POLITECNICO MILANO 1863

Master of Science in Energy Engineering – Renewables and Environmental Sustainability

BIO-ENERGY AND WASTE-TO-ENERGY TECHNOLOGIES

MBT plants for SRF production

AY 2017/18

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OUTLINE

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- *Solid Recovered Fuel*
- *MBT plants introduction*
- *Mechanical treatments*
- *Biological treatments*
- *Plants design and layouts*
- *MBT for material recovery*
- *Impacts on the environment and their control*

Definitions

• GROSS WASTE (GW) → total waste produced from the households, including source separated fractions

• RESIDUAL WASTE (RW) → mixed waste, collected downstream source separation

• DRY FRACTION (DF) → material from a "light" treatment (mechanical and/or biological) of RW, not necessarily compliant with law requirements for SRF

• SRF → Solid Recovered Fuel, according to EN 15359:2011

• POF → Putrescible Organic Fraction

• SOF → Stabilised Organic Fraction

• MBT → Mechanical-Biological Treatment Plant

Solid Recovered Fuels – SRF

RDF: Refuse derived fuel → SRF: Solid recovered fuel

- high calorific value waste fractions are selected in order to:
  - improve its <u>thermal</u> characteristics
    - LHV increase
    - Ash and moisture reduction
    - Homogenisation
  - improve its <u>environmental performances</u> (emissions and residues)
    - Ash reduction
    - Reduction of *chlorine* (PVC)
    - Reduction of *metals* (fine fraction)
- utilisation
  - combustion/gasification in dedicated plants → *fluidised beds*
  - co-combustion in existing industrial plants
    - cement kilns
    - power plants

replacement of coal/petcoke

According to the EN 15359:2011, the SRF classification is based on three parameters: LHV, Cl and Hg. All other chemical parameters are not related to the SRF classification, nevertheless they must be reported

Calorific value → Economic

Chlorine → Technical

Mercury → Environmental

Classification system for solid recovered fuels

		Classes				
		1	2	3	4	5
LHV (MJ/kg)	Mean	> 25	> 20	> 15	> 10	> 3
Cl (% dm)	Mean	< 0.2	< 0.6	< 1	< 1.5	< 3
Hg (mg/MJ)	Median	< 0.02	< 0.03	< 0.08	< 0.15	< 0.5
	80^{th} percentile	< 0.04	< 0.06	< 0.16	< 0.3	< 1

125 possible combinations apply → 125 types of SRF!

Classification system for solid recovered fuels

According to the Italian legislation (DM 22/2013), a "Combustible-SRF" (*CSS-Combustibile*) is defined, which achieves the **"End-of-waste" status,** provided that it is used to produce electric or thermal energy in:

- cement kilns with a daily production > 500 t operating under an Environmental Management System (EMS)
- power plants with thermal power > 50 MWth operating under an EMS

2008/98/EC, Article 6 - End-of-waste status

1. Certain specified waste shall cease to be waste […] when it has undergone a recovery, including recycling, operation and complies with specific criteria to be developed in accordance with the following conditions:

(a) the substance or object is commonly used for specific purposes;

(b) a market or demand exists for such a substance or object;

(c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and

(d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.

Solid Recovered Fuels – SRF

Classification system for “CSS-Combustibile” (DM 22/2013)

		Classes				
		1	2	3	4	5
LHV (MJ/kg)	Mean	> 25	> 20	> 15		
Cl (% dm)	Mean	< 0.2	< 0.6	< 1		
Hg (mg/MJ)	Median	< 0.02	< 0.03			
	80^{th} percentile	< 0.04	< 0.06			

18 possible combinations apply

Solid Recovered Fuels – SRF

	unit of measure	Former CDR	Former CDR-Q	CSS - Combustibile
Legislation		UNI 9903-1	UNI 9903-1	D.M. 22/2013
Moisture	%	25	18	(*)
LHV	$kJ*kg^{-1}$	≥ 15.000	≥ 20.000	Ref. class of SRF
Ash	% dm	20	15	(*)
As	$mg*kg\ dm^{-1}$	9	5	5
Cd + Hg	$mg*kg\ dm^{-1}$	7	-	-
Cd	$mg*kg\ dm^{-1}$	-	3	4
Hg	$mg*kg\ dm^{-1}$	-	1	Ref. class of SRF
Cl total	%	0,9	0,7	Ref. class of SRF
Cr	$mg*kg\ dm^{-1}$	100	70	100
Cu soluble	$mg*kg\ dm^{-1}$	300	50	500 (**)
Mn	$mg*kg\ dm^{-1}$	400	200	250
Ni	$mg*kg\ dm^{-1}$	40	30	30
Pb volatile	$mg*kg\ dm^{-1}$	200	100	240 (**)
S	%	0,6	0,3	-
Sb	$mg*kg\ dm^{-1}$	-	-	50
Co	$mg*kg\ dm^{-1}$	-	-	18
Tl	$mg*kg\ dm^{-1}$	-	-	5
V	$mg*kg\ dm^{-1}$	-	-	10

(*) moisture and ash concentration are agreed between producers and users; (**) total

OUTLINE

MBT plants – rationale

MBT IS A PRE-TREATMENT!

- To improve the «combustible» characteristics of the residual waste → SRF
  - ✓ Decrease of moisture and ash content
  - ✓ Increase of LHV
- To recover some material fractions from the residual waste
  - ✓ Metals (ferrous and non-ferrous)
  - ✓ Plastic, paper
- To decrease the amount of waste disposed in landfill
- To stabilise the residual waste (i.e. to decrease its putrescibility)
  - ✓ Temporary storage

MBT plants – rationale

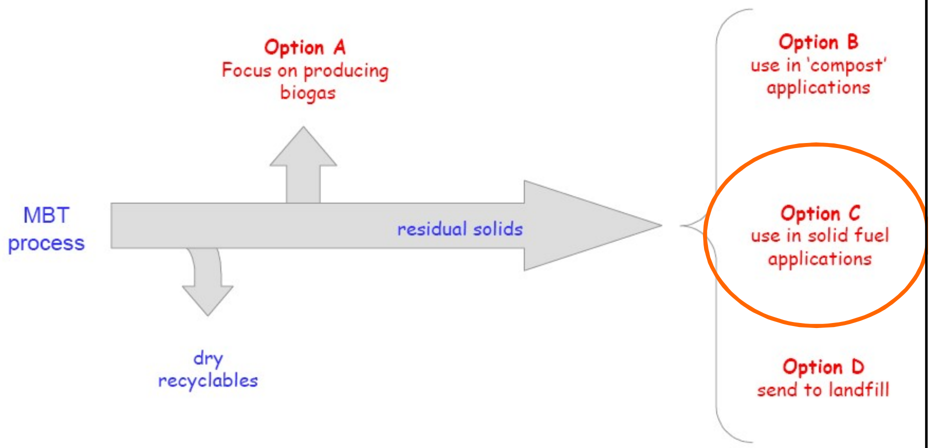
The choice to perform a pre-treatment of the residual waste and of which type of pre-treatment to select must be strictly related to:

- The specific integrated waste management scheme in place or designed
- The local framework/context (type and characteristics of the existing industrial plants suitable for material/energy recovery from waste)

THE PRE-TREATMENT BEING ONLY AN INTERMEDIATE STEP OF THE INTEGRATED WASTE MANAGEMENT SYSTEM, IT CANNOT BE INDEPENDENT FROM THE GENERAL FRAMEWORK, NEITHER IT CAN CONSTITUTE THE "FINAL WASTE SOLUTION"

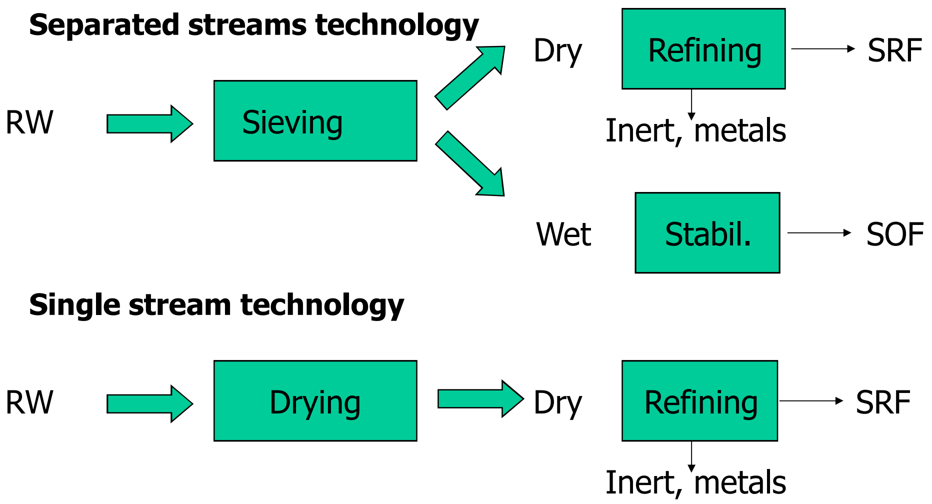
MBT plants – general approaches

Four main options for MBT



Source: Juniper 2005, Mechanical-Biological-Treatment. A Guide for Decision Makers: Processes, Policies and Markets

SRF production from residual waste



SRF production from residual waste

Process units

- mechanical operations

- biological operations (mainly aerobic treatments)
  - stabilisation of the putrescible organic fraction (POF → SOF)
  - waste bio-drying

Mechanical-Biological Treatment Plants (MBT)

OUTLINE

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SRF production from residual waste

MECHANICAL OPERATIONS

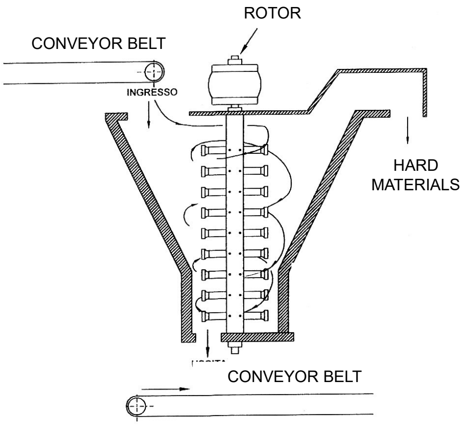
1. Size reduction
   - ✓ bags opening
   - ✓ shredding
2. Separation in different streams, based on:
   - ✓ size
   - ✓ weight/density
   - ✓ magnetic properties
   - ✓ optical properties (NIR, X-ray)
3. Compaction

Mechanical process units

Size reduction

machine	function	typologies	Consumption
BAGS OPENER	To rip and open bags	blade: high throughput and low energy consumption. Not suitable for materials other than bags. Will block with metals items and/or large size inert.	2-4 $kWh \cdot t^{-1}$
PRIMARY SHREDDER	To shred entering material as it is, to rip bags, to tear the textile materials and to shred plastic and wood items. Can be mono rotor or bi rotor.	1. High speed hammer mill (> 600 rpm), with high throughput and small size of output material (< 200 mm) 2. Slow speed cutler (< 15 rpm): suitable for tough and elastic materials (textile, rubber) 3. Slow speed hybrid (< 600 rpm): suitable for a mixed waste; not suitable for tough and elastic materials.	7-15 $kWh \cdot t^{-1}$
SECONDARY SHREDDER	To reduce the size of pre-shredded material down to < 15 cm for fluidised bed combustion or < 3-4 cm for cement kiln co-combustion. Mono or bi rotor, can be damaged by iron and metals.	1. Slow cut (<120 rpm): reliable machine, with clutch; it will stop in case of large size non uncrushable items; suitable for low throughput (< 5 $t \cdot h^{-1}$ for size < 4 cm; < 10 $t \cdot h^{-1}$ for size < 15 cm); 2. Medium/high speed hammer (< 300 rpm): higher throughput (+30%)compared to slow cut and more robust; very expensive and with high energy consumption (+100% compared to slow cut).	15-23 $kWh \cdot t^{-1}$

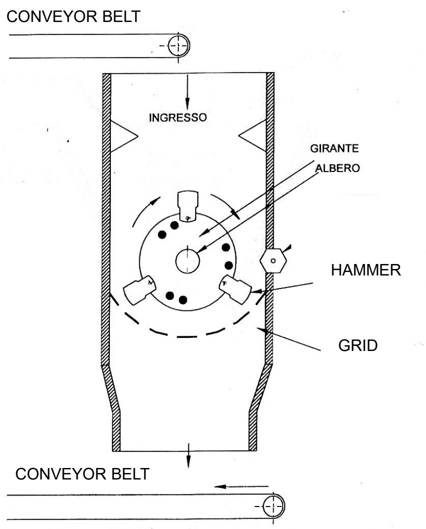
Hammer mill



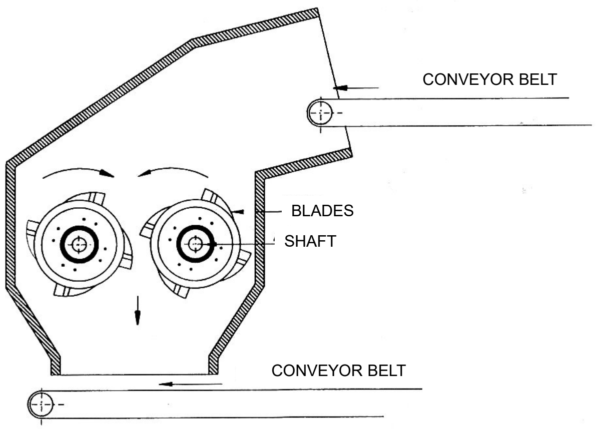
Vertical

High speed
1000-2000 rpm

Horizontal



Preliminary shredder



Low speed, bag opening

Mechanical process units

Separation in different streams/1

machine	function	typologies	consumption
SCREEN/SIEVE	To separate the materials based on their size. Can be mono- or multi-steps, according to the number of section with different screen holes size. Generally two-steps screens are used.	1. Rotating drum: universal large size machine that completely mixes the material; 2. vibrating screen: suitable for small sized materials (< 10 cm) and to select thin items (< 4 cm); holes clogging might happen because of bi-dimensional materials (e.g. iron wires); 3. disk screen: makes the material bound and has high throughput; difficult to set and noisy.	0.5 – 1.5 $kWh \cdot t^{-1}$
IRON REMOVING MAGNET	To separate the ferrous materials. Only for uniform size flows (< 15 cm). Extracted iron is generally “clean”.	1. electromagnetic overbelt: suitable for medium/large flows (10-30 $t \cdot h^{-1}$) and/or medium/large particles size (< 400 mm); simple and not expensive; 2. permanent magnet : suitable for small size (< 200 mm); not suitable for large size materials or in the presence of pieces of iron > 3 kg; 3. overbelt magnetic pulley: not expensive; suitable for small size (< 100 mm) and/or together with overbelt magnet; not suitable for medium/large particles size (> 100 mm).	0.2 – 0.4 $kWh \cdot t^{-1}$ (permanent magnet); 0.6-1 $kWh \cdot t^{-1}$ (electromagnet)

SRF production from residual waste

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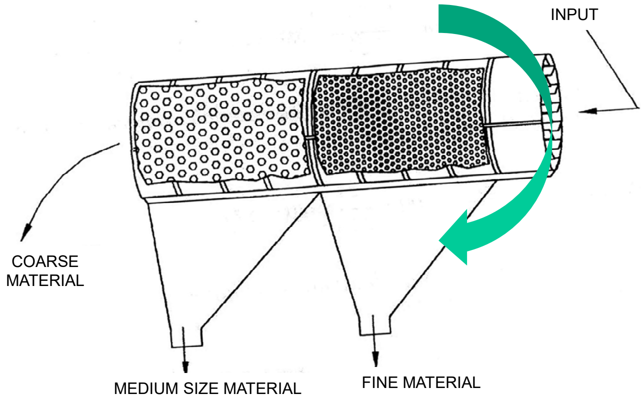
Rotating drum screen



Mechanical process units

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Separation in different streams/2

machine	function	typologies	consumption
EDDY CURRENT SEPARATOR	To select non ferrous metals (except for stainless steel). It is more effective with small size material (< 15 cm).	1. Inductor roller: suitable to medium flows (< 15 $t \cdot h^{-1}$); expensive; 2. permanent magnet: allows to remove aluminium but requires a preventive careful iron removal, otherwise there is a risk of fire, as iron items can bake.	0.7-1.2 $kWh \cdot t^{-1}$
DENSIMETRICAL TABLE	To select an “heavy” fraction from a “light” one based on their specific weight. Good productivity with constant material size (< 25 cm). Can also select a thin undersieve. It is used to separate inert materials.	1. Moving elements 2. Vibrating movement Advantages: suitable for low flows (< 10 $t \cdot h^{-1}$). Disadvantages: large footprint; modest selection efficiency; difficult to setup.	0.5–1 $kWh \cdot t^{-1}$
AERATION SEPARATOR	To select a “heavy” fraction from a “light” one based on their specific weight through air flows. Good productivity with constant material size (< 25 cm). It is used to separate inert materials.	Air flow with suction Advantages: suitable for medium flows (< 15 $t \cdot h^{-1}$); good flexibility. Disadvantages: relevant air flows to be treated; high energy consumption; difficult to setup.	1-3 $kWh \cdot t^{-1}$

SRF production from residual waste

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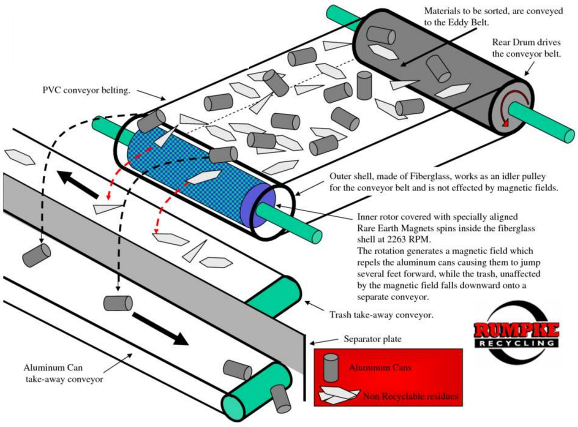
Eddy Current Separator (ECS)

Induces a secondary magnetic field in metallic items, which are thrown forward from the belt into a product bin, because of magnetic repulsion

It uses a very high speed rotating drum with permanent magnets fitted within a non-metallic drum which travels much more slowly



SRF production from residual waste

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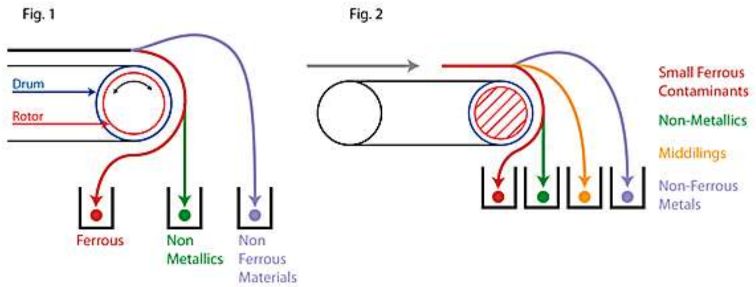
Eddy Current Separator (ECS)

Non-ferrous metals, in contact with the magnetic field, are rejected with a force that is proportional to the ratio between their conductivity and their specific weight and pushed away with different trajectories from those of the inert material, whose stream is collected separately



SRF production from residual waste

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Eddy Current Separator (ECS)

From min. 1:00

SRF production from residual waste

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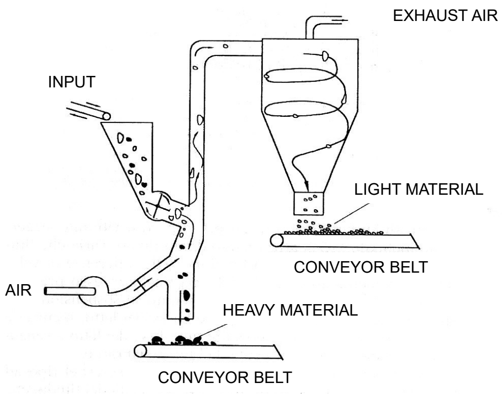
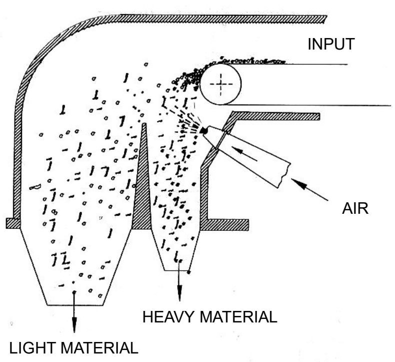
Air classifiers





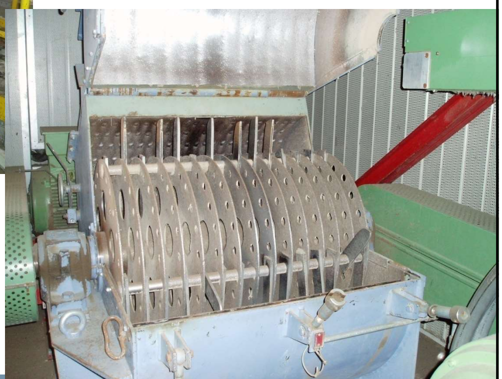
Mechanical process units

Aeration separators

Mechanical process units

Overbelt magnet

Hammer mill



Mechanical process units

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Pelletizer

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OUTLINE

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- Biological treatments
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SRF production from residual waste

Bio-drying

Part of the water content of waste is evaporated thanks to the heat released by the aerobic biological degradation processes

$$C_{organic} + O_2 \rightarrow CO_2 + H_2O$$

- weight loss between 20 and 30%
- duration: 7-15 days
- temperature of 50-55°C is reached → hygienisation

Bio-drying

Process design and sizing

1. Energy balance → evaluation of the amount of water that can be evaporated as a function of the amount of rapidly biodegradable carbon in the waste
2. Kinetic considerations → process duration
3. Stoichiometric considerations → calculation of the amount of air which is necessary for the completion of the process

Bio-drying

Energy balance

1. Heat released by the oxidation of the easily degradable organic carbon (kitchen waste, part of the fines)

$$C + O_2 \rightarrow CO_2 \qquad \Delta H° = - 32650 \text{ kJ kg}^{-1}{}_C$$

2. Heat to evaporate the water contained in the waste (moisture)

$$\Delta H_{EV} = 2400 \text{ kJ kg}^{-1}{}_{H2O} \text{ (@ 55°C)}$$

3. Thermal losses
   - Material heating
   - Losses with the exhaust air
   - Radiation losses

Bio-drying

Energy balance

ENERGY LOSSES

- ✓ thermal dissipation through the walls of biocells
- ✓ heating of the waste
- ✓ heating of the process air
- ✓ heating of the evaporated water (from 15°C to 45°C)

Hp.: organic 31.5%, moisture 32%

Energy balance on the LHV		
LHV of the Residual Waste (RW)	$kJ\ kg_{RW}^{-1}$	10109
LHV of bio-dried material (BIO)	$kJ\ kg_{BIO}^{-1}$	13550
	$kJ\ kg_{RW}^{-1}$	9865 (1)
Energetic losses	$kJ\ kg_{RW}^{-1}$	244
Total	$kJ\ kg_{RW}^{-1}$	10109 (9865+244)
Bio-drying yield	**%**	**97.6**
Power consumption for bio-drying	$kJ\ kg_{RW}^{-1}$	440.6
Overall bio-drying yield	**%**	**93.2**

(1) referred to the residual waste (= 13550 x 0.728)

Bio-drying
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Kinetic considerations

We can assume a first order degradation kinetic for the organic substance

$$\frac{dS_t}{dt} = -k_e S_t$$

S_t = concentration organic substance at time t [g kg^{-1}]

k_e = biodegradation constant [t^{-1}]

$$\mathbf{S_t} = \mathbf{S_0} \exp(-k_e \mathbf{t}) = \mathbf{S_0}\, 10^{-k\mathbf{t}}$$

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Bio-drying
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Stoichiometric considerations

Calculation of the amount of air which is necessary for the completion of the process

$$C + O_2 \rightarrow CO_2$$

Stoichiometric oxygen

↓

Stoichiometric air

↓

Actual air

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Bio-drying

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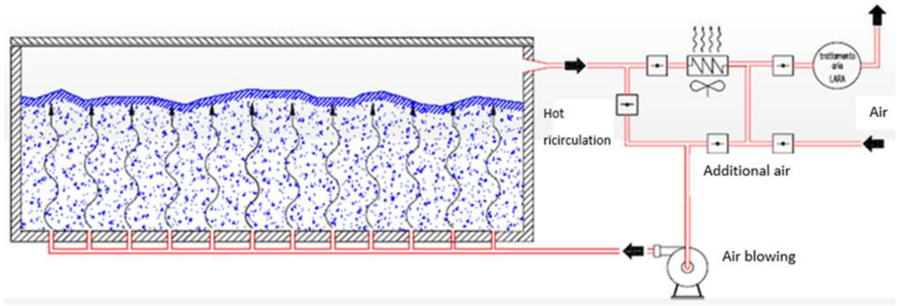
Types of bio-drying technologies



Sealed “bio-cells”

Air recirculation following dehumidification (by condensation) of the exhaust air

Residence time: 7-8 d

Bio-drying

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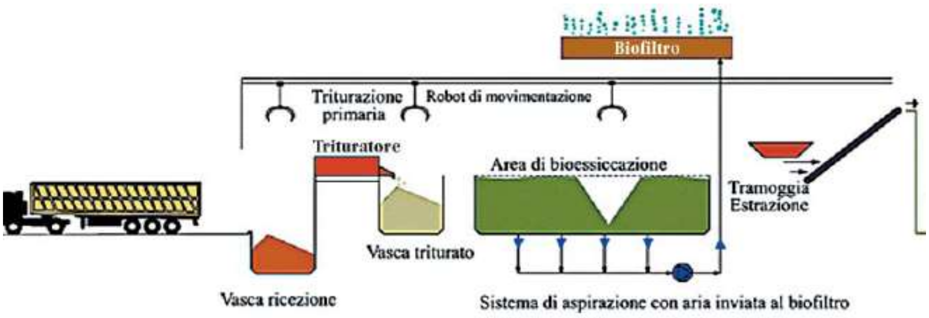
Types of bio-drying technologies



Bio-drying in basin

No air recirculation

Residence time: 8-15 d

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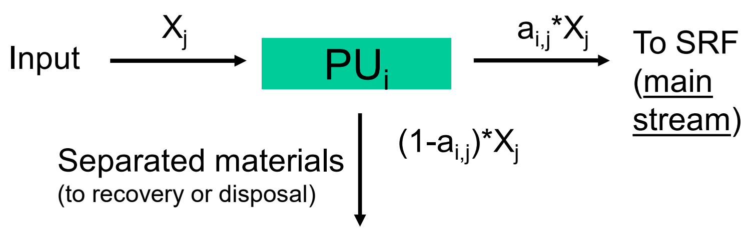
Design of a full MBT plant

We assume that in each process unit (PU)
a binary separation takes place



Where:

X_j is the amount of each waste fraction

$a_{i,j}$ is a separation coefficient for each PU and each waste fraction

$a_{i,j}$ coefficients are provided by the RFTF matrix

Design of a full MBT plant

RFTF matrix (Recovery Factor Transform Function)

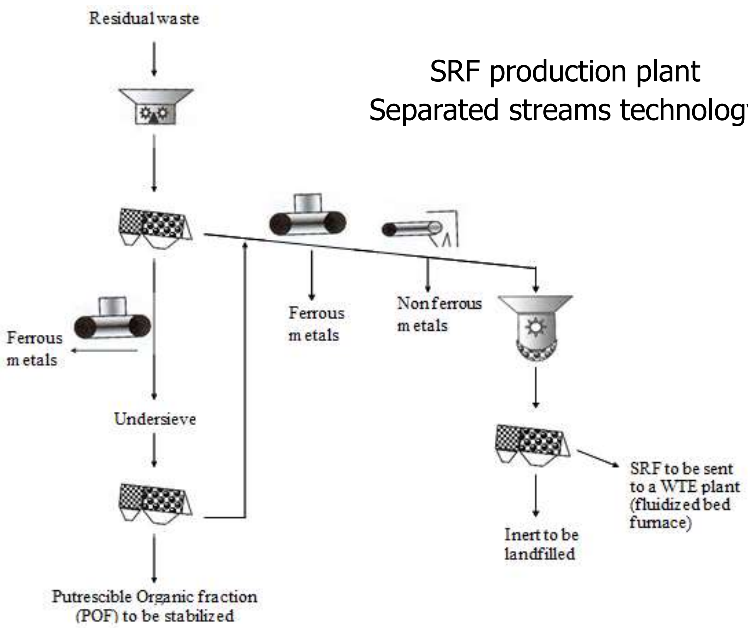
(fraction which remains in the main stream)

		Ferrous metals	Non ferrous metals	Glass	Paper	Plastic	Fines	Wood	Organic	Average consumption (kWh/t)
Bags opener	D	1	1	1	1	1	1	1	1	3
	M	1	1	1	1	1	1	1	1	
Primary shredder	D	1	1	1	1	1	1	1	1	11
	M	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
Secondary shredder	D	1	1	1	1	1	1	1	1	19
	M	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
Drum screen (fine)	D	0.8	0.8	0.2	0.85	0.9	0.25	0.5	0.25	1
	M	0.8	0.8	0.2	0.85	0.9	0.25	0.5	0.25	
Drum screen (coarse)	D	0.41	0.37	0.01	0.69	0.62	0.02	0.2	0.11	1
	M	0.41	0.37	0.01	0.69	0.62	0.02	0.2	0.11	
Air classifier shredded material	D	0.1	0.8	0.7	0.98	0.98	0.2	0.7	0.7	2
	M	0.09	0.72	0.63	0.882	0.882	0.18	0.63	0.63	
Air classifier Non shredded material	D	0.1	0.5	0.02	0.98	0.98	0.15	0.4	0.4	2
	M	0.09	0.45	0.018	0.882	0.882	0.135	0.36	0.36	
Ballistic classifier	D	0.1	0.8	0.7	0.98	0.98	0.2	0.6	0.6	0.75
	M	0.1	0.8	0.7	0.98	0.98	0.2	0.6	0.6	
Magnetic separator	D	0.2	1	1	0.98	0.98	1	1	0.95	0.3
	M	0.2	1	1	0.98	0.98	1	1	0.95	
Eddy Current Separator	D	0.9	0.1	1	0.98	0.98	0.95	0.98	0.98	1
	M	0.9	0.1	1	0.98	0.98	0.95	0.98	0.98	
Densifier, extruder, pelletiser	D	1	1	1	1	1	1	1	1	30

D: dry matter; M: moisture

SRF production from residual waste

SRF production plant
Separated streams technology



SRF production from residual waste

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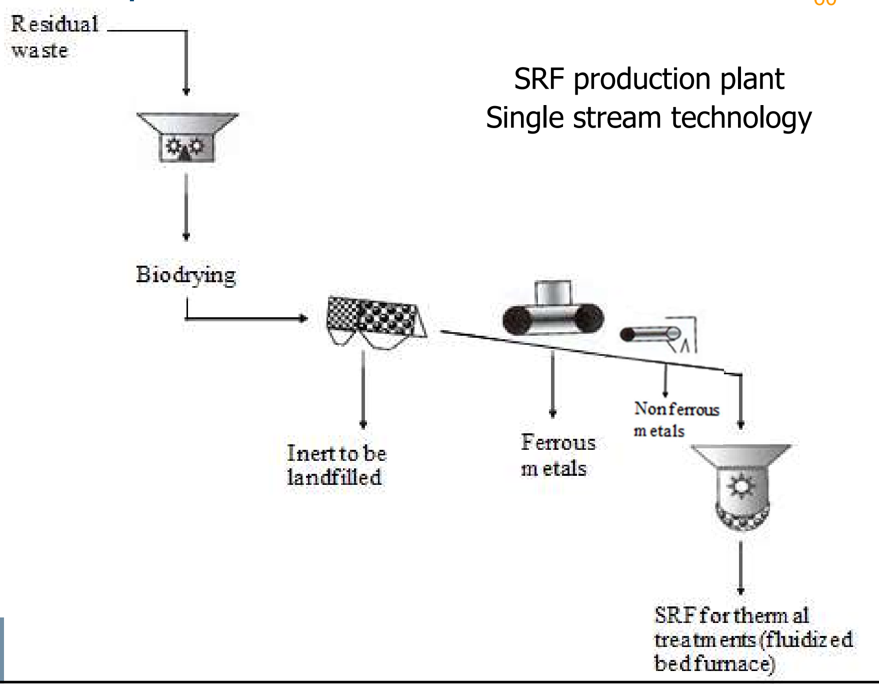

SRF production from residual waste

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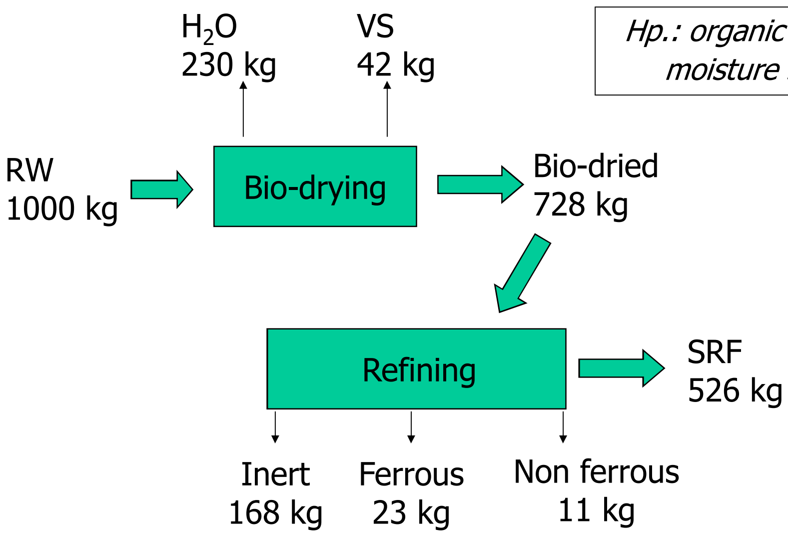
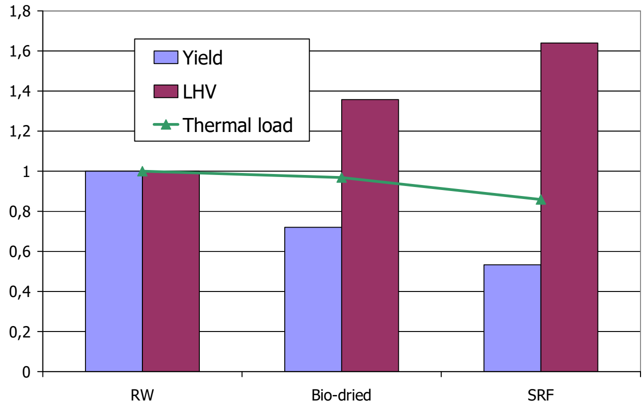
MASS BALANCE (single stream)

Hp.: organic 31.5%, moisture 32%



SRF production from residual waste



Actual average yield measured in Italian plants: 33% [1]

Electric energy consumption: 70 – 80 kWh/t
(30 – 35 bio-drying + 40 – 45 refining)

(1) Source: Rapporto rifiuti

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MBT for material recovery

- Material recovery is part of every MBT plant designed for SRF production → but it is limited to **ferrous** and **non-ferrous** metals
- It is possible to include further recovery of **plastic and paper**, mainly based on NIR (Near Infra Red) sensors
- A **manual refining step** is always required in order to enhance the material quality for its recycling
- **SRF** is still produced, but with **lower yield and quality**
- A bio-dried output stream can also be produced

MBT for material recovery

A possible plant layout

MBT for material recovery

Example of a mass balance *(Ecoparc plant in Barcelona)*

	Recovered materials	Plant residue	Composting Evaporation
	% weight over input	*% weight over input*	
Cardboard	0,15%		
Fruit box (PEHD)	0,10%		
Residue > 350mm		4,00%	
Metals (big)	0,26%		
Glass	0,13%		
Dangerous materials (batteries, gas cans)		0,25%	
Magnet (Fe) <90mm	0,85%		
Paper and cardboard (Optical separator)	2,12%		
Film (Wind shifter)	2,96%		
Magnet Fe (3D)	0,90%		
PET (optical separator)	0,97%		
PEHD (optical separator)	0,46%		
Tetrapack (optical separator)	0,82%		
Mixed plastics (optical separator) PE,PS, PP	0,60%		
Allumiun (Eddy current system)	0,12%		
Residue 3D materials		18,18%	
Magnet (Fe) (2D)	0,10%		
Residue derived fuel (RDF) > 90mm	6,38%		
Composting evaporation			36,20%
Composting final residue to landfill		13,85%	
Biostabilized material	10,60%		
TOTAL	**27,52%**	**36,28%**	**36,20%**

MBT for material recovery

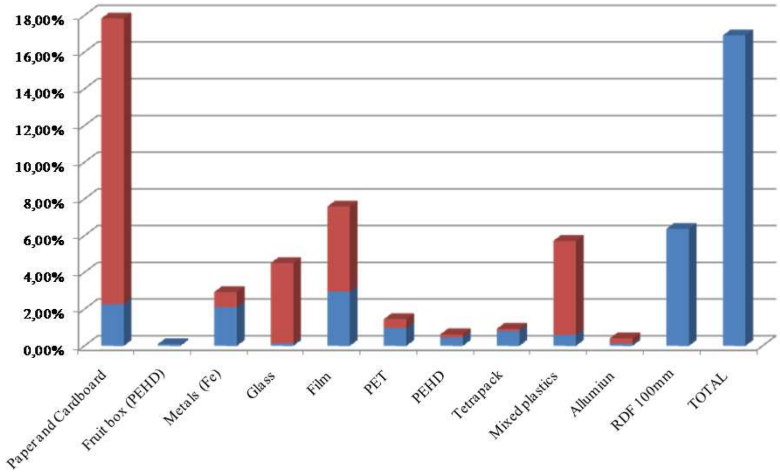
Amount of recovered materials *(Ecoparc plant in Barcelona)*

	% weight over total waste input
Plastic film	3
Paper and cardboard	2.3
Iron	2.1
PET	1
Laminated paper	0.8
Mixed plastics (PVC, PP, PS)	0.6
HDPE	0.5
Fruit boxes	0.1
Glass	0.1
Aluminium	0.1
TOTAL	**10.6**

MBT for material recovery

70

Recovery efficiencies **(in blue)** compared
to the corresponding input *(Ecoparc plant in Barcelona)*



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OUTLINE

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- *Solid Recovered Fuel*
- *MBT plants introduction*
- *Mechanical treatments*
- *Biological treatments*
- *Plants design and layouts*
- *MBT for material recovery*
- *Impacts on the environment and their control*

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Impacts on the environment

Air

- VOC (odours)
- reduced inorganic compounds (H_2S, NH_3)
- particulate matter

Water

- generally speaking, the process is liquid discharge – free

Noise

- generated by mechanical equipments

Other impacts

- proliferation of insects (flies)
- risk of fires (SRF storage and handling)

Impacts on the environment

Control of the impacts on the environment

1. All operations must take place in a SEALED environment, with internal air intake
2. Dust removal with filtration
3. Gaseous pollutants removal through:
   - biofiltration
   - thermal or catalytic combustion
   - wet scrubbing systems (acid, basic, oxidising)
   - adsorption/desorption systems

Air pollution control
74

Biofilter

Engineered bed of soil or compost under which lies a distribution system of perforated pipe and a layer of coarse distribution media

Contaminated air is blown into the perforated pipes and slowly diffuses up through the biofilter media. The contaminant molecules flow through the biofilter media and are consumed by the microorganisms

Conceptually the same process that takes place during bio-drying, but reversed (here the solid material is degrading the gaseous pollutants in the air stream)

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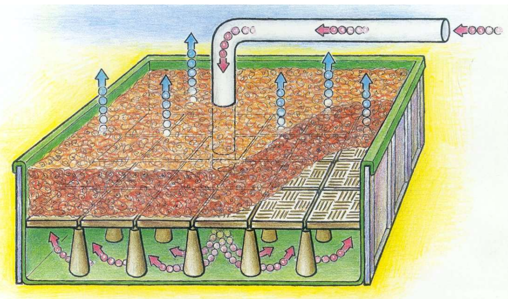
Air pollution control
75

Biofilter



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Biofilter

Biologically active porous media

Thick bed made of:
- bark
- shredded wood
- compost
- peat

Aerobic biological decomposition of the odorous volatile organic compounds contained in the air flow

It takes place thanks to the indigenous microorganisms inherent within the biofilter media, that convert the organic compounds to carbon dioxide and water

Biofilter

	Abatement efficiency (%)
Aldehydes, alkanes	75
Alcohols	90
Aromatic hydrocarbons (benzene)	40
Aromatic hydrocarbons (toluene, xylene)	80
NMVOC	83
PCB, PCDD/F	40
Odour	95-99

Source: BREF Waste treatment (2005)

Basic design parameters

Height (cm)	80 – 200
Contact time (s)	> 36
Specific load ($m^3\ h^{-1}\ m^{-3}$)	< 100

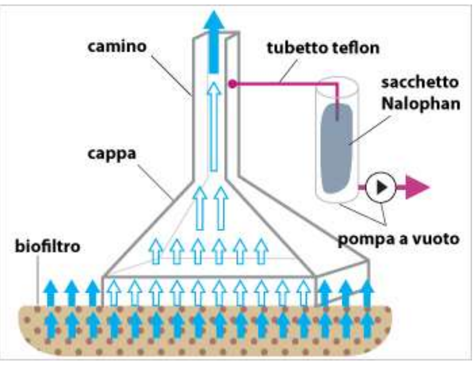
Biofilter is consumed during its operation, and needs to be periodically refilled and replaced

Biofilter

CRITICAL ASPECTS:

- temperature control
  - ✓ optimum for mesophilic bacteria: 37°C; range: 20 – 40°C
- humidification
  - ✓ optimal: 40 – 60 %
  - ✓ need of surface sprinklers
- homogeneous air flux distribution
- problem with the representative sampling of the emitted air

Air sampling from the surface of an open biofilter



Air pollution control

Covered biofilter
for better emission
monitoring