is about only 8,000 kJ/kg. The reason for this is the high content of inert material of about 50-60 %.

The ignition loss provides some information about the organic fractions at this particle size, however it does not determine if the fractions originally come from fossil or biogenic sources. However, the fraction size 0-10 mm accounts for about 45 % of total mass and contains therefore the highest energy content as shown in Figure 3. Therefore investigations should be made into this fraction (Clausen et al., 2013).

Particles 10 to 30 mm contain about 40 % of the energy content noting that half of the material comes from biogenic sources. It is also of note that the distribution of the different fuel groups in the particle size > 10 mm is very similar. This shows that it is not possible to enrich the RRBF in the particle size > 10 mm only by sieving.

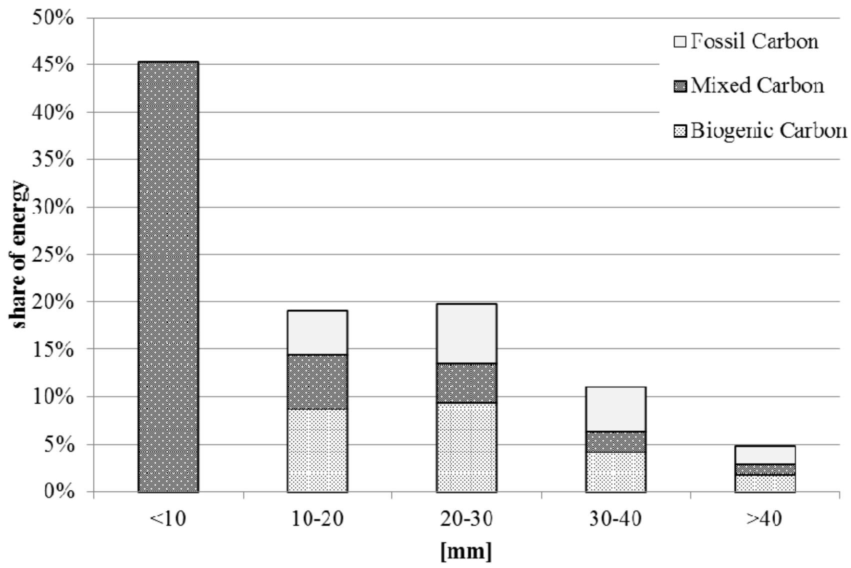

Figure 3: Distribution of the net energy content across the particle size fractions including the allocation of the origin of the energy to fuel groups. (Clausen et al., 2013)

3. Results and Discussion

The following provides a summary of the main results of the material investigation, which were taken into account for the layout of the plant concept.

- Separation into single fuel groups cannot be reached using only sieving steps of size > 10 mm. The removing of fossil as well as inert fractions as a basis to produce a high value RRBF demands further processing steps, e.g. to utilise the huge density difference of the inert and organic materials by density separation.
- Just under half of the mass and the energy content of the dried material in the size group < 40 mm can be found in the fraction size 0-10 mm. This fraction plays an important role in the production of RRBF and therefore must be investigated further to determine feasibility.
- In addition, a higher content of inert materials (about 50-60 %) are contained in the particle size group 0-10 mm in spite of the fact that the heating value is only about 7-8,000 kJ/kg. In order to raise the heating value of this fraction, it would be necessary to separate out the inert fractions.

On the basis of these results further investigations will be carried out in the laboratories and testing units of I.A.R., with the following aims:

- Additional investigations of fractions 0-10 mm.
- Testing of sieve processes under realistic conditions with the aim to produce desired particle groups in a pre-conditioning step required for density separation.
- Wind sifting tests to separate out the heavy fractions i.e. the inert materials.

Fossil content of the fraction 0-10 mm

The determination of the fossil fractions was made in accordance with Chapter II C1, used in the determination of contaminants particles in compost "„Methodenbuch zur Analyse organischer Düngemittel, Bodenverbesserungsmittel und Substrate“. (Kehres et al., 2006). The results of the analyses show that less than 2 % visible plastics are contained in the fraction 0-10 mm. It is therefore possible to reduce the fossil content using sieving at about 10 mm.

Sieving tests

Flip-Flow screens were used for the sieving tests in the Institute of Processing and Recycling (I.A.R.). The functionality of the Flip-Flow screens is described in the relevant literature (Schubert, 2003). The aim of sieving steps are: to distribute the main stream of material, to separate out the fossil fractions and also as a pre-conditioning step for following sorting tests made in the wind sifter to obtain the required particle distribution. The ratio between the maximum and the minimum particle size in the input should not be more than 3:1. The < 40 mm materials were sieved first at 11.5 mm and the sieve underflow followed at 4 mm sieving size. Tests were carried out on the wind sifter for particles sized 4-11.5mm with the following results.

In order to carry out the mass balances, the mass portions, the bulk density and the water content were determined for the separated outputs. In addition, the heating value, the ash content (DIN EN 14775, 2009), the carbon content, hydrogen content and nitrogen content (DIN 51732, 2007) as well as chlorine (DIN 51727, 2001) and sulphur contents (DIN 51724-1, 2012) were determined for the particle size 0-4mm and 4-11.5mm. Figure 4 shows the characteristics of the sieving test in the form of product summary information notes.

Figure 4: Characteristics of the sieving test in the form of product summary information notes.

Wind sifter tests

Particle size group 4-11.5 mm was sifted using a Zick-Zack Wind sifter (Figure 5) at different wind speeds. The materials were separated according to density and their specific surface in a rectangular, air-flowing canal. The heavier, cubic inert materials such as glass and stones were separated out into the heavy material group whereas the lighter organic materials were blown out by the air stream into a cyclone where the particles separate from the air. (Schubert, 2003).

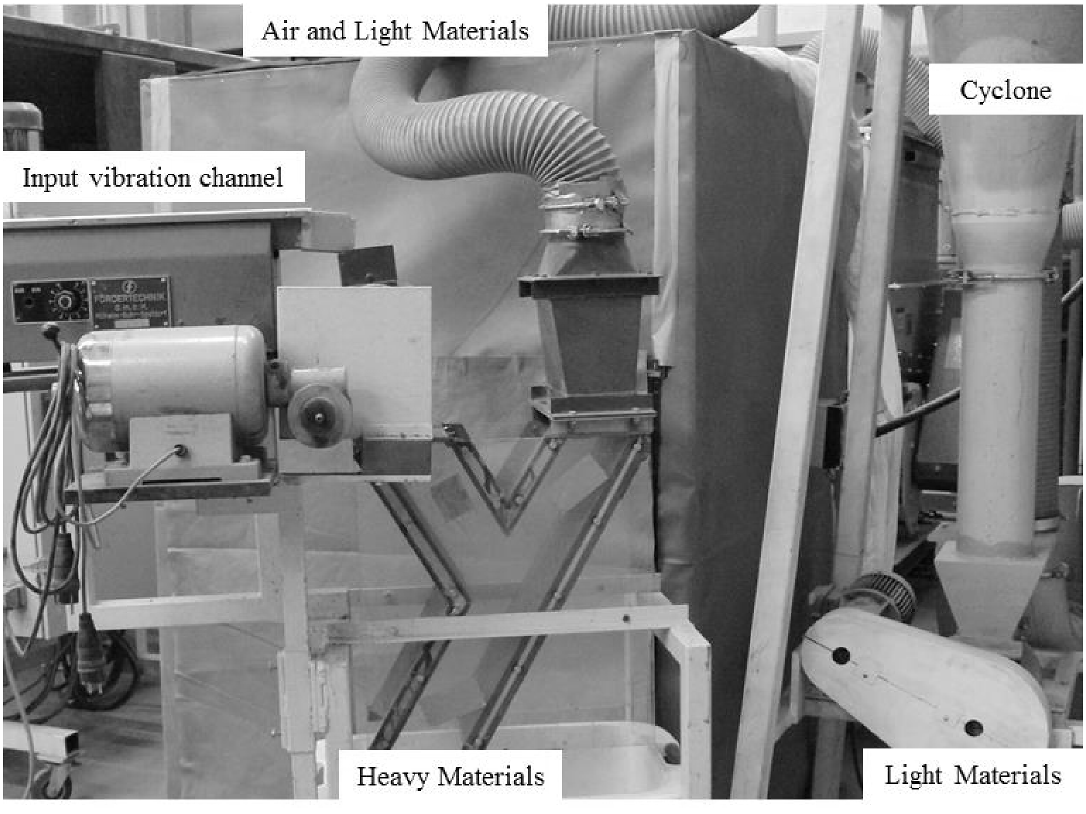

Figure 5: Zick-Zack Air sifter in the technical lab of I.A.R. Aachen.

Three different tests were carried out at three different air velocities, which were measured by a velocity anemometer in the middle of the wind canal. The results of the tests are summarised in Table 1. A specifically low wind speed of about 7.5 m/s was used in the first tests to collect the light fractions and hardly any inert particles were found. The wind velocity was raised in the second tests to about 10 m/s until heavy fractions were obtained, and in which hardly any organic materials could be found. A medium wind speed was used in the third test with about 8.7 m/s.

Table 1: Results of the air sifting tests

Test	Fraction	Velocity [m/s]	Mass content [%]	Bulk density [g/cm³]	Water content [%]	Ash content [%]	Calorific value [kJ/kg]
1	Light	7.5	37	0.22	14	28	12,100
	Heavy		63	0.54	10	67	not analysed
2	Light	10	64	0.28	12	32	10,700
	Heavy		36	0.90	5	85	not analysed
3	Light	8.7	52	0.29	9.8	31	13,300
	Heavy		48	0.78	5	77	not analysed

As expected, the ash content is much higher in the heavy material group than in the light fractions; the heating value of the light materials group could be raised due to the separation out of the inert materials in comparison to the sieved fractions.

The ash content of the heavy material group rose in line with the rise in wind velocity, which leads to the conclusion that less organic material ended up in the heavy material group. In contrast to our expectations, the heating value for test number 3 (medium speed velocity) was higher than the value obtained in test 1 (lowest speed velocity).

The reason for this could be that the woody material with a high heating value can have a two-dimensional surface (in stick form) and tend to fall into the heavy material group at low velocities. This has to be verified in further tests.

Figure 6 shows the results of test number 2 (medium velocity) in the form of product summary information notes.

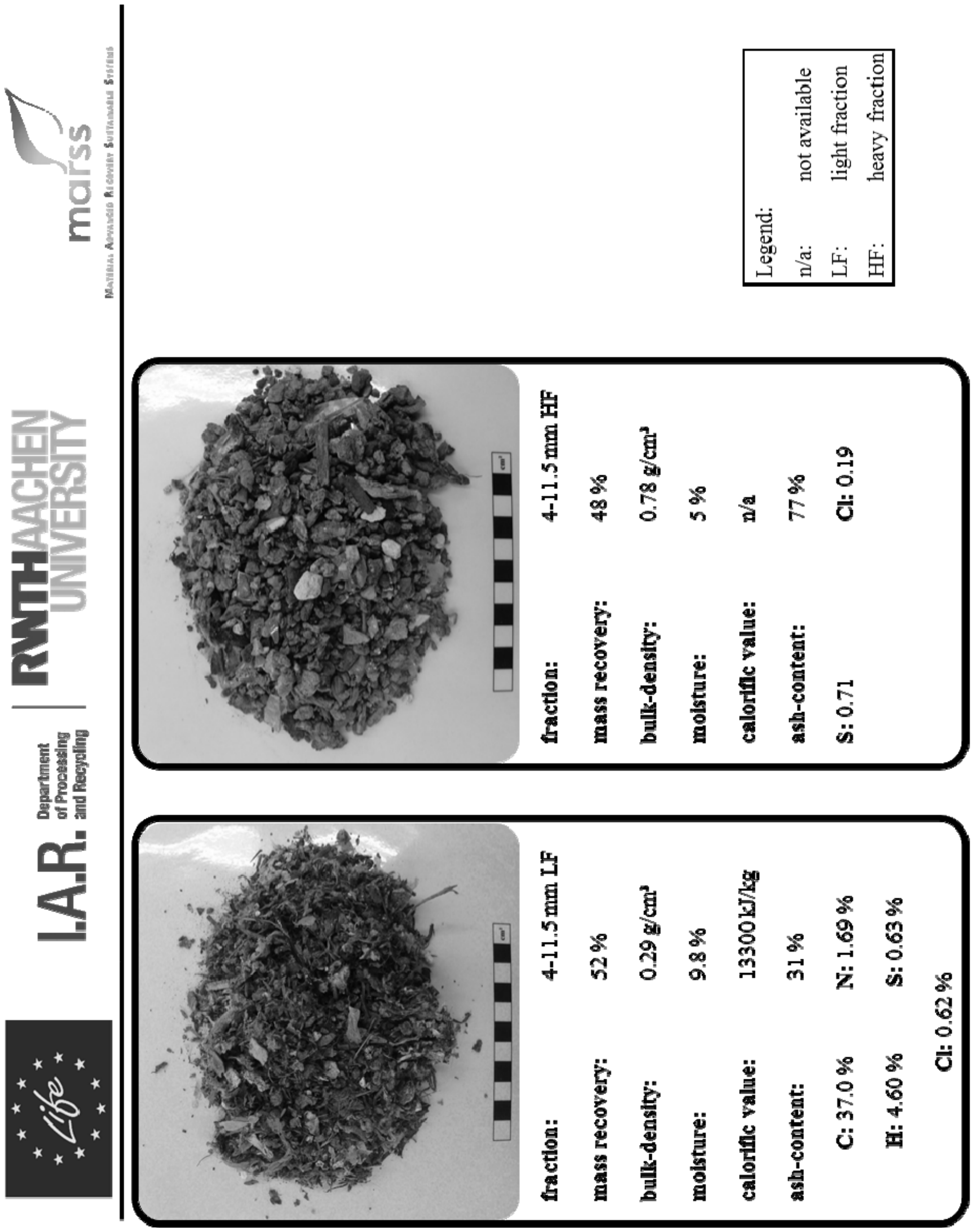

Figure 6: Characteristics of the air sifting tests in the form of product summary information notes.

2.1 Conclusion, process concept and outlook

Taking into account the demands of the plant process steps (Chapter 2), the following conclusions can be made from the results of the testing programme for the layout of the demo plant.

Quality and heating value: It is possible to separate out the fossil components down to 2 % using a sieve size of 10 mm. The heating value of the fraction 4-11.5 mm can be significantly raised using a wind sifter. No separation of materials was achieved using sieves when dealing with material in the size group of 10-40 mm; further treatment steps are necessary.

Mass recovery: Figure 7 shows the mass proportions using sieving and wind sifting (Test number 3) in the form of a Sankey Diagram.

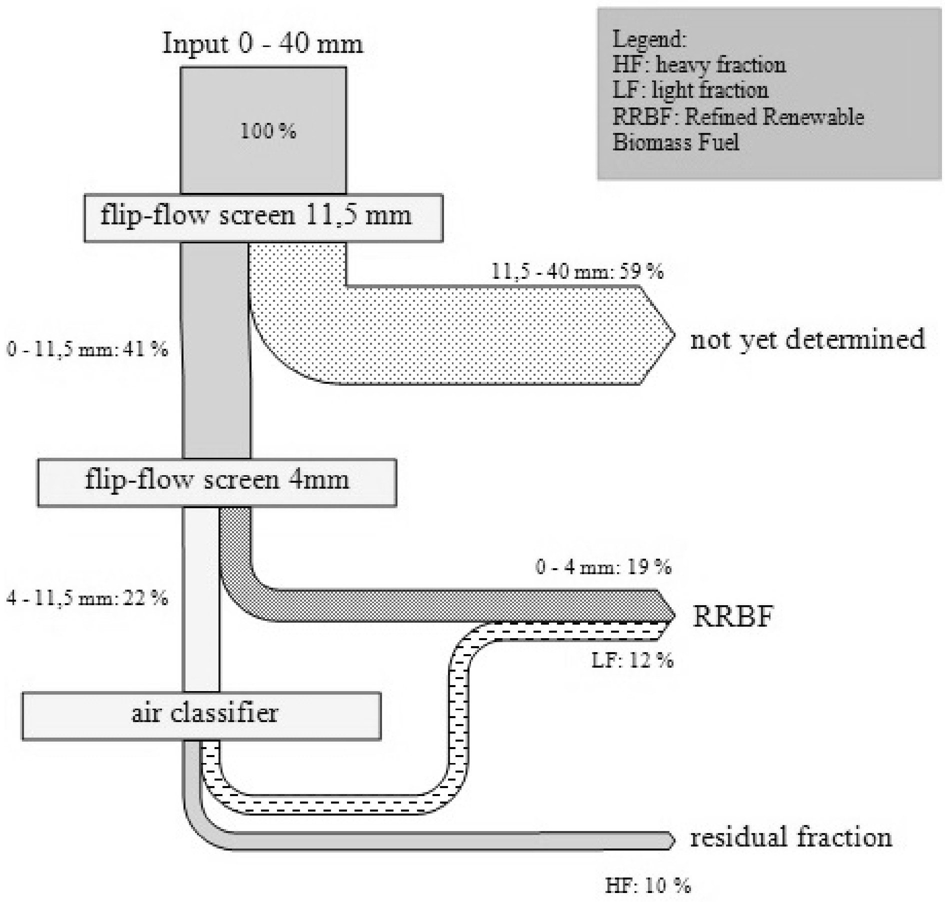

Figure 7: Sankey Diagram showing the mass proportions for sieving and wind sifting.

It is clear that the light fraction from the wind sifter only forms 12 % of the total mass < 40mm. When mixing the light fraction with particle size 0-4mm, the heating value (ar) is about 9,900 kJ/kg and the ash content is raised from 31 to 48 %. In order to raise the quality and the total mass output of the RRBF, the fraction 11.5-40 mm (59 % by mass), which has not been included up to now in the testing programme, should go through further processing steps in order to raise the total output of RRBF. Various possibilities can be considered: First of all, the first sieve size can be increased (e.g. from 11.5 mm to 25 mm). This measure would increase the mass recovery output – however possibly with negative effects on the efficiency of the bulk density sorting which could then impact negatively on the quality and heating value of the RRBF. Alternatively, the whole particle size group 11.5-40 mm could be density sorted, however it would be difficult to separate out materials with similar densities such as plastics from the RRBF. Both approaches will be further investigated in the demo plant as well as in the testing units in I.A.R. in Aachen.

The plant is designed in such a way to be partly mobile. The assembly or maintenance of some conveyor belts and screens can be carried out without major effort. Furthermore, one feed hopper enables the reapplication of intermediate goods. Through this flexible modular plant, several different treatment processes can be simulated. That is why the process can adjust with fluctuations in the range of the input material. Fractions can also be sorted using an air table in addition to the wind sifter. NF metals and FE metals will be separated out in addition to density separation. The following figure 8 shows one possible treatment process chain of the MARSS demo plant.

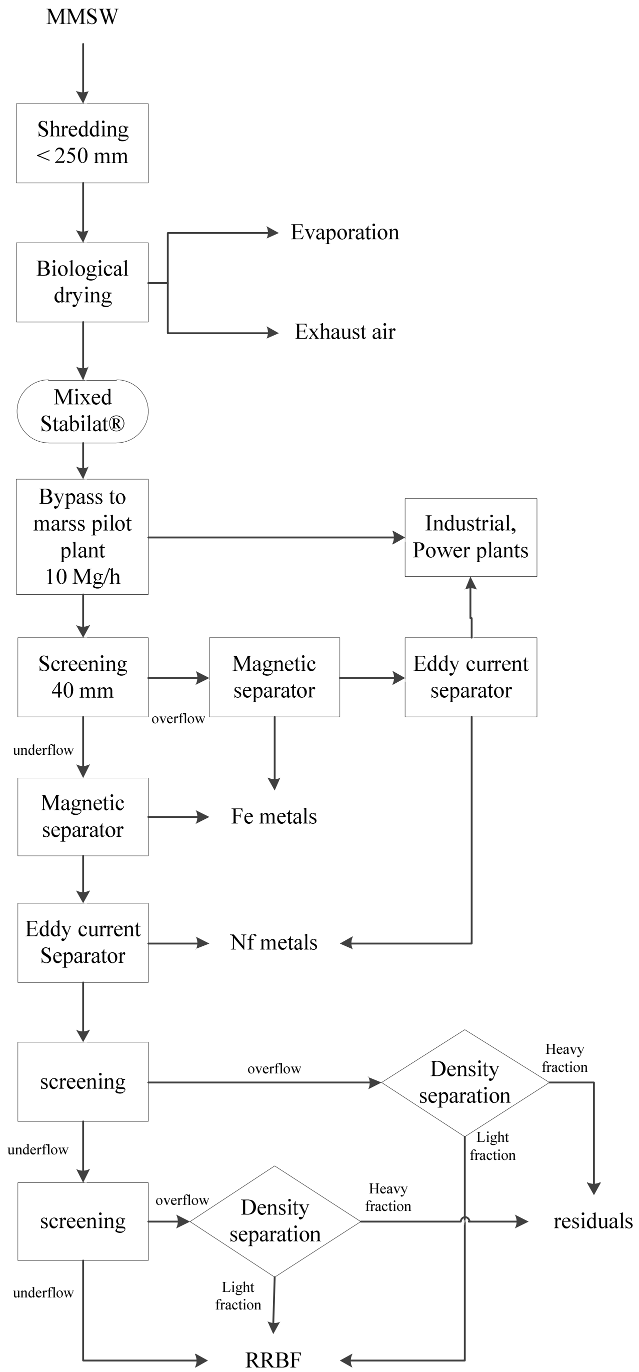

Figure 8: Process flow chart of MARSS demo plant

The process will be further developed with additional test campaigns in the installed demo plant in Mertesdorf, Germany.

In summary, the input material investigation as well as the chosen treatment and sorting steps provide an opportunity to produce a climate neutral RRBF from mixed municipal solid waste. The results obtained from the laboratory and testing units show that the chosen concept outlined in the flow sheet is suited to the production of RRBF. Future tests will deal with the further optimisation and layout of components and parameters in order to raise the quality and output of the production of RRBF from the MARSS demo plant.

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