Tool: Innovative sorting and treating approaches for bio-waste from public space

Wageningen Research

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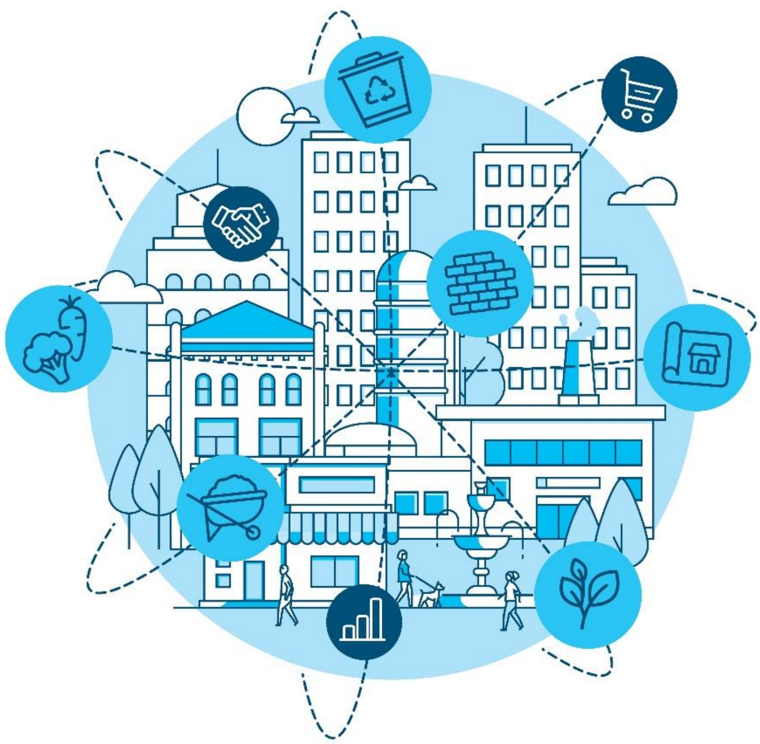

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Abstract	This document contains an overview of sorting and treating processes that can be performed on city scale to prepare bio-waste from green spaces for further processing
Keywords	Bio-waste, Circular Cities, Business cases
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Contents

Summary

This report describes different sorting and treating methods which can be applied to make bio-waste from public spaces suitable as feedstock to produce bio-based products, or as a first step, to show the potential of the bio-waste to interested businesses that are currently using biomass from other sources. Treatment options presented include selectively removing components and/or drying the material, optimising the bio-waste by mechanical or biological pretreatment, or tailoring the fibre properties. The document focusses on technical processes that can be used on city scale. Some examples of methods that can be used during management and maintenance are included.

In the four demonstration projects of Apeldoorn, different techniques were used:

- Leaves to Bokashi

Three sorting and treating methods are used to obtain the right quality of the leaves to be used in the bokashi process. Firstly, the location for the collection of the leaves during the demonstration was chosen based on the amount of litter that was to be expected. Secondly, during collection volunteers are selectively removing larger pieces of litter from the streets. Thirdly, a magnet is used inside the bokashi processing unit to remove pieces of metal.

- Grass to paper

Larger particles in the grass can be removed prior to mowing by volunteers in municipal cleaning. Different strategies can be applied to remove the amount of sand present in the collected grass, after collection washing combined with flotation is the easiest way to separate the sand from the grass, specifically because water is added during the pulping and paper making process.

- Pruning to Biochar

A sieving process is used to select the right size of pruning for biochar production.

- Japanese Knotweed to 3D printing filament

Several processes are applied to prepare JK for processing. Larger waste objects that are accessible are removed by municipal cleaning by volunteers. Knotweed is already collected in a very selective way, separately from other bio-waste. Knotweed is also a dominant plant, preventing most other plants from growing in the same spot. This results in a relatively clean and uniform resource. To obtain the best results in 3D printing the leaves are removed from the stalks mechanically.

Other applications of bio-waste may require different sorting and treating technologies, which may also be implemented at city level. The table below shows a comparative overview of all sorting and treating technologies described in this report. Details are described in chapter 2.

Comparative overview of sorting and treating technologies which can be operated at city level.

Technique	Typical input of biomass	Innovative *1	Complexity *2	Cost *3	Retention time	Capacity
Washing (active)	Non-wood	Low	Medium	M	Medium	Low
Washing (passive)	Open packing structure	Low	Low	L	Long	High
Filtration – belt filter press	Wet and soft	Low	Low	H	Short	Medium
Filtration – screw filter press	Sludge to solid	Low	Low	M	Short	High
Sink-float separation	High & low density contaminants	Medium	Low	H	Medium	Medium
Hydrocyclone	Fine, high density contaminants	High	High	H	Short	High
Wind sifting	Contaminated with different size & density objects	High	High	M	Short	High
Fluidised moving bed separation	Uniform particle form and different density	Low	Low	M	Short	Medium
Inclined vibration screening	Particles with different size/dimension	Low	Low	L	Short	Medium
Rotation screening	Particles with different size/dimension	Low	Low	M	Short	High
Electrostatic separation	Contaminated with metals	Low	Low	L	Short	Medium
Cutting	Woody, free of stones, sand, metals	Low	Low	L	Short	High
Grinding	Woody, free of stones, sand, metals	Low	Low	M	Short	Medium
Drying (active)	Any	Low	Low	M	Medium	Medium
Drying (passive)	Open packing structure	Low	Low	L	Long	High
Pressing	Low bulk density	Low	Low	M	Short	High

*1 Innovative here means: How much effort/knowhow is required to implement and finetune the technology at city level.

*2 Complexity here means: Visible output helps directly to modify equipment settings.

*3 L = low. M = medium. H = high.

1 Introduction

The City of Apeldoorn seeks to develop and pilot valorisation options for bio-waste from public spaces such as leaves, grass, and pruning. In preparation of pilot demonstration actions for the innovative reuse of bio-waste from public spaces, the City of Apeldoorn seeks to develop sorting and treating methods that maximise valorisation options.

This report describes different sorting and treating methods which can be applied to make bio-waste from public spaces suitable as feedstock to produce bio-based products, or as a first step, to show the potential of the bio-waste to interested businesses that are currently using biomass from other sources. Treatment options presented include selectively removing components and/or drying the material, optimising the bio-waste by mechanical or biological pretreatment, or tailoring the fibre properties.

Contaminations that are present in bio-waste include sand, plastic, glass, metal and paper products (e.g. packaging). Depending on the envisaged application biogenic components may also be considered as a contamination (e.g. pruning or leaves in mowed grass). Interested businesses may include composters and bio-gas producers, the pulp & paper industry, building industry (e.g. particle board) and the chemical industru.

1.1 Target groups

- Local Governments (public space maintenance, waste management, circularity management)
- Businesses

1.2 Deployment

The knowledge described in this tool will be used in the demonstration actions from Apeldoorn. Compare initial bio-waste feedstock characteristics and requirements of feedstock for specific business cases, and match by finding suitable sorting and treatment approaches.

1.3 Replication

Basically any owner of bio-waste can follow the following approach: 1) Organoleptic review (seeing, feeling) of the basic quality of the bio-waste (including purity), 2) Scan the (report) tool for sorting and treatment techniques and approaches which allow upgrading specific aspects of bio-waste quality, 3) Get in touch with the potential buyer of the bio-waste feedstock to verify required feedstock qualities, and 4) Select the required treatment(s) and arrange actual sorting and/or treatment, either by the bio-waste owner themselves, or by hiring a third party.

Review requires a basic understanding of potential of bio-waste and its potential applications. As long as respective sorting and treatment approaches are new to a city, involving an independent adviser (e.g. R&D institute, University) may reduce the reliance on well-meant but biased advice of customers of the bio-waste.

1.4 Methods

Several experts in the field of sorting and treating techniques within Wageningen Research and the City of Apeldoorn were contacted to compose a list of existing (existing for 1 field of application may be new for another field) and innovative approaches. Several sorting techniques were tested on labscale, focussing on bio-waste from the public spaces of the City of Apeldoorn: Leaves, grass and prunings.

Next to that, public websites of providers of sorting and treating techniques were reviewed to collect information. Based on the info of public sources and own expertise, key descriptions of the sorting and treatment approaches were prepared, completed by a short indication of input and output bio-waste qualities. Finally, the description of the treatment approaches was reviewed by experts from Wageningen Research.

Barriers

Current use of bio-waste is mostly limited to composting and biogas production. Pretreating bio-waste to be suitable in other applications is a new step. The strengths and challenges in using bio-waste in industrial applications are mostly unknown to industries that are currently using wood or fibre crops as raw material. The effect of new sorting and treating methods on the applicability of the bio-waste in industry will therefor need to be demonstrated in larger scale trials.

Keywords

- #Guidance
- #Recover
- #Recycle
- Upgrading bio-waste quality
- Mobilising volunteers
- Cleaning
- Separation
- Comminution
- Drying
- Densification

2 Tool: Innovative sorting and treating approaches for bio-waste from public space

2.1 Explanation of tool

Aim: Describing a wide range of sorting and treatment techniques and approaches to show their potential to upgrade bio-waste quality and thus allow choosing relevant approaches for using bio-waste in specific business cases.

The approaches are relevant to 1) reduce bio-waste volume and disposal costs, 2) increase circularity of municipalities managing public green space and 3) meet requirements for suitable conversion of the biomass materials obtained from public green space into potentially interesting products and applications.

Target audience: Biomass and Circularity manager at municipalities; Technical staff at municipalities; Industrial stakeholders in bio-based value chains.

How to use: Compare initial bio-waste feedstock characteristics and requirements of feedstock for specific business cases, and match by finding suitable sorting and treatment approaches.

2.2 How sorting and treating can contribute to realisation of business cases

Prunings, grass and leaves collected from public green space often have been considered waste so far. It is treated as waste, disposal comes with financial costs and processing (e.g. composting) focusses on getting rid of the material. When considering bio-waste from public space as potential feedstock for manufacturing products, several sorting and treatment approaches may contribute to the realisation of viable business cases.

Bio-waste may need to be cleaned or purified prior to conversion. Potential contaminants often found in public green space include:

- Sand
- Plastic
- Metal
- Glass

- Paper packaging (cans, bags, bottles, drinking cartons)

However, depending on the target product and required input feedstock, also biogenic components may be considered pollutants:

- Leaves and twigs (in grass)
- Twigs (in leaves)
- ‘Fruits’ (e.g. acorns, chesnuts, etc.)

Transportation (also short distance transport) and storage of biomass feedstock benefits from high density. Handling and conversion processes may require specific particle size (distribution) of the feedstock. Shelf life may require dried biomass, whereas some specific conversion processes may require wet biomass.

A wide range of technical pre-treatment approaches is available to provide solutions for the issues addressed above:

- Separation
- Comminution
- Drying
- Densification

Also non-technical approaches may be considered, such as cleaning on specific times by neighbours of the green space.

Detailed descriptions of (innovative) sorting and treating techniques and approaches have been described in section 2.3, non-technical options in section 2.4.

2.3 Description of sorting and treating approaches

In this section, a range of techniques and approaches for cleaning, purification, drying and densification of bio-waste stemming from public green space has been described. Focus is on technologies which can eventually be implemented at city level.

The following technologies are considered conversion processes, and therefore are excluded in this report: Anaerobic digestion, gasification, pyrolysis, combustion, fermentation, hydrolysis (using chemicals or enzymes), refining (for e.g. paper pulp).

2.3.1 Washing (active)

Aim: Extracting soluble components from another material by dissolution in a washing medium. The washing medium can be as simple as water.

This process can be used to remove impurities or unwanted components from bio-waste in order to improve suitability for further processing. E.g. extracting mono ions like K to avoid contamination of the heat exchanger in a power plant. Or e.g. avoiding higher gas production at the expense of oil production at BTG pyrolysis plant.

Washing can be achieved by spraying e.g. water over a heap of biomass. While the liquid is soaking the biomass, solubles diffuse into the liquid and are removed from the biomass upon leaching out of the liquid. Along with salts, soluble sugars and acids will be extracted. Apart from the kind of washing liquid and its flow rate, washing parameters cannot be controlled, which makes this method a slow process. Although, extraction rate also depends on particle size. On the other hand, it only requires space to store the biomass and a spraying system. Continued washing of subsequent biomass batches on the same place may result in concentrated amounts of extractives in the soil.

Another method of active washing is by filling columns with biomass and flowing an extraction liquid bottom-up. Parameters that can be controlled are flow rate, pulsation and/or agitation, temperature and eventually pressure. As a consequence, this method allows a faster extraction process, however, at higher costs.

Typical input: Non-wood lignocellulosic biomass. Basically no limitations to purity or homogeneity of biomass.

Typical output: Biomass with reduced content of salt ions and soluble organic compounds like acids and sugars.

Typical scale (indication): 1 – ∞ ton/year

2.3.2 Washing (passive)

Aim: Extracting soluble components from another material by simply storing outside in the rain.

Washing may also be performed by storing the biomass outside in the rain. The time required to extract an amount of extractives depends on the amount and frequency of raining. This method of washing is extremely cheap, it only takes a piece of land or eventually a concrete floor to store the biomass. Disadvantage is the relatively long time required to extract components.

It is common practice to collect roadside grass several days after mowing. This reduces the weight of the bio-waste, and it will reduce the number of animals (e.g. insects) and seeds removed from the biosphere.

Typical input: Lignocellulosic biomass. Basically no limitations to purity or homogeneity of biomass.

Typical output: Biomass with reduced content of salt ions and soluble organic compounds like acids and sugars.

Typical scale (indication): 1 – ∞ ton/year

Indication of costs: Cost of land space or paved floor.

2.3.3 Filtration

Aim: Separating solid particles and a liquid by the use of a filter medium that permits the fluid to pass through but retains the solid particles.

The wet biomass may be 'poured over' a filter or screen (Figure 1, Figure 2), or it may be pressed through (Figure 3, Figure 4). Either the clarified fluid or the solid particles removed from the fluid may be the desired product.

Collection of aquatic biomass from ditches and ponds using a screen or net may be called filtration.

Figure 1 Filtration of vegetation from a pond; copied from Inland Aquatics[1].

Figure 2 Manual filtration of vegetation from a ditch; copied from AD[2].

[1] http://inlandaquatics.ca/?page_id=8
[2] https://www.ad.nl/delft/kroosoverlast-in-pijnackerse-sloten-moet-worden-aangepakt

If biomass contains water which is bonded to such extent that it does not leach out anymore, a so called belt filter press (Figure 3) or screw filter press (Figure 4) can be used to press water out of the biomass. In this way, dry matter contents of 20 – 50% may be achieved. These technologies are fairly universally applicable for 'soft' biomass such as grass and leaves.

Belt filter press

Typical input: 'Excessively' wet and 'soft' biomass.

Typical output: Partially dried biomass having dry matter content of about 20 – 50 wt.%. Particles smaller than the mesh size may go (disappear) with the liquid fraction.

Typical scale (indication): 0.05 – 0.5 ton/h solids (5 – 20 m^3/h liquid) per meter belt width.[3]

Indication of investment costs: 150 k€ per meter belt width.[4]

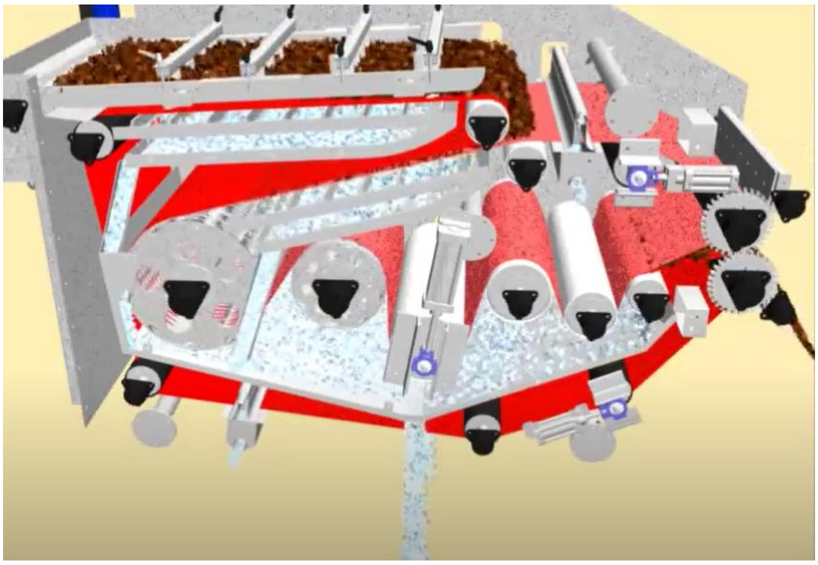

Figure 3 Belt filter press principle: wet biomass is squeezed between 2 moving belts, thus pressing out the liquid; copied from Sekel project[5].

[3] https://www.climate-policy-watcher.org/wastewater-sludge/belt-filter-press.html
[4] https://www.wwdmag.com/filter-beltscloth/belt-filter-presses-still-cost-effective-solution-myth-or-reality , Converted from data in $ with reference year 2011.
[5] https://www.youtube.com/watch?v=Rp4JrN9WvJs

Screw filter press

Typical input: Sludge to solid biomass.

Typical output: Partially dried biomass having dry matter content of up to 45 wt.%[6]. Particles smaller than the mesh size may go (disappear) with the liquid fraction.

Typical scale (indication): 0.01 – 2 ton/h for sludge.[7]

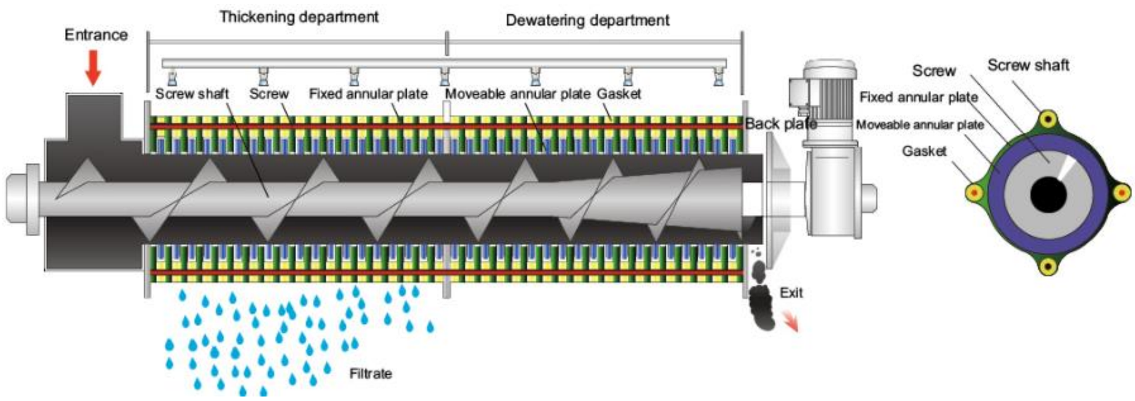

Figure 4 Screw filter press principle: wet biomass is compressed and liquid is squeezed out; copied from BOEEP[8].

[6] Elbersen, H. W., Keijsers, E. R. P., & van Doorn, J. (2001). *Biorefinery of Verge grass to produce Bio-fuel*. Paper presented at 5th Biomass Conference of the Americas, Orlando, Florida, 2001.
[7] https://www.iea-press.com/en/single_page
[8] https://www.chinaboeep.com/Automatic-Self-cleaning-Screw-Press-Sludge-Dewatering-for-Municipal-Sewage-Treatment-pd6054249.htm

2.3.4 Sink-float separation

Aim: Separating materials with different density through immersion of the material mixture in a liquid medium having a density in between the specific densities of the materials

With the sink-float approach, the particles of lower specific gravity float on the surface of the medium, while the particles of higher specific gravity sink to the bottom (Figure 5). The two materials can be removed separately from the medium, thus obtaining higher purity materials. Using water as the medium will facilitate e.g. separating sand from wood (chips), or grass.

It may be noted that the density of lignocellulose tissue is about 1.4 – 1.5 g/cm^3, and that most European lignocellulosic biomass has a density below 1 g/cm^3 due to voids in the plant structure. Consequence is that, when immersed in water for a longer period of time, biomass will take up water and switch from floating to sinking. The smaller the biomass dimensions, the higher the relative water uptake rate.

Typical input: Biomass contaminated with high density materials like e.g. sand, glass, metals.

Typical output: Purified biomass. Biomass which easily takes up water may be discarded with the contaminants.

Typical scale (indication): 1 – 3 ton/h for plastic granules.[9,10]

Indication of investment costs: 290 k€ for second hand 1.5 ton/h plastic separator.[11]

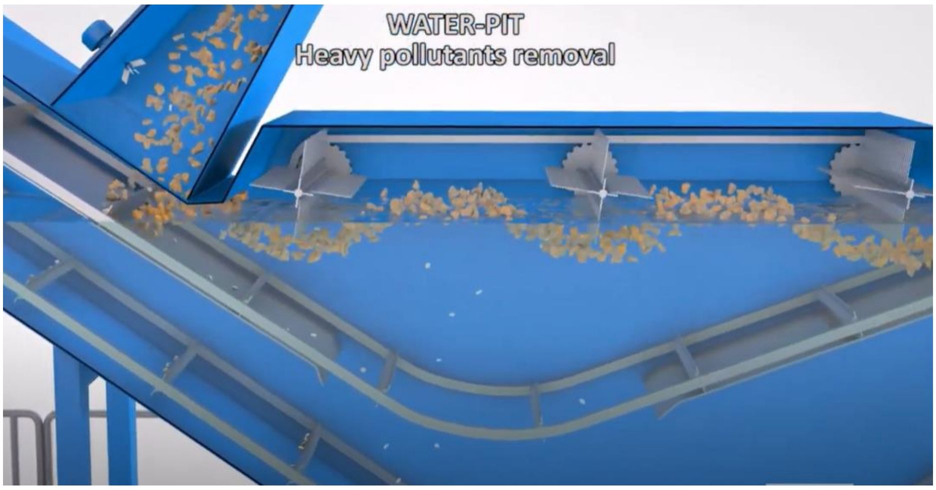

Figure 5 Sink-float principle: light materials float, high density materials sink; copied from PAL[12].

[9] https://www.germanplast.eu/washing-sink-float-separating-tank-2000-kg-h-dmh110
[10] https://www.resale.info/en/recycling-plastic/
[11] https://www.maschinensucher.de/sicon+gmbh+leiblein+gmbh+polyfloat
[12] https://www.youtube.com/watch?v=tYcKk7tmsEA

2.3.5 Hydrocyclone

Aim: Separating large or heavy particles from smaller and lighter ones by gravity and centrifugal forces.

The working principle of a hydrocyclone is nicely presented here (Figure 6). Due to applying forces, a hydrocyclone can result in a faster separation than the sink-flotation method. The material should be a pumpable dispersion, so either the material should be dispersed in a liquid (e.g. water) already, or the material has to be dispersed in water.

Typical input: Biomass contaminated with fine and high density materials like e.g. sand.

Typical output: Purified biomass.

Typical scale (indication): 1 – 360 m^3/h.[13]

Indication of investment costs: 250 k€ for equipment separating oil from an aqueous flow of 1000 m^3/day.[14] Alibaba suggests prices in the range 1 – 30 k$.[15]

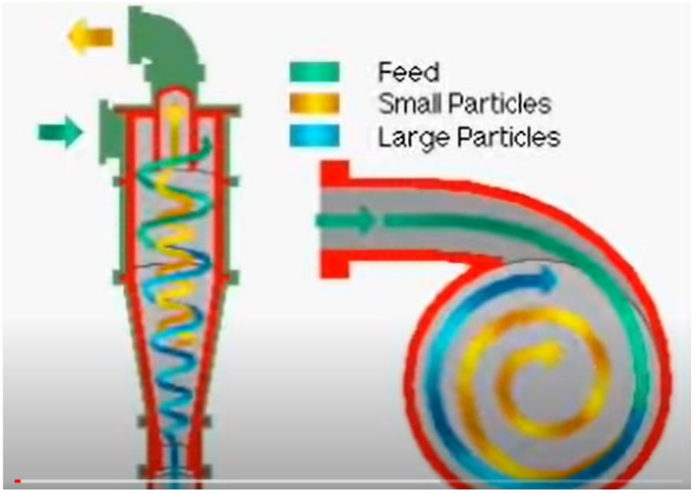

Figure 6 Hydrocyclone principle: heavy and large particles move to outer side and bottom, lighter and smaller particles tend to remain in the centre and move upward; copied from Metallurgist[16].

13 https://www.prominetech.com/hydrocyclone/
14 https://emis.vito.be/en/bat/tools-overview/sheets/hydrocyclone
15 https://dutch.alibaba.com/g/hydrocyclone-price.html
16 https://www.911metallurgist.com/blog/hydrocyclone-workingprinciple

2.3.6 Wind sifting

Aim: Separating materials with different density relative to particle surface by using controlled air flow.

The material is fed into a chamber with an upward air stream. The light particles are transported with an air flow with high speed into the expansion chamber, where the air speed is reduced so much that the light materials reach a container or a discharge belt. The heavy particles fall down into a container or onto a discharge belt (Figure 7).

Using wind sifting, also called wind shifting or air density separation, sand may be separated from grass and leaves, or leaves and plastic bags and films from woody biomass, thus obtaining higher purity materials. The material should be dry in order to prevent the one material adhering to the other.

Typical input: Contaminated biomass.

Typical output: Purified biomass. Potentially, leaves and plastic may be separated from twigs and lignocellulose chips, or sand from grass and leaves.

Typical scale (indication): 80 – 300 m^3/h.[17,18]

Indication of investment costs: 73.5 k€ for 80 m^3/h mobile machine built in 2015.[19]

Figure 7 Wind shifting principle: light particles are transported upward with an air flow, heavy particles fall down; copied from PAL[20].

[17] https://petersoncorp.com/wp-content/uploads/W70-DataSheet.pdf , 80 m^3/h.
[18] https://www.eggersmann-recyclingtechnology.com/en/recycling-machines/terra-select-screening-machines-windsifters/products/ , 100-300 m^3/h.
[19] https://www.trucks.nl/terra-select-w7-mobile-windshifter
[20] https://www.youtube.com/watch?v=PzLwmUIHKAQ

2.3.7 Fluidised moving bed separation

Aim: Separating materials having more or less uniform particle form but different densities.

The gravity separator technology consists of an inclined eccentrically moving screen deck with an air flow bottom-up through the screen which allows separation of dry particles of similar size but different density. The lighter particles are 'fluidized' by the air flow and move 'downhill', the higher density particles have more contact with the perpendicularly vibrating screen and move 'uphill'. For 'intermediate density' particles the forces of uphill and downhill movement are more or less in balance and these particles tend to stay in the central section of the screen. Parameters include: air flow, screen inclination, vibration frequency and vibration amplitude. Potentially, this technology may be suitable to separate e.g. lignocellulosic biomass chips with different densities. Capacity is determined by feed rate and the angle of the screen in longitudinal direction. A visual presentation of the method is presented in this video.

Typical input: Biomass having more or less uniform particle form and different densities.

Typical output: No literature found on separation of other biomaterials than grains, beans and seeds; potentially biomass particles like e.g. wood chips of different densities could be separated.

Typical scale (indication): 250 – 1,000 kg/h for grass seeds and 1,500 – 6,300 kg/h for grains.[21] For grains, also equipment up to 20 ton/h is available.[22]

Indication of investment costs: 50 k€ for type of equipment which can process 1,000 kg/h of grass seeds.[23]

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21 https://www.olivermanufacturing.com/wp-content/uploads/2017/06/hicap_brochure_web_FINALWEB-1.pdf

22 https://www.olivermanufacturing.com/wp-content/uploads/2017/06/maxicap_brochure_web-3-1.pdf

23 https://agriresources.ag/used-equipment-for-sale/ols/products/oliver-hi-cap-240am-gravity-table (Oliver 240 AM, resembling Oliver 241 mentioned in 2nd previous footnote)

Figure 8 Fluidised moving bed separator; copied from Oliver[24].

[24] https://www.youtube.com/watch?v=FQkK7hdK270

2.3.8 Inclined vibration screening

Aim: Separating materials having different particle size.

The inclined vibrating screening technology allows separation of particles into 2 fractions, those falling through the screen those staying on the screen (Figure 9). The inclination angle and the vibration frequency and amplitude determine the separation efficiency and potential throughput. Also, systems with multiple screen decks on top are available.

Typical input: Biomass particles having different sizes/dimensions.

Typical output: Biomass particles (e.g. wood chips) separated into 2 particle size fractions.

Typical scale (indication): 250 – 3500 kg/h for plastic granules.[25]

Indication of investment costs: 20 k€.[26]

Figure 9 Vibrating screen separator; copied from Leizhou[27].

Rotating screen

A variation to the vibrating screen is the rotating screen. This can be used to separate wood chips of different size, or sand from twigs and roots.[28,29]

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25 https://www.sinfo-t.jp/pdf/Data/vibrator/E95-002.pdf
26 https://www.made-in-china.com/products-search/hot-china-products/Vibration_Separator_Price.html, 5-20 k$ FOB in China.
27 https://www.youtube.com/watch?v=XLi8BbehaEo
28 https://www.youtube.com/watch?v=vbRB-jnkO3I
29 https://www.youtube.com/watch?v=DL3FDLEB2Yc

Typical input: Biomass particles having different sizes/dimensions.

Typical output: Biomass particles (e.g. wood chips) separated into 2 particle size fractions.

Typical scale (indication): up to 200 m^3/h.[30]

Indication of investment costs: 160 k€ for used 200 m^3/h equipment.[31]

[30] https://www.herwijnenmachinery.nl/pronar-trommelzeven/pronar-mpb-20-55/

[31] https://www.machinio.com/cat/windshifters#results, used Pronar MPB 20.55

2.3.9 Electrostatic separation

Aim: Separating materials with different electrostatic chargeability by applying electric field.

Electrostatic separation is a process that uses electrostatic charges to separate particles or products. Materials acquire a charge if they are passed through an intense electric field. Conductors like metals pass on their charge when emerging from the field, while non-conductors retain their charge for a moment. When the mix of metal and non-conductor particles leave a transportation belt which is clamped over a metal cylinder at a certain speed, the non-charged metal particles will follow the normal ballistic trajectory, while the charged non-conductor particles will be attracted to the metal cylinder and consequently follow a different path (Figure 10). This technique is in particular suitable to remove non-ferrous metals from biomass.[32]

To remove ferrous metals, also a magnetic system may be used.

Typical input: Biomass contaminated with metals.

Typical output: Biomass cleaned from metals.

Typical scale (indication): 150 – 1,750 kg/h for plastics.[33]

Indication of investment costs: 23 – 70 k€ for 0.5 – 3 ton/h capacity equipment.[34]

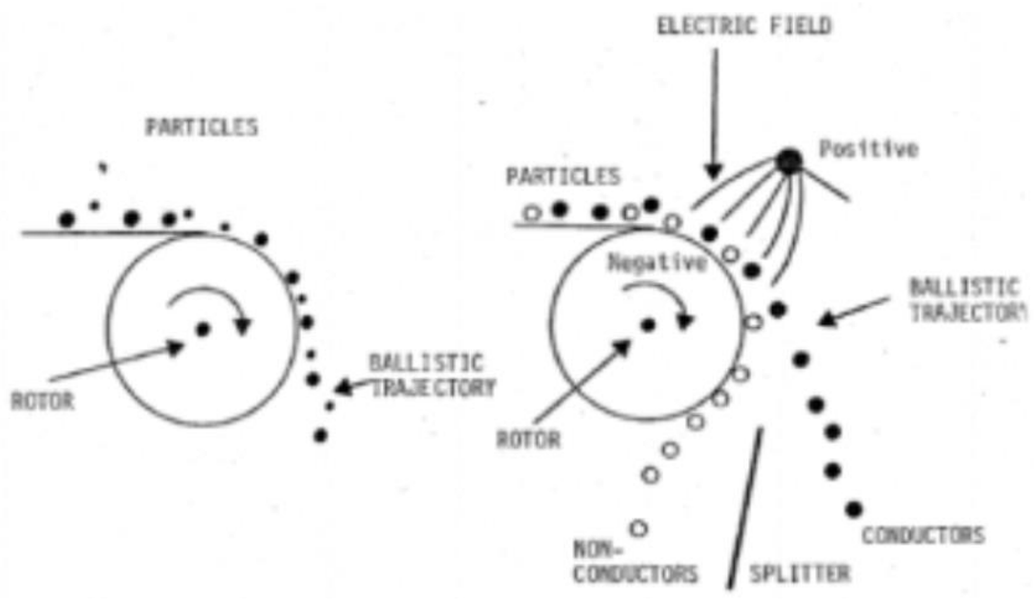

Figure 10 Electrostatic separation principle; copied from Metallurgist[35].

32 https://www.youtube.com/watch?v=3E5EAfLboqs
33 https://redoma.com/sites/default/files/ESS_EN_160523_low.pdf , https://redoma.com/en/single-machines/electrostatic-separators-ess
34 https://www.alibaba.com/showroom/electrostatic-separator, 28 – 85 k$ FOB in China.
35 https://www.911metallurgist.com/blog/electrostatic-separation-procedure

2.3.10 IR cleaning

Aim: Separating materials having different composition by detecting the composition using IR scanning and blowing different materials in different bins.

This technology is used for separating different types of plastic from packaging items after use to allow recycling. An IR signal is used to analyse the chemical composition of a piece of material, and the reflected signal is benchmarked against data in a library. Depending on the type of plastic identified, the item is blown one way or the other to end up in separate ‘bins’. This method works quite well for mono materials like PE, PP and PET bottles and trays. To separate items consisting of different materials or items comprising small differences in composition like woody biomass, this technique would need to be validated. Separation techniques based on differences in density and size seem more suitable for separating biomass.

2.3.11 Cutting

Aim: Reducing size of biomass.

Woody biomass can be cut to smaller pieces like chips or chunks to improve 1) handling and/or 2) suitability for further processing.

Typical input: Woody biomass, free of stones, sand an metals.

Typical output: Biomass chunks or chips (chips have small dimensions than chunks).

Typical scale (indication): up to 500 kg/h of Eucalypt trimming waste using 20 cm diameter chipper, indicated to correspond to 8 m^3/h.[36] Tractor powered equipment can produce 40 – 50 m^3/h of chips, independent-engine chippers can produce 60 – 90 m^3/h. Fuel consumption is reported to be about 0.5 L diesel per m^3 chips, independent of chipper type.[37]

Indication of investment costs: 3,200 € for chipper up to 20 cm diameter stems (excluding > 60 hp tractor).[38]

Figure 11 Tractor powered biomass chipper; copied from Shahid[36].

[36] https://www.cabi.org/gara/FullTextPDF/2019/20193133180.pdf
[37] https://www.sciencedirect.com/science/article/pii/S0961953414002104
[38] https://woodlandmills.nl/product/wc88-8-pto-wood-chipper/

2.3.12 Grinding

Aim: Reducing size of biomass to fine fibres or powder.

Usually, prior to grinding, biomass size has been reduced already using chipping or shredding action. Depending on material and grinding configuration, the resulting material form will have rather fibre or powder shape.

Typical input: Woody biomass chips, free of stones, sand an metals.

Typical output: Biomass fibres or powder.

Typical scale (indication): 1 kg – 5 tonnes/h for biomass.[39,40]

[39] https://www.clarksonlab.com/Retsch/Crushing/sm100gb.pdf
[40] https://peppink.com/en/peppink-mills/production-mills/

2.3.13 Drying (active)

Aim: Reducing moisture content of materials by applying heat.

Reducing moisture content of materials may be helpful to: 1) improve shelf-life, 2) reduce transportation costs and/or 3) increase calorific value per unit of weight.

Wood chips, shavings or sawdust are often dried using a rotary drum dryer. The principle is: tumbling material in a rotating drum in the presence of hot drying air. The drum is positioned at a slightly horizontal slope to allow gravity to assist in moving material through the drum. The machinery is specially designed for the type of material. The throughput of the equipment depends on the size of the drum, the heating capacity, the size of the material, the moisture content of input and output material.

Solid wood may be dried using a kiln dryer: a kind of hot air oven in which the material is heated and evaporating moisture is collected and condensed outside the oven.

Typical input: Biomass containing more moisture than desired.

Typical output: Biomass with reduced moisture content.

Typical scale (indication): Rotary drum dryer: 0.5 – 70 t/h.[41]

Kiln drying: (at least) up to 100 m^3 per batch.[42]

Indication of investment costs: 110 k€ for second hand 90 m^3 rotary drum dryer in good condition.[43]

24 k€ for second hand 100 m^3 kiln dryer in good condition.[42]

41 https://www.hncrusher.com/product/dryer/rotary
42 https://www.machineseeker.com/wood%20drying%20kiln, offered in Slovakia.
43 https://www.machineseeker.com/Dryer%20%28rotary%20Drum, offered in Lithuania.

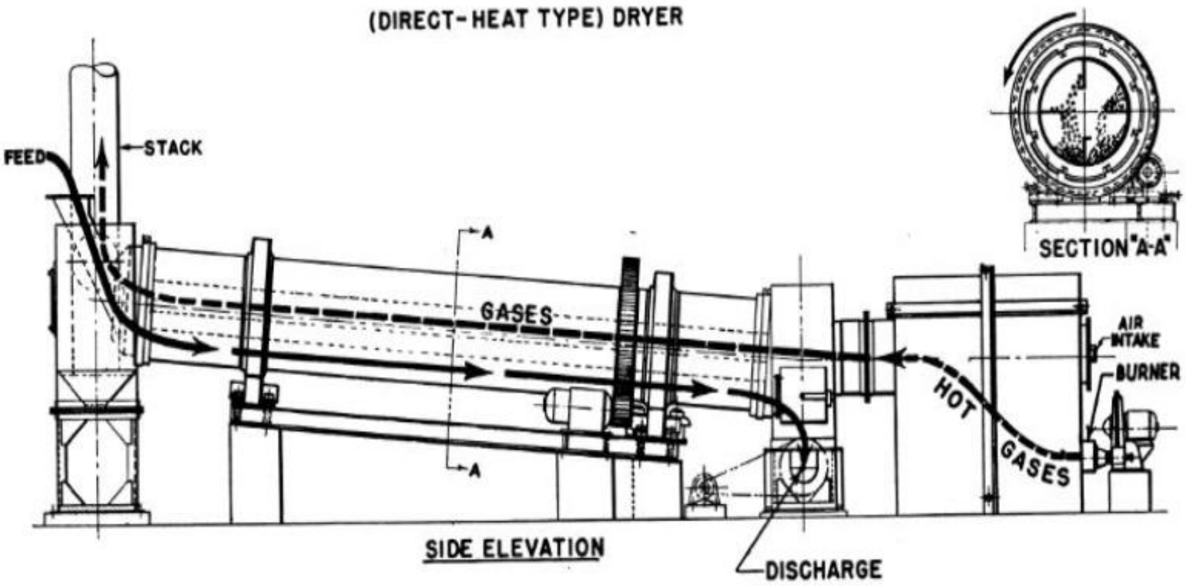

Figure 12 Simplified scheme of rotary drum drying principle; copied from Sunco[44].

[44] http://www.suncomachinery.com/news/industry/rotary-dryer-35.html

2.3.14 Drying (passive)

Aim: Reducing moisture content of materials by direct sunlight irradiation or natural convection.

Passive drying can be achieved by placing the material in direct sunlight, or by storing under a roof and have natural convection (wind) drying the biomass material. When drying in the sun, it should not rain too often in order to efficiently and effectively being able to dry the biomass. Also, the layer thickness is limited by the penetration of irradiation heat. Depending on layer thickness, drying time may be reduced significantly by turning the material once or twice a day. Sun drying could be very suitable for biomass with at least one dimension being about 1 mm or less like grass, and which becomes available during the spring/summer/early autumn period when there is sufficient sun irradiation.

Passive drying under a roof can be performed for thick layers of biomass, up to meters, however, it requires that the biomass does not heat. In other words: that the biomass is open enough for heat to be dissipated by the natural convection.

Several composting units in the Netherlands are considered ‘organic drying’. These systems involve regular ‘stirring up’ of the biomass to aerate (avoid methane production) and avoid heating.

The time required for passive drying is usually longer than for active drying, however, these methods are cheaper as well. For sun drying, it only takes a piece of land or eventually a concrete floor to put the biomass. For natural convection drying it requires a roof, however no expensive drying equipment.

Typical input: Biomass containing more moisture than desired.

Typical output: Biomass with reduced moisture content.

Typical scale (indication): 1 – ∞ ton/year

Indication of costs: Cost of land space or paved floor, or liquid proof floors.

Figure 13 Swathing of partly sundried roadside gras; copied from Edepot[45].

[45] https://edepot.wur.nl/350624

2.3.15 Pressing

Aim: Reducing volume by increasing bulk density.

Increasing density of materials may help to reduce transportation and storage costs.

Examples include baling grass. The biomass material should be dry prior to baling in order to avoid heating.

Typical input: Biomass with low bulk density.

Typical output: Biomass with increased bulk density (by up to a factor of 10, up to about 300 kg/m^3).[46,47]

Typical scale (indication): 10 – 25 ton/h.[48]

Indication of investment costs: 10 – 65 k€ for used round balers and rectangular balers (excluding tractor).[49]

Figure 14 Baling of dried roadside grass; copied from Edepot[50].

46 https://cp22243.tripod.com/cpibalingsystem/id1.html
47 https://www.dairynz.co.nz/feed/supplements/density-and-storage-of-feeds/
48 https://www.researchgate.net/figure/Throughput-reached-a-maximum-capacity-The-relationship-of-the-performance-data-to_fig1_271431986
49 https://www.traktorpool.nl/gebruikt/a-Weidebouwmachines/11/b-Persen/168/
50 https://edepot.wur.nl/213566

2.4 Description of other options to improve bio-waste quality

2.4.1 Manual cleaning prior to collection

Prior to collection of bio-waste from green public space, the area may be cleaned from plastics, metals and other kind of (packaging) products by organising a clean-up tour by enthusiastic persons in the area. It will require mobilising the 'cleaning' team in such a way that the moments of cleaning and bio-waste collection are aligned. Depending on the effort it takes to mobilise the volunteers, this cleaning method seems more efficient than passing a polluted stream through a mechanised cleaning operation like an IR cleaning line (like is being used to separate plastic waste streams, see e.g. section 2.3.10) or electrostatic separation (like is being used to remove metals from waste streams, see section 2.3.9).

Figure 15 Manual cleaning of park; copied from AD[51].

In Apeldoorn an active group of volunteers regularly cleans the city. Tools necessary to pick up plastics are provided by the city. Activities are organised by Zero waste Apeldoorn (a foundation of volunteers)[52] and "Heel Apeldoorn is rein" (initiative of City)[53,54]. Collected waste can be presented to the city without charge.

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[51] https://www.ad.nl/utrecht/lichtblauwe-invasie-raapt-peuken-en-andere-rommel-in-griftpark
[52] https://zerowasteapeldoorn.com/Heel-Apeldoorn-Schoon/
[53] https://www.apeldoorn.nl/wonen-en-leven/wonen-en-uw-buurt/uw-buurt/heel-apeldoorn-rein
[54] https://www.facebook.com/ApeldoornRein

Figure 16 Invitation to citizens for communal cleaning in Apeldoorn.

2.4.2 Moment of collection

During autumn/winter, minerals tend to flow from the upper ground part of the plant back to the roots. As far as relevant, collection of biomass at the end of winter may be a simple method to collect biomass with lowest possible content of mono ions like potassium (K) and chlorine Cl) which tend to contaminate heat exchangers in power plants. Costs of collection in winter will not be very much different compared to collection at other moments in the year. A potential further benefit could be that wintertime is a quiet period for workers in green space.

Figure 17 Mechanical pruning of trees during winter; copied from Youtube[55].

[55] https://www.youtube.com/watch?v=YWvOEmeAs2s

2.4.3 Optimisation of mowing and collecting

Techniques can be used to avoid the uptake of soil and other impurities during mowing and collection of specifically grass. Examples of these options are:

- Increasing the mowing height, thereby reducing the uptake of soil
- Increasing the flatness of the area by grass rollers
- Reducing the effect of mole infestations by levelling mole heaps at the beginning of the year

Figure 18. Flattening mole heaps [WFBR].[56]

[56] Harvesting, logistics and upgrading of herbaceous biomass from verges and natural areas for use in thermal conversion, W. Elbersen, E. Keijsers et al. 2015

2.5 Complementary approaches

Several ‘bio-waste – biobased product’ combinations may require a combination of sorting and treating technologies and approaches. Guidelines for such combinations include the following:

- Approaches which improve the purity of feedstock prior to collection/harvesting (section 2.4) may be considered in any case.
- Wet cleaning techniques (washing, sink-float separation, hydrocyclone) are preferably executed prior to drying.
- Cutting/grinding may cost less energy on non-dried biomass. However, cut/grinded biomass cannot be passively dried, as there is the risk of scalding. In this case forced drying is required.
- Dry separation technologies (wind sifting, fluidized moving bed, inclined vibration screening, electrostatic separation) require dry biomass.
- Pressing requires dry biomass, to avoid scalding.

CityLoops is an EU-funded project focusing on construction and demolition waste (CDW), including soil, and organic waste (OW), where seven European cities are piloting solutions to be more circular.

Høje-Taastrup and Roskilde (Denmark), Mikkeli (Finland), Apeldoorn (the Netherlands), Bodø (Norway), Porto (Portugal) and Seville (Spain) are the seven cities implementing a series of demonstration actions on CDW and OW, and developing and testing over 30 new tools and processes.

Alongside these, a sector-wide circularity assessment and an urban circularity assessment are to be carried out in each of the cities. The former, to optimise the demonstration activities, whereas the latter to enable cities to effectively integrate circularity into planning and decision making. Another two key aspect of CityLoops are stakeholder engagement and circular procurement.

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