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Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction

Deliverable No. D3.1

Working paper on evaluation criteria and selection of feedstock

Dissemination Level		
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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1 Summary

In this working paper, the feedstock specification and requirements for the torrefaction related tests foreseen in the SECTOR project with the ECN, CENER and Umeå University facilities are described. This information forms deliverable 3.1 of the project. For this deliverable input from ECN, CENER and Umeå University is mandatory. As Topell also will be performing torrefaction tests, Topell is encouraged to provide similar information as well.

2 Description of deliverable no. 3.1

Deliverable 3.1 is a working paper on evaluation criteria and selection of feedstock that is written by the partners within the SECTOR project that are operating the test facilities for torrefaction. The working paper forms the input for WP2, in which a broad set of raw materials are selected for the experimental work in lab scale at an early stage of the project, and a more focused selection for the pilot and demo phase.

3 Results

3.1 Energy research Centre of the Netherlands (ECN)

3.1.1 Facilities

Within the SECTOR project ECN is operating three facilities for torrefaction purposes. For screening purposes, a Mettler Toledo TGA850 lab scale thermo gravimetric analyser will be applied that can determine on the basis of a few grams the biomass weight loss as a function of temperature and time (figure 1). In order to also be able to determine the exothermic behaviour of the torrefaction processes a lab scale 20 litre batch fixed bed reactor will be applied (figure 2). The production of larger amounts of torrefied materials will be done on the semi-industrial pilot scale 50-100 kg/hr continuous moving bed reactor Patrig (figure 3). The design is based on moving bed technology with direct heating of the biomass materials by recycled product gas.

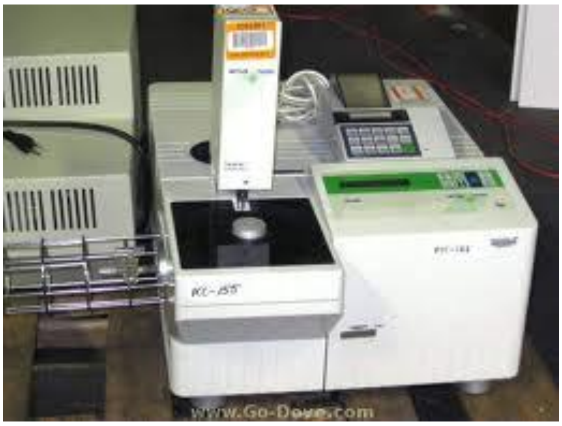

Figure 1: TGA

Figure 2: batch reactor

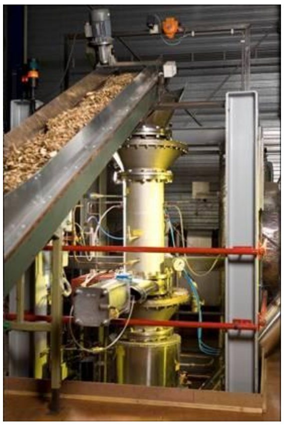

Figure 3: Patrig

3.1.2 Evaluation and selection criteria

With regards to the TGA no real evaluation and feedstock selection criteria are valid. The biomass applied will be a sample taken from larger batches and before analyses grinded and dried. Only with rather inhomogeneous batches, it could be complicated to obtain a representative sample. This is however something to take into account when performing the tests rather than when describing the evaluation criteria and selection of feedstock.

With regards to the batch and pilot reactor the evaluation criteria and selection of feedstock becomes important. The batch and pilot torrefaction reactors at ECN will require chipped or cut particles. For the torrefaction process developed by ECN this would mean particle sizes of ≤ 40x40x15 mm and no particles smaller than 5x5x5mm.This relates to handling characteristics, but more important also to thermal treatment characteristics. The particles should have an uniform thermal treatment. With particles becoming too large, the outer side of the particle will already be well heated, whereas the inner side is still cold and not being torrefied at all. As a consequence, the product would not be torrefied homogeneously, with all kinds of consequences for downstream processing (i.e. densification) and end-use.

In addition, ECN would like to work with a feedstock with a moisture content of 10-20 wt%. Feedstock with higher moisture contents would have to be dried before being fed into a torrefaction reactor. In a commercial plant (also in ECNs demo plant currently in construction), a conventional drying step will be installed, however at ECN such a drying facility is not available. For the lab scale batch reactor ECN is able to dry enough feedstock for testing, for the pilot scale reactor ECN will have to rely on drying the feedstock before delivery.

With regards to the batch reactor ECN can allow a broad range of feedstock for testing. With regards to the pilot reactor some restrictions will be in place that relate to either (i) the handling behaviour before and during torrefaction or (ii) the thermochemical behaviour during torrefaction. With regards to handling behaviour the feedstock should not get stuck during the processing. As an example of chipped feedstock that could easily be torrefied two pictures are presented below (figure 4).

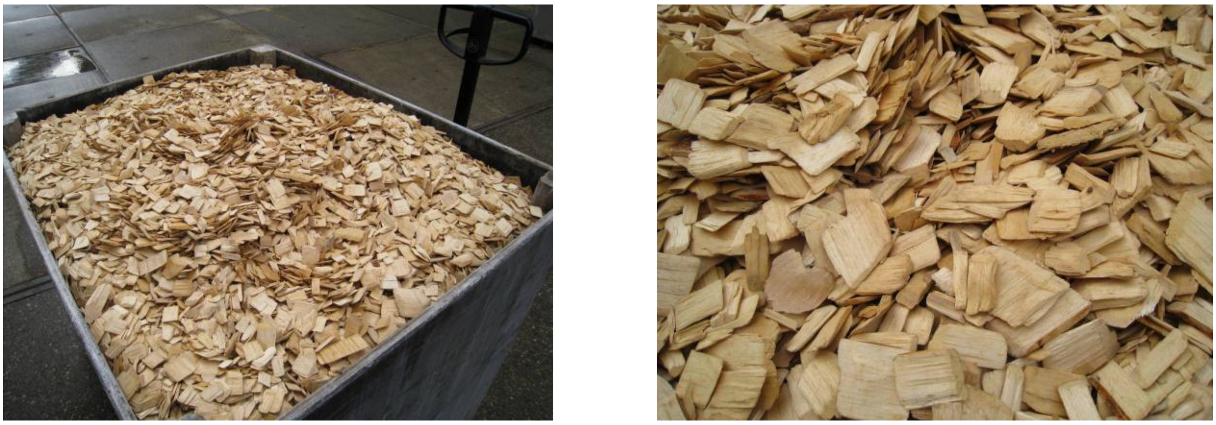

Figure 4: Feedstock suitable for ECN torrefaction

ECN would prefer proper handling characteristics, in particular no bridge formation during handling. Hence, as examples of feedstock that could/will provide complications one can think about feedstock as presented in the pictures below (figure 5).

Figure 5: Feedstock complicated for ECN torrefaction

With regards to the thermochemical behaviour ECN will test feedstock (in particular when working with new/unconventional feedstock) on batch scale first in order to determine whether or not the feedstock would be acceptable for the pilot facility, the demo plant and/or future commercial plants.

3.2 Umeå University

3.2.1 Facilities

Within the SECTOR project, Umeå University is operating different facilities for torrefaction purposes. Thermo analytical instruments (TGA Q5000IR, DTA Q600 and DSC Q1000, all from TA Instruments, figure 6) and a pilot torrefaction plant for parametric studies with a capacity of around 50 kg/h (figure 7). The TGA will be used for screening purposes in lab-scale (a few mg) and as a support for the evaluation of the torrefaction behaviour of the biomass in the torrefaction pilot plant. The TGA runs will supply information concerning mass yields as a function of temperature and time and raw material characteristics regarding hemicelluloses and cellulose content and thus information on decomposition behaviour. DTA and DSC will enable evaluations including also calorimetric information.

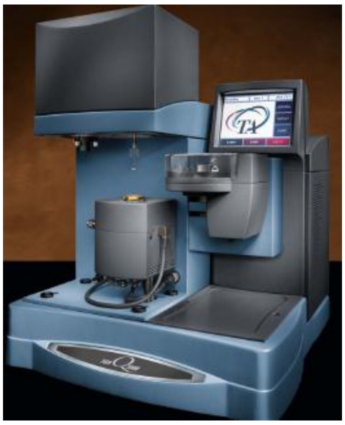

Figure 6: TGA

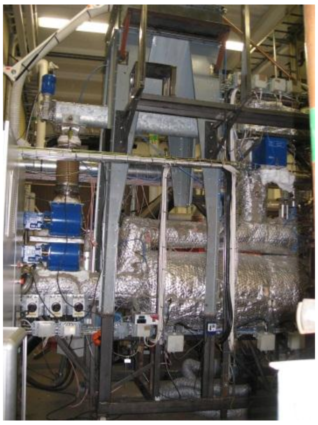

Figure 7: batch reactor

The production of larger amounts of torrefied material will be done in the continuous torrefaction pilot plant with a rotary drum and an internal shaft less screw with a capacity of around 50 kg/h.

3.2.2 Evaluation and selection criteria

In the use of the instruments for thermal analysis no restrictions of the biomass is made, since the biomass will be ground and sample divided before analysis. A common method for sample pre-treatment before analysis could facilitate comparisons between the different laboratories. A suggestion is grinding using a mixer ball mill to particles smaller than 30 µm to make all evaluations in the kinetic regime. Also, when working with heterogeneous materials, it would be of interest to separate different fractions and thereby possibly being able to support results in pilot scale with detailed information from fundamental studies. For instance, torrefaction of “whole tree” would be accompanied by TGA results from stem wood, bark, twigs, shoots, leaves/needles...

With regard to the pilot torrefaction plant some restrictions regarding the size and handling characteristic of the biomass are topics to consider. Typically, wood (fuel or pulp) chips are used. The maximum chips size to be fed into the pilot plant is 10x20x40 mm (figure 8). For agricultural and other non-wood raw materials, corresponding sizes are desired. Pellets are also easily fed and processed. At the Umeå University facility, there is the capacity to sieve the material to be able to exclude oversized material and fine fraction (<8x8 mm). These size demands have its origin in the size of the screw feeders that feed the biomass into the torrefaction drum. The fine fraction is removed in order to reach a homogeneous torrefied material. Although previously documented not to be a major problem in the utilized technology, too small or too large particles may lead to differences in the torrefaction degree attained between different particles.

Figure 8: Torrefied wood chips

The moisture content of the material that can be accepted is in the range of 0-60%. However, delivery of material above 20% moisture content needs to be fast to suppress the problems of microbiological activity and degradation. No mouldy material will be accepted. Before entering the torrefaction process, all biomass are pre-dried to about 5-10% moisture content using a batch fixed bed dryer.

Feedstock with known bridging and valving properties cannot be handled in the pilot plant today, but it could be possible later on after some modifications of the feeding system.

Feedstock with different thermochemical behaviour can be tested and the exothermal behaviour can be evaluated.

3.3 CENER

3.3.1 Facilities

Regarding torrefaction, CENER has a pilot plant divided into three units: Chipping and chopping, drying and torrefaction (figure 9 to figure 11). In Chipping and chopping unit, particle size of biomass feedstock is reduced below 20-40 mm. It is required to increase reactor throughput, improve heat transfer rate and guarantee homogeneous product characteristics.

Figure 9: Chipping and chopping

Figure 10: Drying

Figure 11: Torrefaction unit in CENER facilities

In the drying unit, the biomass is dried down to 5-10% moisture content before torrefaction. A hammer mill is also available if particle size reduction below 10 mm screen size is required. In torrefaction unit, an indirectly heated reactor using thermal fluid at temperatures between 250 and 300ºC converts raw biomass into torrefied product. The combustible vapours from torrefaction reaction are burned in a thermal oxidiser.

The core of the process equipment is the torrefaction reactor. It is a cylindrical horizontal reactor with an agitator shaft and attached elements of special design procuring axial transport characteristic for all kind of biomass, radial product homogenisation inside the reactor and excellent heat transfer conditions (figure 12).

Reactor heating is carried out indirectly through the hot reactor walls, the actively heated shaft tube and the actively heated internal shaft elements using thermal oil as heat transfer fluid.

Figure 12: Torrefaction reactor in CENER facilities

3.3.2 Evaluation and selection criteria

With regards to raw material selection CENER take into account some properties of biomass as shown below (table 1). Some of them are still under revision, as more experience is gained with pilot plant operation, and they should still be considered as indicative. Figure 13 gives an example of feedstock treated in CENER torrefaction pilot plant. New biomass material is tested first at cold conditions with opened inspection windows to check the flowability behaviour.

Table 1: Biomass properties acceptance criteria for torrefaction at CENER pilot plant

Parameter	Pilot plant	Torrefaction reactor
Dimension /nominal size, mm	Woody < 150 x 2500 mm Bales < 110 x 240 cm	< 40 mm
Bulk density, kg/m		>50 (1)
Moisture, %	<50%	5-10%
Angle of repose, º		< ~50 ((1)
Amount of fines, % (≤ 3,15 mm)		< 20% (1)
Dust content (250 < microns)		<2%

(1) Indicative values under revision

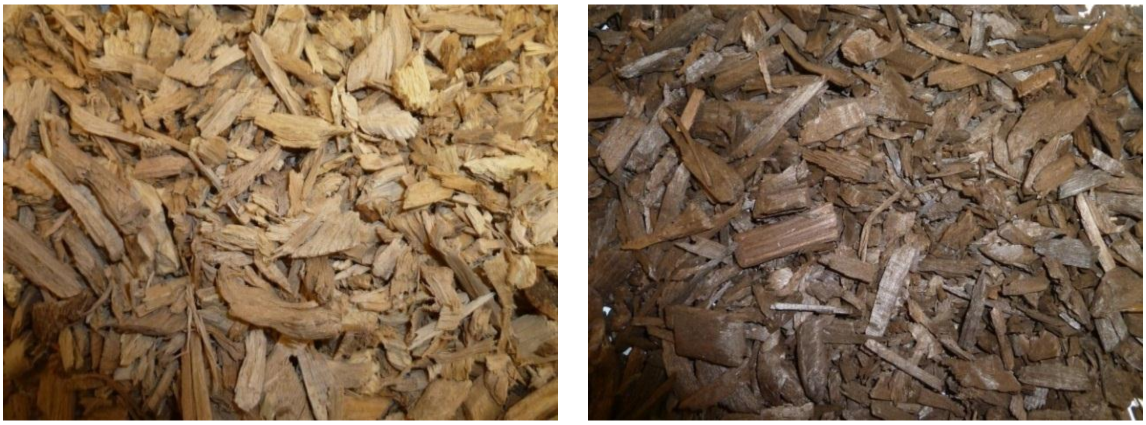

Figure 13: Beech wood treated in CENER pilot plant (left original sample, right torrefied sample)

Furthermore, CENER outsources services of thermo gravimetric analysis (TGA) to determine the reactivity of each feedstock. From TGA results and particle size distribution, torrefaction weight loss percentage and operation conditions can be tested in a simulator before pilot plant tests. No restrictions are established for feedstock characteristics for TGA analysis.

3.4 Topell energy

3.4.1 Facilities

Topell Energy is operating a full-scale commercial production plant located in Duiven, Netherlands (figure 14). This plant is designed to produce 60.000 ton torrefied pellets per annum. These pellets are made from various wood chips from different sources.

The plant consists of three main sections; pre-drying, torrefaction & cooling and densification. In the core of the process – torrefaction – a system of four torbed reactors is used (figure 14). These reactors process the biomass in a directly heated mode using hot flue gas. The heat for torrefaction and pre-drying is produced by a torbed wood combustor.

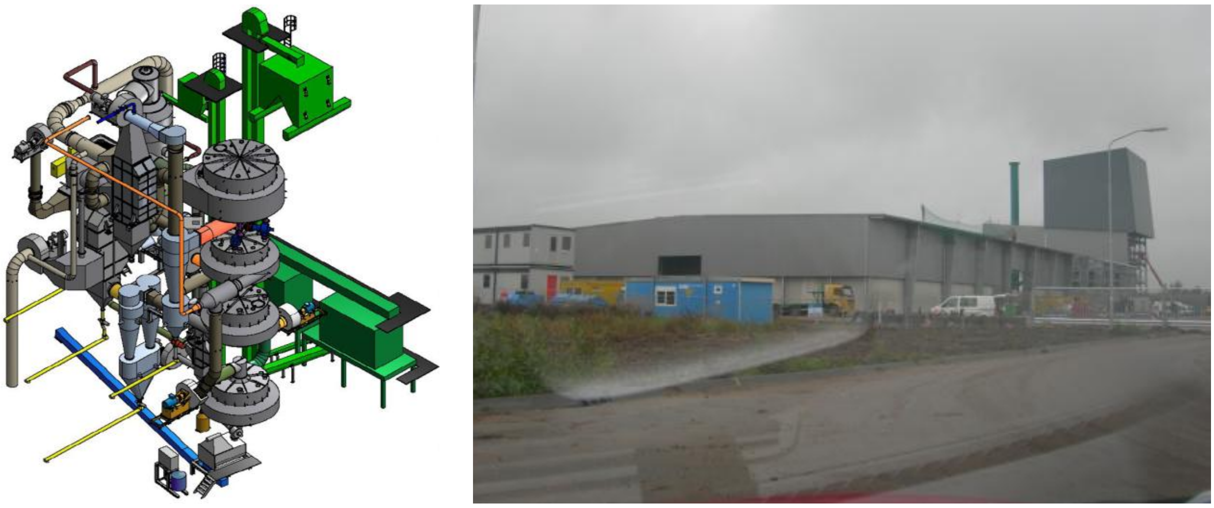

Figure 14: Torrefaction unit at Topell production plant

The plant was originally designed for a mixture of chips and biomass of poorer quality. At the moment (plant is in commissioning phase) mostly wood chips are processed. A main contribution to the project will be the production of larger batches of product from selected feedstock within the project.

3.4.2 Evaluation and selection criteria

The plant's feedstock acceptance criteria are still under revision. Different from R&D environments is that quality is always evaluated on the basis of price. In addition, the site logistic- and pre-treatment system is under development to improve the feedstock flexibility. Currently, the following properties criteria are applied to the acceptance of biomass (see table below).

Table 2: Biomass properties acceptance criteria for Duiven Plant

Parameter	Gate	Torrefaction reactor
Dimension /nominal size, mm	Sieve mesh 4 to 17 mm	Sieve mesh 4 to 17 mm
Angle of repose, º	(free flowing)	(free flowing)
Moisture, %	< 42	< 20%
Amount of fines, %		< 3% smaller than 4 mm
Stones	None	
Sand	< 1%	
Metals	None	

With respect to biomass dimensions, it is important that the maximum thickness of the particles are 10 mm or smaller. There are no stringent limitations to the length to diameter ratio. When testing different biomass in the Duiven plant, special attention to the site-logistics is to be paid.

4 Conclusion

The biomass properties acceptance for the different torrefaction facilities is rather similar. In general, the moisture content should not be too high and particle dimensions should be between some millimetres up till some tens of millimetres. In addition, amount of fines should be low and the biomass should have proper handling properties, i.e. should not show bridging behaviour during handling. These properties are summarised in table 3.

Table 3: Biomass properties acceptance criteria for ECN, Umeå University and CENER pilot plants

Parameter	ECN	Umeå University	CENER	Topell Energy
Dimension / maximum size, mm [1]	≤ 15x40x40	≤ 10x20x40	≤ 40	≤ 10x17x17 [4]
Dimension /minimum size, mm [2]	≥ 2x2x2	≥ 8x8		
Bulk density, kg/m^3			> 50 [4]	
Moisture, % [3]	10-20	5-10	5-10	<20 [4]
Handling properties	proper handling no bridging	proper handling no bridging		free flowing
Angle of repose, º			< ~50 [4]	
Amount of fines, % (≤ 3,15 mm)			< 20% [4]	< 3% [4]
Dust content (250 < microns)	< 1% [4]		<2%	[5]
Treatable feedstock [6]				
Non-treatable feedstock [6]				

(1) *Chipping facility only available at CENER, not at ECN, Umeå University or Topell Energy*
(2) *Sieving facility only available at Umeå University, not at ECN, CENER and Topell Energy*
(3) *Drying facilities available at Umeå University, Topell Energy and CENER (< 50% moisture), not at ECN*
(4) *Indicative values under revision*
(5) *Less than 1% sand and in addition no stones and metals*
(6) *Examples of feedstock*