WASTE MANAGEMENT

Edited by
László ALEKSZA

- Principles and Legal System of Waste Management
- Collection and Transport of Waste
- Prevention, Reuse, Recycling, Disposal of Waste
- Energetic utilization of Waste
- Composting, Biogas production
- Mechanical-biological treatment (MBT)
- Treatment of Food Industy Wastes and Animal By-Products

Handbook

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Waste Management

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I. WASTE TREATMENT PRINCIPLES

I.1. Basic terms, classification of wastes by EWC codes

(Hilda Farkas)

I.1.1. The definition of waste

Creating an exact definition of waste has been a struggle both for European and Hungarian regulation for a long time, although it is essential to clearly distinguish between those materials and objects that fall within the scope of waste regulation and those that should not be regarded as waste. According to the former regulation, "waste means any object or material belonging to one of the categories defined under Annex No. 1, from which its owner disposes, will dispose, or is obliged to dispose." However, categories defined under Annex No. 1 of the regulation proved to be far too general, leading to significant debate. As a result, Directive 2008/98/EC of the European Parliament and the Council of 19 November 2008 on waste and repealing certain Directives (Waste Framework Directive: WFD) modified the definition, which has been verbatim taken over by Act CLXXXV of 2012 on waste (Waste Disposal Act: WDA). According to this Act, "waste means any material or object from which its owner disposes, will dispose, or is obliged to dispose".

Since the definition is fairly open, the new regulatory environment tried to close it from "outside"; that is, to also define those conditions under which a material or object shall not be regarded as waste. For this reason, the status of waste was terminated ("end of waste" status or EoW) and the term "by-product" was introduced. Both measures are aimed at bringing marketable basic materials back into to production, this way promoting sustainable resource management. The termination of the status of waste can be achieved through a high level of recycling resulting in the manufacturing of marketable products of the same quality as basic materials. The main difference between the two statuses is that, while by-products do not become waste due to their immediate reuse in other industrial processes, EoW refers to products manufactured from materials formerly defined as waste. The process is described under Figure I.1.1.

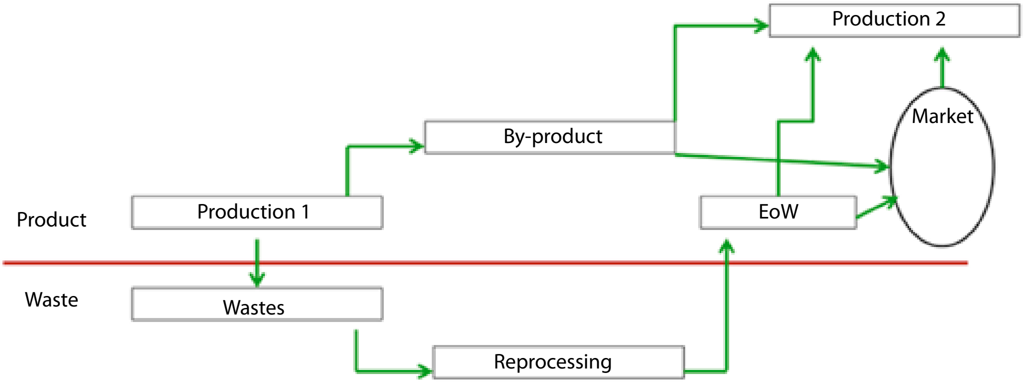


Figure I.1.1: Connection between by-products, the termination of the waste status and production

I.1.2. The environmental impacts of wastes

One of the major impacts of wastes is that, after entering the natural environment, they may endanger its components and human health. Consequently, the proper collection and transportation of waste that is produced and the adaptation of management methods that lead to the highest available utilization levels of waste (or its material content) and to the disposal of non-utilizable wastes are high priority issues in waste management. All these operations shall be carried out without endangering or damaging the natural environment or human health.

The environmental impacts of wastes are very diverse when the components of waste get into nature (e.g. volatile components evaporate to the surrounding air or soluble components enter the groundwater). Soil quality deteriorates if waste directly contacts or enters the deeper layers of the ground (in the form of solid or liquid wastes). Furthermore, the decomposition products of wastes may also lead to environmental damage, such as methane releases during the process of biodegradation, changes induced by the sun, precipitation, heat or light, break-up and ablation by the wind.

From the perspective of environmental impacts, hazardous and non-hazardous wastes can be distinguished. A special sub-group of non-hazardous wastes is called inert waste. This kind of waste does not emit harmful materials into the natural environment. During recycling operations avoiding occupational health impacts that may affect employees who are executing the different work phases is of high importance, while during thermal utilization and disposal (landfilling, incineration) the harmful components of waste shall be prevented from entering the natural environment. The conditions for landfilling primarily depend on the amount and hazardousness of soluble components, while the rules that apply to thermal waste management technologies are defined by the total harmful material content of the waste (e.g. heavy metals, sulphur and chlorine content).

I.1.3. Classification of wastes

Wastes can be classified in several ways based on specific goals, but it should be noted that, consequently, these groupings are usually arbitrary. The most important division is the differentiation between hazardous and non-hazardous wastes. This categorization is so important because the further management of waste is based on this kind of classification. Since under uncontrolled circumstances hazardous wastes may cause severe damage to environment and health, every single operation that is carried out related to them (collection, storage, transportation and management) shall be carried out according to strict rules.

Wastes are also often classified based on their origins. From this point of view, the following categories can be differentiated: industrial (from the producer), agricultural, residential and service-related wastes. Although this kind of categorization is only of statistical importance in many cases, it is a fact that the number of residential types of waste is much less than those produced in the other sectors. On the other hand, these categories overlap to some extent, since household-type waste is also generated in the production sector (e.g. in offices and community areas, and, for example, building-demolition waste is also generated by normal citizens.

Wastes can be further categorized based on their state of aggregation. From this perspective wastes can be solid, sludgy, liquid or gaseous. On the one hand, this is important from the perspective of their further management, while it should also be taken into account because of the environmental impacts they cause. Some part of agricultural wastes shall not be regarded as waste any longer: e.g. biomass that is redirected into the natural cycle during agricultural activities, or by-products of animal origin, which are today regulated by a separate European Union decree. Only a fragment of this latter group becomes real 'waste'.

I.1.4. Basic terms for characterizing wastes

Basically, three different approaches can be distinguished when characterizing wastes. The first approach is based on the origin of wastes, such as building-demolition waste, waste generated in medical institutions, household waste, household-type waste, junk, municipal waste, production waste and mixed waste. These definitions can be found in the act on waste or in its enforcement orders.

The second approach primarily considers the components of waste, such as organic waste, biodegradable waste, packaging waste, used oil, waste of electric and electronic appliances, battery and accumulator wastes, end-of-life vehicles, waste containing PCB or sewage sludge. Although some of these waste types are not legally defined, it is not even necessary.

The third approach differentiates between wastes according to their environmental impacts by using the categories of inert waste and hazardous waste. Three further important basic terms also need to be mentioned here. Waste type means a waste which can be characterized with a specific code number from the waste list, while waste class refers to the characteristic material composition of the waste (e.g. wood, metal, paper, glass, composite, plastic, biodegradable, etc.). This latter term can therefore be primarily connected with the second group in the above-mentioned classification. The properties of waste indicate if it is inert, non-hazardous or hazardous. Figure I.1.2 illustrates the distribution of inert, non-hazardous and hazardous wastes within the building-demolition waste group.

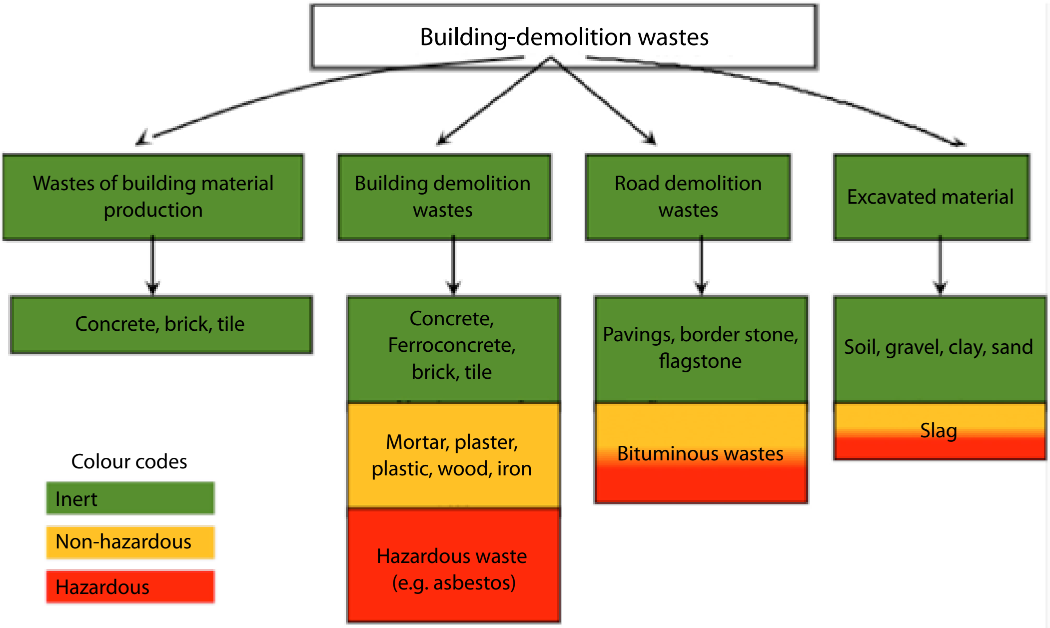


Figure I.1.2: Distribution of building-demolition wastes according to their environmental hazardousness

I.1.5. The hazardousness properties of wastes

It is important to correctly decide if the given waste is hazardous or non-hazardous, since the rules for its further management depend on this classification. Significantly stricter rules apply to the field of hazardous waste management, including collection, transportation or management. According to the definition of the law, the given waste shall be regarded as hazardous if it has at least one hazardousness property. Hazardousness properties are listed under Annex No. 1 of the WDA. They are marked using an "H" (meaning hazardous properties), and their value ranges between H1-H15.

"H" factors can be divided into more groups based on their impacts.

- Groups H1-H3 include materials with aggressive characteristics in the environment, e.g. they are explosive, flammable, or reactive with other substances. For wastes with such characteristics, following fire safety regulations is regarded as standard. This category includes, for example, waste organic solvents or the wastes from explosives.
- Groups H4-H8 include materials that can damage the physiological processes of living beings, for example by being irritating, toxic, carcinogenic or corrosive. This category includes, for example, chemicals leaving production processes, wastes containing heavy metals, halogens or PCB, the wastes of pesticides or the other wastes of the chemical industry.
- Group H9 includes infectious wastes. The two most important categories of infectious wastes are medical wastes and wastes of animal health origin.
- Groups H10-H11 include hazardous materials that cause heritable and non-heritable genetic mutations.
- Although not the next on the list, group H13 is used for wastes with biological impacts, including those harmful allergenic substances that are so common nowadays. Groups H12, 14 and 15 characterize the environmental hazardousness of materials.

I.1.6. The EWC codes

There were two different waste lists in use in the European Union: one for hazardous and another one for non-hazardous wastes. Using these lists proved to be extremely complicated and they were not standardized with each other so it was not uncommon in practice that – depending on the production technology – the same waste could be regarded as hazardous or non-hazardous. To improve this situation the European Union elaborated the unified European Waste Catalogue in 2001 which was also adopted by Hungary when joining the European Union (Decree No. 16/2001 (VII. 18.) of the Ministry of Environmental Affairs on the register of wastes). This list creates a unified frame for both hazardous and non-hazardous wastes by grouping them into 20 main categories.

Basically, the list is technology-based, and classification depends on the production and formation process (main categories), but it is also complemented by a few material-type chapters (e.g. main categories No. 13, 14 and 15). Wastes which cannot be put into the above mentioned categories are grouped under main category No. 16, while the treatment-oriented main category No. 19 has been created for the separation of secondary wastes.

The waste registry includes 20 main categories. There are 111 subcategories within the main categories. The naming of wastes (waste type) is systematized within the subcategories. Each kind of waste has a 6-digit numeric code number (EWC code). The first two characters of the 6-digit code show the main category, the second two characters refer to the subcategory, while the last two characters identify the type of waste. For hazardous wastes there is also a 7th character ("*") meaning that in general the given waste should be regarded as hazardous waste. Altogether, there are 838 waste types in the list, from which 403 are hazardous. Below you can find an example of the subcategories found within main category No. 2 (see Table I.1.1) and wastes included in subcategory No. 02 01 (see Table I.1.2.).

As presented in Table I.1.2, the waste list also includes items whose description differs only in terms of their hazardousness properties. Items with the same description but marked as hazardous and non-hazardous at the same time are called parallel items. The last item from each subcategory has a code ending with 99, meaning that the wastes not clearly defined. These wastes should be listed here according to their origins or properties, but they are different from other elements in the given subcategory.

Main category/ subcategory	Name
02	**Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing**
02 01	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing
02 02	Wastes from the preparation and processing of meat, fish and other foods of animal origin
02 03	Wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tabacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation
02 04	Wastes from sugar processing
02 05	Wastes from the dairy products industry
02 06	Wastes from the baking and confectionery industry
02 07	Wastes from the production of alcoholic and non-alcoholic beverages (except coffee, tea and cocoa)

Table I.1.1: Subcategories of wastes of agricultural origin

I.1.7. Classification of wastes based on the waste registry

Instructions for classifying can be found under Annex No. 3 of the decree on the list of wastes. First, the waste shall be identified according to the titles of the main categories No. 01-12 and 17-20 based on the activity of origin, and then the respective 6-digit code belonging to the waste should be looked up.

If the waste in question cannot be placed into the main categories No. 01-12 or 17-20, then main categories No. 13, 14 and 15 shall be used for its identification.

If none of the above-mentioned main categories is appropriate for classifying the waste, then it has to be assigned a proper category according to main category No. 16.

If the waste cannot even be found in main category No. 16, then code No. 99 (unidentified wastes) should be used for the main and subcategory of the registry that matches with the given activity of origin. However, hazardous wastes cannot be labelled with codes ending with 99 (except for code No. 13 08 99*).

Separately collected packaging waste (including mixtures of different packaging wastes) shall be put into subcategory No. 15 01, and not into subcategory No. 20 01. Figure I.1.3. presents the process of classification which includes those cases mentioned only later (classification based on composition or waste qualification process).

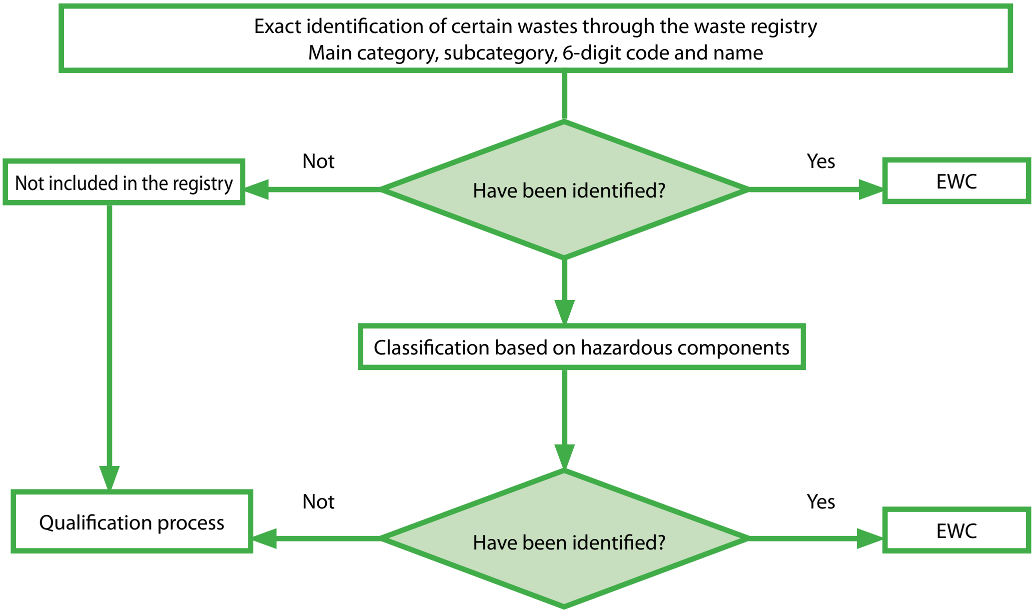


Figure I.1.3: Flowchart of waste classification

I.1.8. Categorization based on hazardous components and characteristics of hazardousness

Properly categorizing waste is the responsibility of the producer whose activity leads to the generation of the given waste. Making the correct decision about the hazardousness of the waste is a particularly great responsibility for the producer.

If a non-hazardous waste is categorized as hazardous, it shall be collected, transported and managed according to the rules applying to hazardous wastes, this way generating undue expenses for the producer.

On the other hand, by categorizing hazardous wastes as non-hazardous we may infringe the law by "endangering the environment" and may get a huge penalty from the authorities.

A given waste shall be always regarded as hazardous if it has any hazardousness properties, it is marked with a "*" in the waste list, or its composition is unknown. In the latter two cases the owner of the waste may verify the non-hazardousness of the waste by conducting analyses. This activity is called the waste qualification process.

I.1.9. Connection between the "H" properties and limit values

In order to be able to make a correct decision about the hazardousness of a given waste we have to be aware of its components and its other impacts on the natural environment and human health. These characteristics are described by "H" hazardousness properties.

For hazardousness properties No. H3-H8 and H10-H11 decrees define limit values. If these limit values are exceeded, wastes shall be regarded as hazardous wastes.

Property No. H3 refers to flammability with a limit of ≤ 55 °C, referring to the indoor flash point.

Property No. H7 indicates carcinogenic features. In this category one should distinguish between heavily carcinogenic (Class No. 1 and 2) and carcinogenic (Class No. 3) materials when measuring such substances in waste.

Limit values for properties No. H4-H6, H8, H10 and H11 are defined by the toxic features of chemical compounds found in waste. Hazardous chemical compounds are characterized by the "R" (risk) sentences which can be also found in internet databases and on safety data sheets. For the limit values of the different H hazardousness properties the R sentences described in Table I.1.2 shall be taken into account.

H	Effect	R sentence
H4	Irritant	R 36/37/38
	Irritant	R 41
H5	Harmful	R 20/21/22
H6	Toxic	R 23/24/25
	Very toxic	R 26/27/28
H8	Corrosive	R 34
	Highly corrosive	R 35
H10	Teratogenic	R 62/63
	Heavily teratogenic	R 60/61
H11	Mugatenic	R 40
	Heavily mutagenic	R 46

Table I.1.2: Connection between H hazardousness properties and R sentences

During the evaluation of properties No. H9 (infectious) and H14 (dangerous to the natural environment), the limit values listed under section "Qualification of wastes" of the government decree on the conditions for carrying out activities related to hazardous waste shall be taken into account, while for characteristics No. H15 (danger of leaching) leaching limit values referring to the takeover of wastes as specified in the annexes of the decree on the landfilling of wastes shall be taken into account.

I.1.10. The process of categorization based on hazardousness properties

For the proper categorization of a given waste the first and most important step is to get acquainted with the H properties of the waste, to have a list of its hazardous materials (compounds), and to know their concentration as measured in the waste (or calculated based on the material balance).

Limit values shall be assigned to hazardous components one by one. The same applies to R sentences in the case of chemical compounds characterized by R sentences and carcinogenic categories for carcinogenic substances. To evaluate the given H hazardousness property the concentration of all hazardous components marked as having R sentences shall be added together.

The same method shall be followed also for carcinogenic materials, with the only difference being that they shall be grouped by classes. If the total concentration of materials (referring to the given H property) reaches the limit value of the H property in question (see Table I.1.3.) the waste shall be classified as hazardous.

For properties No. H9, H14 and H15, evaluation shall be carried out according to the limit values set by the regulations marked in the table. If any of the analyzed parameters exceeds the given limit value the waste shall be classified as hazardous.

H	Feature	R sentence	Limit value	Properties
H1	Explosive			
H2	Oxidizing			
H3-A	Highly flammable			
H3-B	Flammable		≤ 55°C	indoor flash point
H4	Irritant	R 36/37/38	20%	irritates respiratory tracts, the eyes and the skin
	Irritant	R 41	10%	may cause severe damages to the eye
H5	Harmful	R 20/21/22	25%	
H6	Toxic	R 23/24/25	3%	
	Very toxic	R 26/27/28	0.1%	
H7	Carcinogenic		1%	carcinogenic class No. 3
	Heavily carcinogenic		0.1%	carcinogenic class No. 1 or 2
H8	Corrosive	R 34	5%	causes burns
	Highly corrosive	R 35	1%	causes severe burns
H9	Infectious		Decree on hazardous wastes	national virulence limit values
H10	Teratogenic	R 62/63	5%	teratogenic toxicity class No. 3
	Heavily teratogenic	R 60/61	0.5%	teratogenic toxicity class No. 1 or 2
H11	Mutagenic	R 40	1%	mutagenic class No. 3
	Heavily mutagenic	R 46	0.1%	mutagenic class No. 1 or 2
H12	Releases gases			
H13	Capable by any means			
H14	Ecotoxic		Decree on hazardous wastes	national ecotoxicity limit values
H15	Prone to leaching		Decree on landfills	takeover requirements of landfills

Table I.1.3: The relationship between H properties and limit values

I.2. The International and Hungarian legal system of waste management (Hilda Farkas)

I.2.1. The aims and means of waste management

The aims of waste management can be summarized as follows:

- protecting human health, conserving the natural and the built-up environment, promoting sustainable development and developing environmentally conscious behaviour by means of waste management;
- saving natural resources;
- minimizing the environmental burden caused by waste, preventing the generation of waste in order to avoid pollution (the most efficient use of materials acquired from nature, the development of reusable products with a long product lifespan), reducing the amount and level of hazardousness of waste generated;
- utilizing the highest possible amount of waste generated and keeping it in the consumption-production cycle;
- disposing of non-usable and non-recyclable wastes in an environmentally-sound way.

Adequate legal regulation, an institutional system for implementation and development-supporting financial incentives are all needed to achieve these waste management objectives.

The legal system defines the rights and duties of the different actors and means for the monitoring of implementation, such as acting authorities, licensing, monitoring and sanctions, and also defines economic regulations (e.g. environmental product charges, landfilling fees, etc.).

The institutional system primarily refers to the acting authorities, but the other background institutions – taking part, for example, in the processing of data that is supplied or planning processes – also belong here.

The objectives be achieved shall be supported by subsidies. The source of the subsidies can be the European Union (development sources), they may originate from the national budget (e.g. from environmental taxes), or they can be provided by the different actors themselves.

I.2.2. The hierarchy of waste management

Waste is not only an environmental but also a social and economic problem. Environmental impacts are described in detail in Chapter I.1, "Basic terms ...".

The social impact of waste primarily comprises damage to health, but the damage originating from the occupation of land necessary for the disposal of wastes (spoil banks, slag heaps, landfill sites and other management plants) can also be listed here since these areas can no longer be used for other more valuable activities, this way reducing our living space.

Economic problems emerge mostly in the form of costs spent on waste management; this also includes the expenses paid to people. On the other hand, it has been realized that the utilization of the materials found in waste may be advantageous from an economic perspective while favourably reducing environmental, social and economic problems at the same time. As a result, by now waste has become one of the major elements in efficient resource utilization. In order to make the process more efficient, also the hierarchy of waste management has been modified.

In fact, the hierarchy (see Figure I.2.1) defines the preferred order of measures which shall be followed during the planning and implementation of waste management activities. According to this, the most important task is to prevent the generation of waste. This is the task of the actors of production and includes the use of low-waste technologies and the development of products with a long and useful life.

However, when waste is already generated when possible a product should first be repaired or cleaned in order to restore its functionality, this way enabling its further use (preparation for reuse). If this option is not possible, then the materials found in the waste shall be utilized through reprocessing, or their energy content shall be harnessed through thermal utilization. Disposal is the least preferred waste management method (this includes landfilling and incineration).

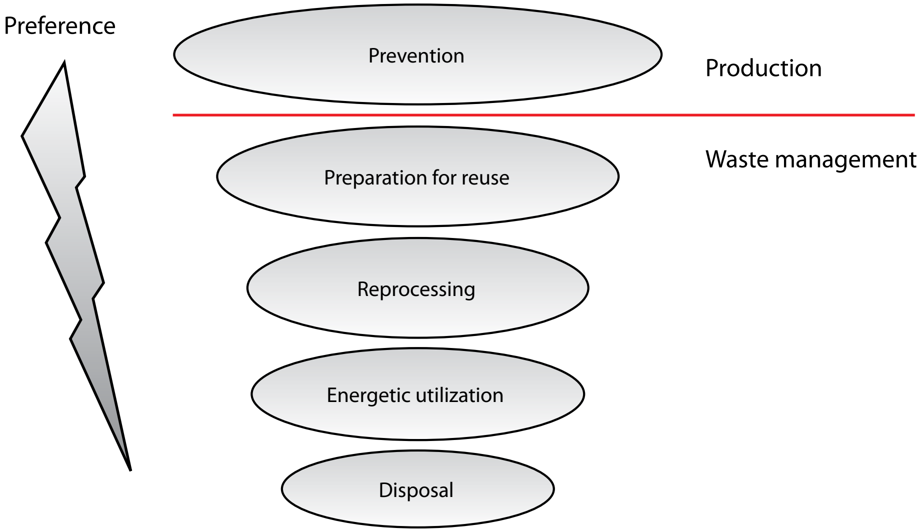


Figure I.2.1: The hierarchy of waste management

I.2.3. The connection between waste management and sustainability

Figure I.2.2 presents the connection between waste management and sustainability. During the process of production people turn natural resources into products. Sooner or later, all products become waste.

The adequate amount of natural resources necessary for production can be maintained in the long run only if they are not only exploited, but they are also redirected back into natural cycles. In other words, we should strive to close the cycle. Consequently, where possible, wastes shall be redirected back into the natural cycle, this way reducing the amount of natural resources consumed. For example, the composting of biodegradable materials or the treatment of sewage are such methods.

Unfortunately, not all kinds of wastes can be treated this way, therefore methods that reduce the need for natural resources must be found. The most efficient way to do this is by reducing the resource demand of production at the beginning of the process by introducing low-waste, basic material and energy-saving technologies. These measures belong to the category called prevention.

From the product side, natural resource demands can be reduced by preparation for reuse. In the case of materials or objects already qualified as waste, all useful material shall be recovered for production purposes (reprocessing, energetic utilization), this way further reducing the demand for natural resources.

From the perspective of sustainability, disposal (landfilling, incineration) of wastes is particularly disadvantageous since these wastes can be regarded as lost both to the economy and from the stock of natural resources. In addition, their disposal and treatment also generate financial costs. However, it has to be emphasized that these measures are still necessary in order to provide protection from their harmful impacts.

It also has to be noted that the activity of 'waste mining' is gathering ground nowadays. This term describes the picking up of formerly-disposed wastes in order to recover the useful materials found in them.

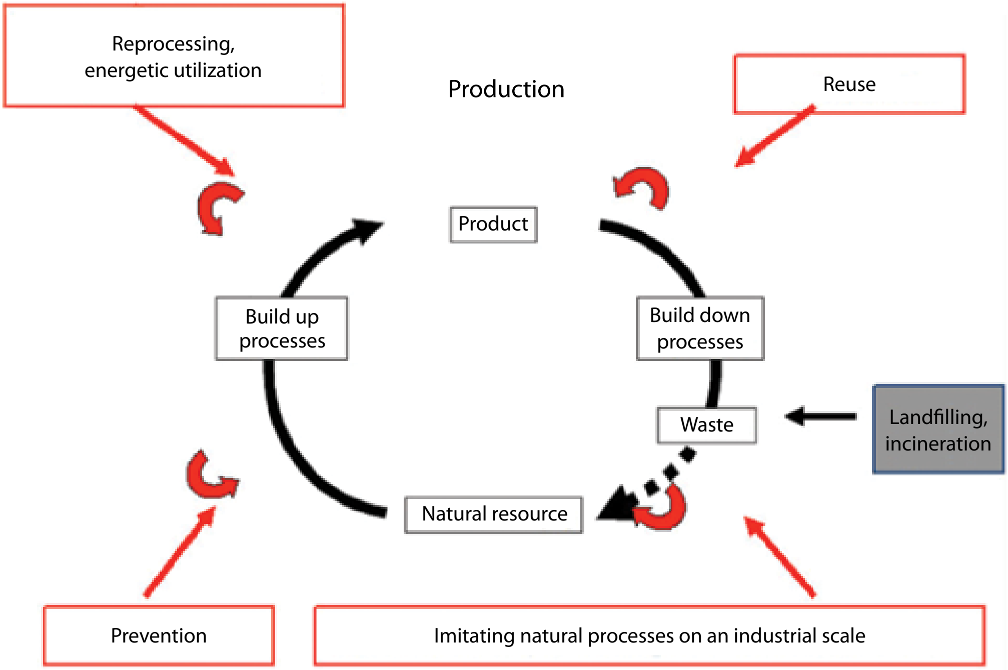


Figure I.2.2: The connection between sustainability and waste management

I.2.4. Sources of law in the regulatory system of the European Union

In the European Union, Basic Agreements shall be regarded as the primary sources of law, while due to their authorization legal materials created by the institutions of the European Union are regarded as secondary sources of law. Regulations can be found at the top of the hierarchy of secondary sources of law and refer to community legal norms with a general scope. Their direct and full implementation is obligatory in all member states therefore it is not necessary to issue separate national legal acts in each country. There are only two regulations in the field of waste management. One of them is Regulation (EC) No. 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste, while the other is Regulation (EC) No. 2150/2002 of the European Parliament and of the Council of 25 November 2002 on waste statistics. A third regulation (Regulation (EC) No. 1069/2009 of the European Parliament and of the Council of 21 October 2009 lays down health-related rules as regards animal by-products and derived products not intended for human consumption, and the repeal of Regulation (EC) No. 1774/2002 (Animal by-products Regulation) also needs to be taken into account here, since it removes by-products of animal origin from the scope of waste regulation.

A Directive is a community legal instrument obligating member states to achieve certain goals, but in this case the method of reaching the goal, the choice of measures and means and their adaptation to the national legal system fall within the competence of the member states. Consequently, in contrast to regulations, member states are obliged to create a legal act according to the orders of the directive through national law-making by a given deadline. In the field of waste management, directives are the most significant sources of law.

A Decision is a community legal act that deals with concrete cases and refers to certain recipients. They are totally binding for their recipients. Recipients can be member states, natural persons or even legal entities. In the field of waste management they are usually used for concrete measures connected to the implementation of certain directives: e.g. for the publication of the implementation rules of reporting commitments or measuring methods to be applied. For example, the European waste list also entered into force through a decision (Commission Decision No. 2000/532/EC of 3 May 2000 replacing Decision No. 94/3/EC establishing a list of wastes). It is also possible to issue recommendations and opinions in community decision making, but these are not legally binding sources of law.

I.2.5. The waste strategy of the European Union

In spite of the continuously expanding regulations and the unequivocally demonstrable successes, waste was and still is a serious problem for the European Union, since its volume is constantly increasing, and due to its improper management severe environmental damage has often been caused. Furthermore, the implementation of the law also leaves much to be desired, since significant differences can be witnessed among member states both regarding the interpretation and the implementation of regulations.

This problem was recognized at an early stage by the European Commission which lead to the elaboration of a community waste strategy dating back to 1989 and 1996. The last community waste strategy was adopted in 2005. These strategies are not sources of law. Their role is to define the operating principles, goals and direction of development of the different professional fields. By analyzing the trends of the formerly longer periods they reveal undesirable or inefficient processes and the broader economic and social context of the different professional fields.

Accordingly, accepted strategies also define how the regulatory environment and the content, subject and time-related scope of the sources of law shall be developed or altered. The 6th European Environmental Action Programme, lasting from 2002 to 2012, depicted a uniform natural resource, product and waste policy. At the same time, it also called upon the European Commission to develop seven thematic strategies. One of them is a thematic strategy on the prevention of waste generation and the reprocessing of wastes, which was harmonised with the strategy on the sustainable use of resources.

The thematic strategy on waste has the following 5 main goals:

- mitigating the environmental impacts of waste;
- reducing the amount of waste generated;
- expanding the scope of reprocessing;
- modernizing and simplifying regulation;
- fully implementing legal acts.

For the mitigation of negative environmental impacts, the lifecycle approach shall be introduced to waste management policy, this way connecting the thematic strategy on resources with the forecasting and modelling systems used by integrated product policy.

Regarding the prevention of waste generation, the strategy supports the application of the Integrated Pollution Prevention and Control Directive (IPPC Directive) and the use of integrated product policy and other means. At the same time, besides exactly defining the necessary commitments, the strategy leaves the elaboration of national policies and programmes within the sphere of authority of the different member states.

In order to expand the scope of reprocessing, the strategy promotes the expansion of processing capacities, the development of requirements for the unified operation of facilities and the elaboration of community-level standards for processed materials and tries to ensure better access to processable materials for the industry of the European Union within the internal market.

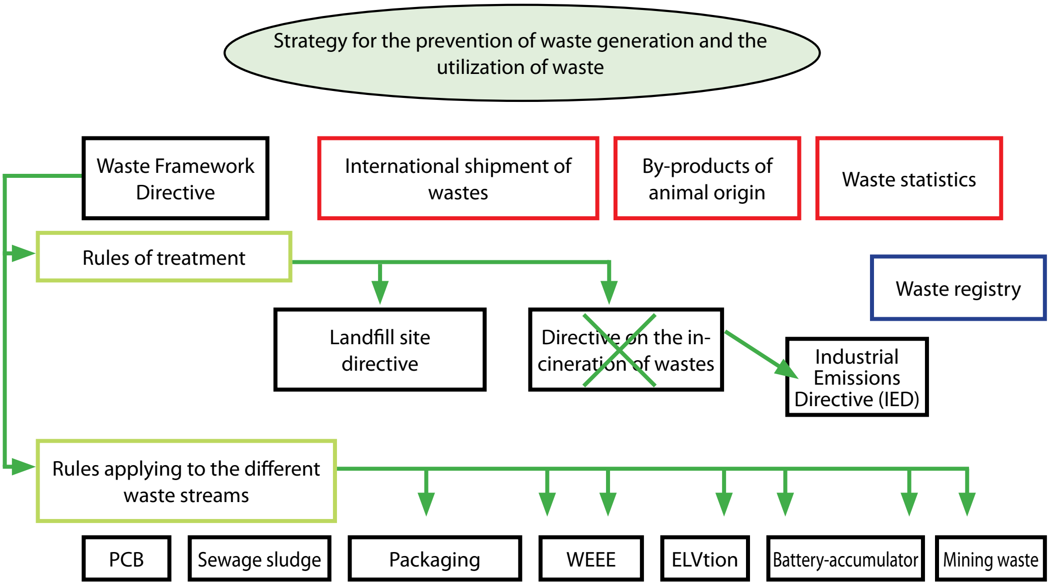
I.2.6. The regulatory hierarchy of the European Union

In order to reach these goals the regulatory system also needs to be simplified. Regarding the review of legal tools, the waste strategy has an exact time schedule, and defines which terms, activities and utilization goals shall be reviewed, and which legal acts shall be harmonized with each other.

The reformed legal system is presented in Figure I.2.3. Regulations are marked with red frames, directives are marked with black frames, while decisions are highlighted by blue ones.

Among directives (marked with black frames) the WFD is of high importance. Compared to the former system, this directive already includes regulations about hazardous wastes and slop oils, which have been earlier regulated by separate directives. Further directives issued for the implementation of the WFD can be divided into two groups: rules applying to treatment and rules dealing with waste streams. Formerly, two directives were in force for the regulation of treatment. One of them was the landfill site directive, while the other was the directive on the incineration of wastes. However, rules about incineration were built into the directive on industrial emissions (Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) or the Industrial Emissions Directive: IED) which were effective from 2010 and replaced the former IPPC Directive. With this step the European Union expressed that the thermal treatment of wastes (aiming at the utilization or the disposal of wastes) is no different from other industrial activities, and its environmental impact shall be judged according to its emission level, irrespective of the place of utilization, let this be an incinerator, power station or at a cement works in the form of co-firing. Directives on waste streams include the special collection and utilization rules to be applied for each given waste stream. Their number is much higher than presented in the figure, and they will be discussed in detail later. Our figure shows only one piece of decision, of course their number is much higher.

The several-times-amended Commission Decision that includes the list of wastes (Commission Decision No. 2000/532/EC of 3 May 2000 replacing Decision No. 94/3/EC establishing a list of wastes, marked with a blue frame) is so important because in practice the whole administration of waste management (licensing, data services, documentation for transport, etc.) is based on the waste categories presented in the list and the code numbers assigned to them.



Notes: PCBs: polychlorinated biphenyls and terphenyls
WEEE: wastes of electrical and electronic equipment
ELV: wastes of end-of-life vehicles

Figure I.2.3: The regulatory system of waste management in the European Union

I.2.7. The Waste Framework Directive

The new framework directive, in force from December 2008, primarily focuses on the following three issues:

- the protection of human health from the harmful impacts of wastes,
- efficient prevention,
- the most widespread use of waste as a resource.

Basically, the protection of human health can be continuously traced through the directive. The main points are grouped under a separate article, and this is referred to several times in the text. In order to enhance the effectiveness of prevention, the WFD orders member states to elaborate national prevention programmes to be presented to the European Commission by the end of 2013.

The WFD also stipulates that member states shall take measures to facilitate reuse (collection, repair centres, channels for putting objects into circulation again), introduce low-waste technologies, spread eco-design and promote the use of the eco-label system, the voluntary commitments of obligants and awareness-raising.

In order to enhance resource efficiency the European Union aims to turn the European community into a recycling society. For this end, the current level of utilization shall be further increased (this includes organic waste, building-demolition waste, residential paper, metal, plastic, glass, electronic waste, batteries and accumulators), collection systems shall be developed (curb side collection, waste yards, takeover points), sufficient management capacities shall be developed (by providing financial sources for development), and the development of the interest systems of residents and municipalities shall be facilitated. The WFD also sets the following concrete goals for member states:

- build-up selective waste collection systems for residential paper, glass, metal and plastic wastes by 2015;

- reach a reprocessing level of 50% for residential paper, glass, metal and plastic wastes by 2020;
- reach a reprocessing level of 70% in the case of non-hazardous building-demolition wastes.

The WFD also introduced new regulatory elements. The most important one is the reform of the former 3-step waste hierarchy into a 5-step hierarchy which has been already described in detail above. Important new basic terms that were already detailed under Chapter I.1, "1 Basic terms ..." were introduced. Extended producer responsibility was also described in more detail compared to the former regulation.

One new element, connecting to licensing, is that it became possible to perform certain waste management activities after only registration, and in some cases member states may specify a lesser frequency and intensity of monitoring activities. Another important element of the WFD is that it emphasizes the provision of social participation and publicity during the development of waste-related regulations and policies.

I.2.8. Treatment-oriented rules - landfilling

As described above, Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste is one of the rules that apply to the treatment of waste. This directive aims at the introduction of measures preventing or mitigating negative environmental impacts caused by the landfilling of waste, such as the contamination of surface waters, groundwater, the soil and the air, including the emission of greenhouse gases and every factor endangering human health from the beginning of disposal in landfill sites until their closing down and during the period of post-treatment.

The directive defines in detail which kind of wastes can be disposed of in the different landfill sites by category (takeover requirements), the course of the takeover process, the process of licensing, monitoring activities to be carried out during operations, the course of closing down and post-treatment of landfill sites and financing issues related to them.

The directive defines three landfill site categories:

- landfill sites for non-hazardous wastes,
- landfill sites for hazardous wastes and
- landfill sites for inert wastes.

Takeover requirements include limit values for the hazardous materials found in the waste and the harmful contaminants which may get released from different categories of landfills.

In the case of municipal landfill sites there are no limit values, but it is an important stipulation that by 2016 the proportion of biodegradable waste disposed in landfill sites shall not exceed 35% of the amount of that produced in 1995. The technical specifications of landfill sites are also described in detail in the directives, including the rules for insulation and the collection and treatment of leachate and landfill gas.

The different annexes of the directive provide detailed information about the necessary monitoring analyses to be carried out during operation and abandonment in order to guarantee that the activity does not pollute the soil, the groundwater or the air. The directive defines a general period of 30 years for post-treatment activities. The European Union gave its member states 10 years to implement the requirements of the landfill directive. Such a long deadline was necessary because during this period member states had to review if their currently operating landfill sites met the defined technical specifications or not, and because building the necessary modern capacity to replace the closed landfill sites also took time.

Hungarian example: by 15th July 2009 more than 2500 outdated municipal landfill sites were closed-down in Hungary (see Figure I.2.4); their recultivation is still in progress today. In the meantime, a modern network of 77 landfill sites has been established, mostly with the help of European Union sources (see Figure I.2.5).

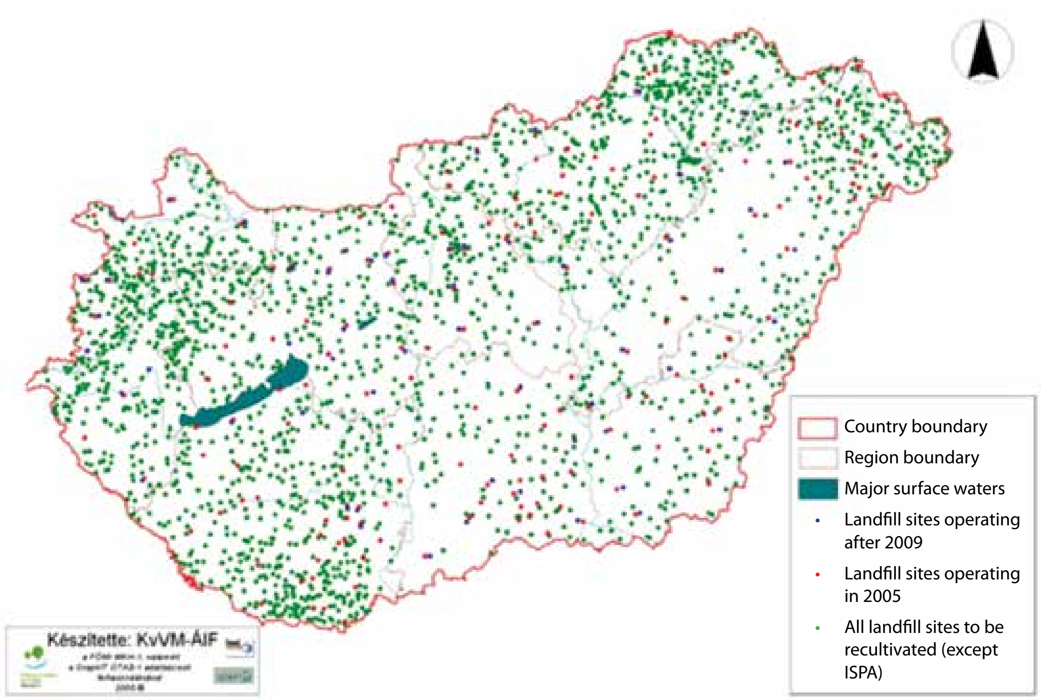


Figure I.2.4: Operating and abandoned municipal landfill sites in Hungary, as reviewed in 2002

Further operating landfill sites taking over municipal solid waste according to the status of 16th July 2009

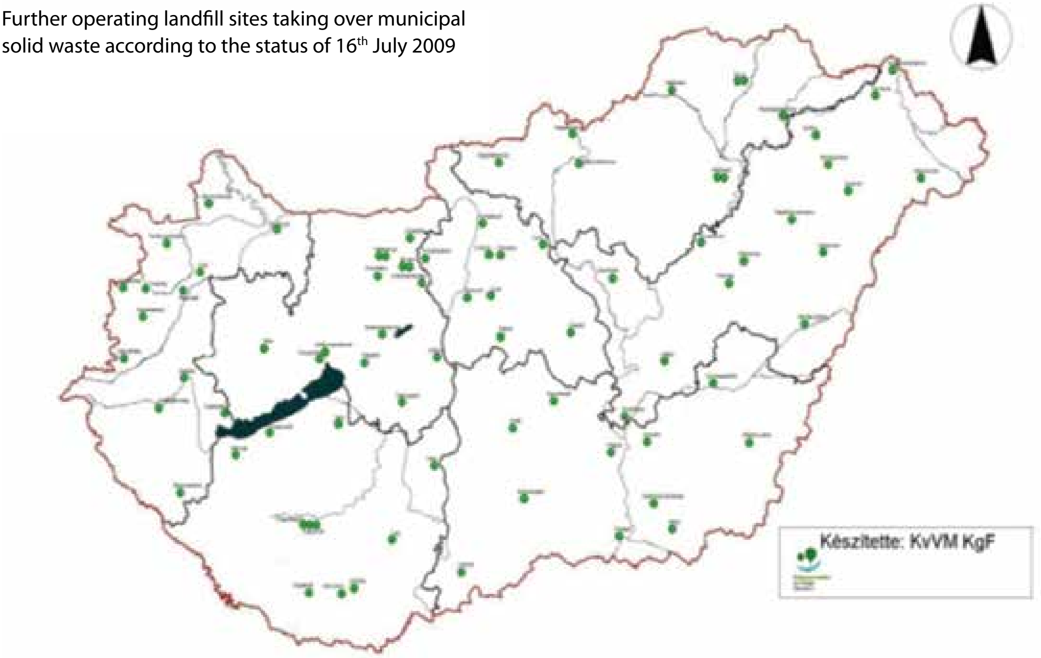


Figure I.2.5: Municipal landfill sites operating after 15th July 2009

I.2.9. Treatment-oriented rules – thermal treatment

The aim of thermal treatment can be:

- energetic utilization or
- incineration with the aim of disposal.

In the latter case, the primary goal of treatment is to eliminate some of the hazardous properties of waste through combustion (e.g. in a hazardous waste incinerator). For thermal utilization the goal is the production of electricity or heat energy or its utilization during cement, brick and tile or ceramics production in the building industry. Consequently, thermal utilization may be carried out either in incinerators designed for such a purpose, or through co-firing: e.g. in power stations or during cement production.

The former regulation created a separate source of law for incinerators (Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste). Besides defining emission limit values, the directive was aimed at regulating the circumstances of operation and technical specifications of incinerators and co-firing plants. In 2010 the directive was repealed, and rules applying to thermal treatment facilities were incorporated into the directive on industrial emissions (IED), this way putting them into the category of other industrial plants. It is compulsory for these facilities to use best available technologies (BAT) during their operations, while observing emissions regulations that specify the limit values for the concentration of the compounds in the emitted flue gas. The European Commission regularly issues reference documents about the best available technologies (http://eippcb.jrc.ec.europa.eu/reference/).

It has to be mentioned that in the last 20 years many debates have been generated about the difference between thermal utilization and disposal. According to the legal interpretation issued by the European Commission, the main difference lies in the primary purpose of the given facility, meaning whether it has been primarily built for energy production or for the incineration of waste. However, according to this interpretation those municipal waste incinerators that generate a significant amount of energy should be also regarded as waste disposal facilities.

In order to resolve this problem, the WFD defined the energy efficiency requirements for R1 utilization activity. For municipal waste incineration, if a municipal waste incinerator reaches the desired energy efficiency level then it can be regarded a waste utilization facility. However, this is not the case for hazardous waste incinerators, so their activity has to be regarded as disposal even if these technologies often produce a significant amount of energy.

I.2.10. Waste-oriented regulation

Waste-oriented regulations mean those directives that define the norms for some special waste streams. Rules connecting to producer responsibility are separate from these (see next chapter). The most important ones are as follows:

- Directive on wastes originating from the titanium-dioxide industry (incorporated into IED);
- Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture;
- Council Directive 96/59/EC of 16 September 1996 on the disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCBs/PCTs);
- Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC.

Since there is no titanium-dioxide industry operating in Hungary, this directive is not relevant from our point of view. On the other hand, the agricultural use of sewage sludge is quite significant in Hungary.

The directive on the use of sewage sludge primarily sets rules about the protection of the soils against heavy metal contamination and defines limit values for the concentration of the different heavy metals (Cd, Cu, Ni, Pb, Zn, Hg, and Cr) that may be present in soils used for agricultural purposes and sludge that is to be used. Detailed instructions for the analysis of the soil and the sludge that are aimed at characterizing these media are defined by the member states. Furthermore, based on the heavy metal concentration of the sludge, member states have to define the maximum amount of sludge which can be used per area unit per year. The PCB directive states that environment and health-damaging materials containing PCBs shall be withdrawn from operation by 2010, and they shall be disposed of together with the discarded equipment that contains them.

A separate directive on the management of waste from extractive industries had to be developed, because drilling mud, mining waste and residual preparation materials (slurry, dust and debris) produced during excavation activities which are collected and stored for longer than a certain time – that is get disposed in an excavation waste treatment facility – mean an enhanced environmental and accident risk due to their huge volume and the contamination originating from them which may enter the natural environment. In order to mitigate such risks, the regulations mandate a risk assessment, the categorization of treatment sites, licensing, the development of a waste management plan and, in some cases, informing residents who live in the surrounding area.

I.2.11. Rules of extended producer responsibility

The main point of extended producer responsibility is that economic entities performing production activities are obliged to take environmental protection interests into account not only during the manufacture and design of their products, but they should also manage their recollection after they become waste and utilize them, either on their own, or through a waste utilization company, while bearing all the costs of such activities in the meantime. Consequently, the regulation puts general responsibility for the waste onto the producer.

According to the regulation of the European Union, the producer can fulfil its recollection and utilization duties by itself, collectively or through organizations specialized in this activity. The operation and task-related costs of organizations that take over these commitments may be covered from the financial contributions of manufacturers. Directives that belong to the sphere of extended producer responsibility are as follows:

- Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles;
- Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE);
- Directive 94/62/EC of the European Parliament and of the Council of 20 December 1994 on packaging and packaging waste;
- Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC;
- Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

A common feature of all above-mentioned regulatory elements is that they define the minimum amounts to be recollected and the minimum amount of reprocessing and thermal utilization that must be undertaken, besides including target dates by which member states shall fulfil such requirements. Fulfilment is supervised by the European Commission, and member states have to submit progress reports on a regular basis. If a serious delay in fulfilment is found by the European Commission, it may initiate a proceeding for failure to fulfil an obligation against the member state in question. Respective utilization target values are summarized in the Glossary. Utilization targets are continuously reviewed and increased by the European Union. Currently, the new utilization targets for electric and electronic wastes are being introduced, and a review of the utilization targets of packaging wastes has also been launched.

I.2.12. The international transport of wastes

The Basel Convention came into being due to an incidence of poisoning caused by hazardous waste that was transported to Nigeria by an Italian company in 1988. This convention deals with the control of transboundary movements of hazardous wastes and their disposal, and bans the export of hazardous wastes from developed countries to developing ones. Developing countries are those who are not members of the Organisation for Economic Cooperation and Development (OECD).

The convention includes two waste lists. The yellow list contains hazardous wastes (whose export is banned), while the green list consists of non-hazardous wastes. Among OECD countries, wastes on the yellow list can be transported for further treatment after prior notification is submitted to authorities.

The European Union has further elaborated its regulation about international shipments of waste (Regulation (EC) No. 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste) based on the Basel Convention. According to this, prior notification must be given about all wastes to be disposed of and all hazardous wastes to be utilized before their transport within the European Union (this also includes the member states of the European Free Trade Association, EFTA). Non-hazardous wastes can be freely transported for further utilization, while their transportation out of the European Union shall be undertaken according to the Basel convention.

Based on the duty to notify, the enterprise sending the waste is obliged to notify the competent authority of the sender country, during which process data shall be provided about the waste to be transported, the transit and target countries of its freight, the waste management company receiving the freight (including details about its licence) and the route and time of transport among others. The authority of the sending country sends these data about the freight to the competent authorities of all transit and target countries according to the notification, which they confirm. If all confirmations arrive, the authority in the sender country allows the transport of the waste.

The regulation also stipulates that if waste is transported illegally, the sending enterprise has to transport it back to the sending country, incurring all costs. If the sending enterprise cannot be identified, the authority of the sending country has to arrange for retransport.

I.3. The prevention of waste generation (Hilda Farkas)

I.3.1. The concept of prevention

In the field of waste management the concept of prevention means more than the classical environmental protection related principle of prevention, since it not only includes the avoidance and minimization of environmental burdening, endangering and pollution caused by wastes, but also the conscious and monitored control of waste producing activities by which the generation of waste – a factor that endangers natural elements – is also avoided, or is at least mitigated.

According to the general rules of environmental protection, every activity that uses the environment shall be organized and carried out in a way that it causes only the lowest level of environmental burden and stress, prevents environmental pollution, and avoids damaging the environment (including the mitigation of waste generation). For the sake of prevention, the most efficient method – in some cases the best available technology – shall be applied during the use of the environment. The definition of prevention set in the EPA stipulates the same. From the point of waste management the interpretation of prevention is defined in Act CLXXXV of 2012 on waste (Waste Disposal Act: WDA) in accordance with Directive 2008/98/EC of the European Parliament and the Council of 19 November 2008 on waste and repealing certain Directives (Waste Framework Directive: WFD) .

I.3.2. Demand for and the significance of prevention

Due to the increase in the population and the expansion of a consumer society and the welfare state it has become clear that it is impossible to maintain such a system according to the former patterns of production and consumption. Natural resources are finite, and their wasteful and irresponsible appropriation and contamination cannot be continued. This recognition lead to the elaboration of the concept of sustainable development, whose widely-known definition was expressed by the Brundtland Report, called "Our common future", accepted by the United Nations World Commission on Environment and Development in 1987. The definition is the following: "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs".

According to the principle of sustainability, keeping economic growth, environmental protection and social equality in balance is a basic survival pre-requisite for both mankind and planet Earth. The issue of waste appears in this three-part system, making it unequivocal that the most efficient way of moving towards sustainable development is to prevent the generation of waste. The replacement of the hazardous substances used during the manufacturing of products and the use of material-saving and low-waste technologies decrease demand for waste management activities (and save waste management costs at the same time).

Waste management – and prevention within this – have become the part of the global material and product lifecycle and one of the most important elements of integrated product and production policy, planning and sustainable consumption and production.

The "Rio Declaration on Environment and Development" accepted by the Rio Conference (the first Earth summit conference held in 1992) and the related action plan, Agenda 21 (Tasks for the 21th century) include three chapters that deal with waste and have a separate section that is devoted to the issue of minimizing waste as the highest priority task. It stipulates that efforts shall be focused on preventive waste management by changing current lifestyles, production and consumption patterns. It aims at the stabilization and the mitigation of the amount of waste that is disposed of, the development of waste-mitigating professional policies and the use of separate collection in order to enhance reuse and reprocessing activities. Regarding hazardous wastes, the most important task is to minimize its generation through the modification of industrial methods and consumer patterns, e.g. by the development and execution of pollution prevention and cleaner production strategies, or by the application of "low-waste" technologies. First of all, efforts shall be focused on mitigating the hazardousness of waste generated, using it, and transforming it into useful materials.

Earth summit conferences on environmental issues that have been held every 10 years after the first conference made no significant changes to the fundamental concepts laid down at the Rio Conference. The plan of execution connected to the "Johannesburg Declaration on Sustainable Development", accepted at the "Rio+10" conference in Johannesburg in 2002, calls upon countries to:

- prevent and minimize the generation of waste,
- maximize reuse and the use of environmentally sound alternative materials,
- improve upon resource efficiency,
- promote the manufacturing of reusable consumer goods and biodegradable products.

In the final report of the "Rio+20" conference held in Copenhagen in 2012, waste appears under the same title as chemicals, and the application of the lifecycle approach is introduced as a new element in waste management. The most concise definition of prevention was phrased by the 6th European Environmental Action Programme: decoupling growth (be it economic, consumption or population-related) from waste generation. This also requires a fundamental change of attitudes and behaviours both from the side of economic actors and the population.

I.3.3. The place of prevention in the waste hierarchy

According to the principles of sustainable development, the prevention of waste generation has the highest priority in the 5-step hierarchy of waste management. From the point of prevention priority No. 2, called preparation for reuse, is also important. Although it shall be regarded as a waste management activity, it may also contribute to the reduction of the amount of material to be treated as waste. In this case, objects that become waste go through a kind of treatment during which some of their components that are capable of fulfilling their original function are separated from the other components which cannot be further utilized (e.g. the recovery of operable components from discarded or unserviceable devices). This former group – after going through a quality check and the necessary repairs – can be marketed as used components, or can even be built into new products.

I.3.4. Prevention Activities

According to the WFD, prevention is not regarded as a part of waste management by the WDA since measures taken to reduce the quantity or the quality (hazardousness) of wastes occur "before" the material or the product becomes waste. From the different preventive measures it defines reuse separately, and also defines the activity preparation for reuse. Defining the content of the lifecycle approach that must be addressed during the application of the waste hierarchy is also an important issue . Other prevention activities besides reuse are mentioned as commitments:

"In order to prevent the generation of waste and to mitigate the quantity and hazardousness of waste generated, priority shall be given to the following activities:

a) application of material and energy saving and low-waste technologies;

b) keeping materials in the production-consumption cycle;

c) manufacturing products leading to the generation of the lowest possible amount of waste (regarding weight and volume), less contaminants, and causing less environmental burdening;

d) replacing materials that become hazardous wastes."

The act also stipulates that materials and products become waste only when leaving the production-consumption cycle. Accordingly, efforts shall be made to redirect technological residues back into the production process, and to keep used products which can be used for their original purpose again within the production-utilization cycle.

I.3.5. The duties of producers

In order to guarantee the realisation of the priority of prevention the WDA stipulates that the principles of reuse and preparation for reuse are basic principles. According to this, the reuse, repair and refilling of products, the preparation of waste for reuse and the development of reuse and repair networks shall be facilitated by legal, economic and technical means, by defining criteria, and by setting numerical goals for the procurement of the given material or object.

Producer responsibility is also stated to be a basic principle, meaning that the producer is responsible for ensuring a favourable choice of product and technological features according to the requirements of prevention and waste management, including the selection of the raw materials used and the design of the resistance of the product to external impacts and its lifespan, reusability and reparability. In some predefined cases (e.g. in the case of vehicles that belong to categories M1 and N1, electric and electronic equipment, batteries and accumulators or wrapping materials that are regulated by separate legal acts) the responsibility of the producer is also extended to the recollection of used products or the takeover and treatment of products that have become waste. During the management of waste which has been recollected or taken back, efforts shall be made to follow the implementation of the principles of reuse and preparation for reuse, according to the waste hierarchy.

Besides defining producer responsibility a basic principle, WDA also stipulates a general prevention commitment in implementing producer responsibility. As a result, producers have to strive to design and develop products and their packaging and manufacturing technology and product developments in a way that leads to the most efficient material and energy use achievable during manufacturing and the use of the products, and to the prevention of waste generation and the reuse of products. To this end, producers are obliged to prefer those raw and basic materials, products or wrapping materials whose production and application leads to a lower material and energy demand, smaller environmental impacts or the generation of fewer hazardous wastes which have lower hazardous substance content, which are more durable, and which can be used several times.

I.3.6. By-products

Through distinguishing between wastes and by-products, the usability of technological residues and their marketability in the form of products may significantly contribute to the reduction of the amount of materials which shall be later treated as waste.

Besides the main product, the primary goal of production, other materials or residues are also often produced. However, their owner does not want to get rid of them as 'waste' because they are regarded as marketable goods.

Through defining criteria for by-products it became unequivocal that by the proper development of the production technology, technological residues (or at least some part of them) can be withdrawn from the waste cycle and can be marketed as ordinary products. The Communication from the Commission to the Council and the European Parliament on the interpretative communication on waste and by-products COM (2007) 59 – by setting specific conditions for some typical by-products – is significant help when applying the criteria system developed for the qualification of materials as by-products. Additionally, in order to stop waste regulation duties being evaded, WDA stipulates compulsory registration in the case that by-products are generated, this way making the approval of the authorities indispensable for those performing such activities. Furthermore, similarly to wastes, data about by-products shall also be carefully recorded.

I.3.7. Industrial ecology and the "Zero Waste" goal

The idea of industrial ecology is based on the concept that since there is no waste in nature, the elimination of waste also should be a goal for industry; that is, the by-product of a process can become the basic material of another one. This concept aims to engender a state where the level of energy and material use is optimal, the amount of wastes and other pollution is at a minimum, and every (by-) product has an economically-viable role in production processes.

In fact, the goals of "Zero Waste" originate from the generalization of the idea of transforming the economy into a closed circle by following the principle that, similarly to natural processes, final waste shall not be generated from production and consumption processes, since all material that leaves these processes can be used as a resource at another place (see the condition system of by-products). In order to reach or come close to the "Zero Waste" state, products shall be planned and processes shall be operated and controlled in a way that, on the whole, the amount and the hazardousness of waste decrease (see the target system of prevention).

It is also a part of the "Zero Waste" approach that resources shall not be buried (disposed) or incinerated, but should be kept and utilized (see the target system of utilization in material). According to this idea, if the "Zero Waste" model becomes widespread, emissions to the natural world will cease. Consequently, the objective integrates, systematizes, and makes an economic strategy and lifestyle goal from the goals and means of prevention and reprocessing. In fact, this is the principle which is embedded into international and national professional policy documents such as the Rio documents and the thematic strategies of the European Union which include "Sustainable consumption and production", "Integrated product policy", "Prevention and reprocessing", or the Hungarian "National Sustainable Development Strategy" and the "National Prevention Programme".

I.3.8. Categorization of prevention measures and means

Basically, prevention activities can be divided into two groups:

- measures that reduce the amount of waste generated (quantitative prevention),
- measures that reduce the hazardousness of waste generated, and facilitate the treatment of waste (qualitative prevention).

Economic measures that apply to the production sector and residential measures that target consumption can be differentiated between in both groups.

Within the economic sector, the measures and means referring to the different products can be distinguished from those that apply to production and manufacturing technologies. Of course, consumer behaviour has a significant impact on the efficiency of prevention in the case of products, and residential prevention activities may be interpreted as separate technologies.

Measures and means may appear in the form of legal regulations (duties and bans), economic regulations (subsidies and sanctions) or volunteer commitments (regulated or ad hoc agreements without legally-binding force).

Education, training and awareness-raising have a significant impact both on the prevention activities of economic actors and the population. The WFD – and thus the WDA according to the WFD – lists 16 prevention measures in its annex, which can be divided into three categories:

- measures affecting framework conditions connecting to the generation of waste,
- measures affecting the design, production, and marketing phases,
- measures affecting the consumption and the utility phase.

I.3.9. Prevention in the economy – designing production

According to the principle of producer responsibility, the manufacturers of the products are responsible for managing processes in a way that the amount and hazardousness of waste originating from production stays as low as possible. These features are defined by two basic factors: production technology and the quality of the basic materials used.

1. The choice of basic materials:

- the avoidance and the minimization of hazardous materials;
- the replacement and substitution of hazardous materials;
- generating the lowest possible amount of waste during the preparation and processing phases of the basic material ("clean": uncontaminated basic materials, using only the minimal amount of material necessary for the given product).

2. Technology (low-waste technology):

- material efficiency (material balance, minimizing the amount of "lost" material, reaction residues, surface treatment in a closed system);
- avoidance and minimization of hazardous material residues (cleaning and redirecting residues);
- redirecting residual materials back into the technological process (with cleaning if necessary);
- further processing of residual materials (by-products);
- application of closed cycle technologies (residues become the basic material of another technology);
- on the whole, the application of best available technology (BAT);
- the application of environmental management systems (EMAS, ISO 14001);
- quality certification, environmental sustainability report.

I.3.10. Prevention in the economy – designing products

The concepts of quantitative and qualitative prevention can also prevail during the designing and development of products. On the one hand, waste generated during the utilization or the use of the product has to be taken into account, and then it also has to be assessed what happens when the product becomes waste.

Preventive measures related to products that are also based on the principle of extended producer responsibility:

- products containing no hazardous substances, and the minimization and replacement of hazardous components;
- products causing smaller environmental stress and burden during their use phase;
- durable products with a long lifespan;
- reusable products (e.g. refillable packaging or batteries, avoiding and replacing single-use products);
- reparable products (repairing network, provision of spare parts);
- recollection of used products (repairing, cleaning, qualification, marketing for reuse);
- easily degradable products (separability of hazardous components, preparability for reuse, qualification and marketing of reusable components, or using them again during production);
- eco-label, quality certification;
- informing consumers (user's manual).

I.3.11. Prevention in consumption

The choice of consumers' purchasing products and their behaviour regarding discarded products also significantly facilitates the prevention of waste generation. Consumer purchases that involve prevention and take environmental interests into account at the same time are called "green procurement" (although this term usually refers only to purchases by larger economic entities).

To take prevention into consideration during the purchase of products (services), the following features may be examined (these are mainly identical to those required from the manufacturer of the product within the framework of producer responsibility):

- durability,
- reparability,
- reusability,
- returnability (the possibility of replacement),
- the availability of spare parts and services,
- the absence of hazardous materials (or only a low hazardous material content, the identifiability of hazardous components),
- eco-label, quality certification.

Behaviour required from the consumer to promote waste prevention (beyond product selection):

- buying low-waste products (especially in relation to wrapping and hazardousness);
- offering used, obsolete or discarded products for reuse;
- buying products that just fulfil the demands of the consumer (both from a quantitative and qualitative perspective – e.g. medicines, foodstuff, detergents or technology products), or even buying used products;
- home composting of garden wastes.

I.3.12. Incentives for economic entities – economic regulators

Economic regulatory tools and the financial support for development are the primary incentives for the application of low-waste technologies and the development of low-waste products.

Also, the WDA stipulates that producers that use product or technology development measures aimed at prevention become entitled to allowances in a predefined way and to a certain extent when fulfilling specific requirements defined in acts or government decrees (unfortunately, no such legal acts have been created so far).

In any case, the opportunities for financial support are given since the national and international investment and development supporting schemes (operated by the European Union, Switzerland or Norway) provide support for technology and product development and RDI (research, development and innovation) through grant applications. It is also possible – and this opportunity is used in some countries – to offer tax relief for such products or for the application of environmentally sound technologies.

The different enforcement fees – e.g. penalties, taxes, environmental product charges or landfilling fees – are used as negative economic incentives. These motivate both consumers and producers to use and manufacture products that generate less waste.

I.3.13. Reduction of the hazardous substance content

Legal regulatory tools usually stipulate the desired direction of action, the conditions and limits of the different activities, or bans in some cases. In the field of prevention, the restriction or banning of the use of different hazardous substances has proved to be the most successful in the last years.

Through the implementation of producer responsibility, the use of mercury, cadmium, lead and hexavalent chromium has been banned in packaging, motor vehicles, electric and electronic equipment, batteries and accumulators in the European Union (reasonable exceptions are defined by separate commission directives). The replacement or the cleaning of equipment (including more than 5 dm^3 liquid containing PCBs/PCTs) and the disposal of waste generated this way has been also ordered within the framework of waste management regulations by setting the end of 2010 the deadline for such commitments.

The production and the use of 16 POP materials (persistent organic pollutants, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dioxins, furans, brominated flame retardants (BFRs), short-chain chlorinated hydrocarbons, some solvents and pesticides, etc.) have been restricted or banned within the framework of air pollution prevention and chemical-related regulation (Aarhus Convention, 1998). In 2001 the Stockholm Convention introduced further regulations applying to all POP materials with the aim of terminating their use completely.

Similar restrictions and bans have been introduced for volatile organic compounds (VOC, Geneva Convention, 1991), greenhouse gases (Kyoto Protocol, 1997), substances that deplete the ozone layer (Montreal Protocol, 1987), mercury (Minamata Convention, 2013) and products containing asbestos.

A common feature of all these international agreements is that, according to their content, the production, marketing and the use of the regulated materials becomes restricted or banned after certain deadlines and – in some cases – becomes restricted to some specific fields of application. Furthermore, the existing stocks of these materials have to be continuously eliminated and disposed of as hazardous waste. Although due to the legal commitments these measures often temporarily increase the amount of hazardous waste to be treated (since the reuse of these materials is strictly prohibited), after the execution of implementation programmes these kinds of wastes will no longer be generated.

I.3.14. Tools for motivating consumers

The following tools facilitate the waste prevention activities of consumers or those who use products:

- the introduction of the environmental product charge in order to affect product selection (it would be also possible to introduce VAT relief for similar purposes);
- providing opportunities for the take back and the collection of used products (take back/replacement at the place where the product is marketed, development of reuse centres);
- developing and expanding repair and service networks;
- supporting the trade in certified used products;
- facilitating green procurement and the application and support of the principles of green public procurement;
- facilitating and supporting home composting;
- providing information about the opportunities for prevention, demonstrating its environmental and economic benefits and its utility, and teaching the meaning of eco-labels to people by the means of education, training and awareness-raising.

Of course, the effectiveness of the above-mentioned tools depends on the characteristics and the traditions of a given society, the financial status of individuals and their cultural relations.

It is beyond question that the use of discounts would be the most efficient way to motivate Hungarian society since only a fragment of domestic consumers can afford to spend a part of their income buying more expensive products after taking environmental features into account. However, presumably there would also be huge interest in the development of the trade of tested, used quality products; therefore this field should also receive more attention.

I.3.15. Voluntary commitments

The main point of voluntary commitments is that the given enterprise acts to achieve specific environmental goals not according to legal enforcement tools, but through voluntary effort. One of the opportunities for this to happen is when the given enterprise develops an operating system that takes environmental protection features into account to the greatest extent (e.g. an environmental management system), and its implementation is regularly verified through external certification. The other possibility is to draw up a volunteer agreement in which the enterprise agrees with some public administrative body about reaching specific prevention goals.

I.3.15.1. Environmental management systems

Environmental management systems have been established to facilitate comparison of the environmental performance of economic entities and to certify their operations from the perspective of the principle of sustainable development.

Certificates that verify compliance with environmental provisions are issued by independently accredited certifying organizations.

I.3.15.2. Volunteer agreements

Volunteer agreements are one of the available prevention measures listed under the annexes of WFD and WDA. In fact, this means the development of agreements with governmental bodies and consumer or producer committees, or agreements developed during sectoral negotiations, according to which the affected parties take on prevention-oriented plans and goals (that they themselves define, or create through consultation processes) or commit to providing facilities for repairing products and wrapping that generate excessive quantities of waste.

I.3.16. Eco-design, eco-labels

Based on the principle of producer responsibility, it is the basic responsibility of the economic entity that manufactures the product to design its technology and products according to the principle of sustainable development and by taking environmental perspectives into consideration (eco-design). It is common that eco-design is interpreted only from the perspective of mitigating the environmental impacts of products. From the point of view of prevention, eco-design means the planning and implementation of prevention measures which may be applied across the economy.

Practically, the eco-label is a visible manifestation of a certification that indicates the environmental performance and indicators of products, technologies or services, and characterizes the results of eco-designing activities which can be put onto a product. In fact, eco-design and the obtaining of eco-labels are voluntary commitments, but references to eco-design can be also found in environmental regulations as a general commitment (without any predefined technical condition systems). Mandatory eco-label systems certifying the environmental performance of products are being developed for more and more types of products and environmental performance indicators today (e.g. energy consumption indicators for electric equipment, or quality certification for the noise generation qualities of tyres, etc.).

Classic eco-label systems certify compliance with specific environmental indicators or characteristics applying to certain products and/or activities. There are several international and national eco-labels of this kind. In Hungary, the eco-label of the European Union (ECOLABEL) and the national "Environment-friendly product" label can officially be obtained.

The operation of the eco-label of the European Union is based on Regulation (EC) No 1980/2000 of the European Parliament and of the Council of 17 July 2000 on a revised Community eco-label award scheme. According to this legislation, the eco-label can be given to those products whose characteristics represent a significant leap forward from major environmental protection perspectives. Based on the authorization of the regulation, the individual criteria – originating from those defined by the Eco-label Committee of the European Union – for the awarding of the eco-label are drawn up for each product category. Ecological criteria and the relevant assessment and monitoring requirements are issued through the decisions of the European Commission.

I.3.17. Green public procurement

According to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on public procurement for a better environment COM (2008)400, green public procurement means a public procurement process whereby public institutions prefer those products, services and activities that cause less environmental burden (based on their whole lifecycle) compared to other products, services and activities with the same purpose. From the perspective of the prevention of waste generation this means that the public body issuing the call for tenders may also define criteria requiring low-waste characteristics for the given product, the manufacturing circumstances of the goods, or the provision of the specific services.

It can also be a prerequisite that the supplier uses an environmental management system, the product has an appropriate eco-label, or even that it should be a once-used product.

The Handbook on Green Public Procurement that was published in 2005 as the recommendation of the European Commission, reviewed and extended in 2011, presents alternatives for the enforcement of environmental criteria at the different stages of the public procurement process, and defines a concrete system of criteria in the case of 21 product and service categories. The recommendation suggests that member states develop their own national green public procurement policies, and apply the pre-existing criteria systems.

I.4. Waste management activities; the collection and transport of wastes (Tamás Antal)

I.4.1. General rules for the collection and the recollection of wastes

Waste management also includes the collection and the transport of waste. The aim of waste collection is to transport waste to the appropriate management facilities. The preliminary sorting and storing of waste belongs to the phase of collection.

Collectors refer to those economic entities (not including waste producers) who collect and take over waste from its owner or from waste management facilities, and who sort and store it prior to its transport, if necessary.

Container means a waste collection bin or bag with a standard volume or a piece of equipment or appliance that is operated for the purposes of selective waste collection.

The collection and transport of different kinds of waste are closely related to each other. The method of collection and transport depends on several factors:

- the characteristics of waste generated;
- the timing of its creation (how much is produced, and how often);
- the features and the capacity of the place of waste generation;
- the method of collection;
- sanitary, environmental protection and economic characteristics that affect collection and transport.

The coordinated storing and material-handling process of waste collection and transport is called the waste collection system, which can be a single-stage or a double-stage process.

Single-stage waste collection means the handling of waste without trans-shipping that is undertaken with the same special-purpose machine that transports the waste from collection to the facility of utilization or disposal (see Figure I.4.1).

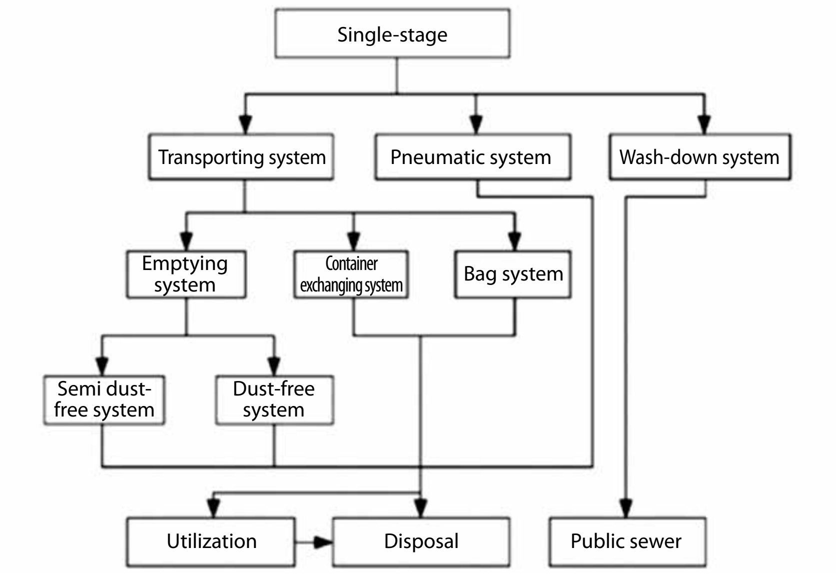


Figure I.4.1: Single-stage waste collection
(http://www.tankonyvtar.hu/hu/tartalom/tamop425/0021_Hulladekgazdalkodas/ch03.html)

Double-stage waste collection is different from the above-mentioned method in that the waste is first trans-shipped (or even pre-treated in some cases) at a so-called waste transfer station, and then is transported to the facility of utilization or disposal (see Figure I.4.2). Waste transfer stations can be used for the trans-shipping of mixed waste that is collected by different kinds of collection vehicles in closed roll-type containers.

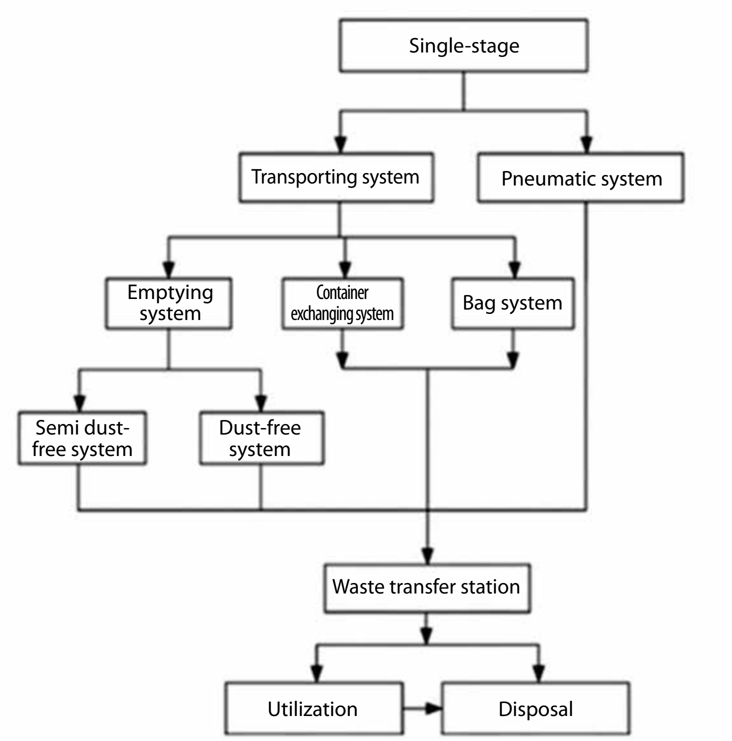


Figure I.4.2: Double-stage waste collection *(www.tankonyvtar.hu)*

Waste transfer stations also can be used for the compaction of the huge amount of waste collected from remote areas, which can then be directly transported to the facilities for its utilization or disposal after this treatment.

I.4.2. Collection and recollection of non-hazardous wastes

Waste collection includes the gathering of waste for its temporary, short-term storage at the place of waste generation. This activity is designed to deposit the waste for further management operations without polluting the environment.

If the waste is non-hazardous, collection activities may be performed in a mixed or separated way – production waste shall be collected separately. In order to ease handling, disposal or utilization it is practical to collect waste selectively by category or material type.

Non-hazardous wastes may originate from industrial production, public institutions or the population. Wastes of different origins but of the same category can be treated together due to their similar characteristics (domestic and garden wastes).

I.4.2.1. Indoor, municipal (communal) and selective waste collection

Municipal (communal) waste originates from residential consumption, institutional, retail and catering activities and from the cleaning of public places. Its composition and amount closely correlates with living standards and consumption patterns. Within this category, municipal solid waste and municipal liquid waste can be distinguished between.

The most commonly-used method for eliminating municipal solid wastes is the removal system (see Figure I.4.2). There are three different versions of this, depending on the technology used:

- an emptying system (semi dust-free and dust-free);
- a container exchanging system;
- a bag system.

In the case of the semi dust-free variety of the emptying system, waste is emptied by hand into a collection vehicle that has either an open or a closed superstructure. The advantage of this technology is that any kind of container can be emptied this way. The disadvantage of this technology is that, since in most cases the system is open, it also generates a significant amount of dust and odour. Accordingly, the use of such a collection method should be avoided.

For the dust-free variety of emptying system, the collection vehicle has a special superstructure and a standard mechanism for automatic feeding. The disadvantage of this technology is that it can be operated only using standard containers that are fitted to the automatic feeding mechanism. Waste collected in the closed containers with a cover is lifted automatically, and then the cover of the container is opened only within the closed superstructure; this way it can be emptied without the generation of dust. On the whole, this method can be regarded a hygienic, fast and modern technology. This collection system is the most widely-used one all over the world (see Figure I.4.3).

Figure I.4.3: The collection of municipal waste with a dust-free emptying system *(www.fkf.hu)*

For the container exchanging system, the collection vehicle has a special superstructure with which the working machine lifts the filled, closed containers into itself, without emptying them, and transports them to the processing facility. Containers filled with waste are replaced by empty ones during the removal process. This technology is hygienic and requires a minimal amount of labour. The drawback is that collecting waste into a container requires further organizational work. It is recommended that it is used in places where a larger amount of waste is generated, collection into containers is feasible, there is a lack of available labour, and the processing-depositing facility is situated close to the area.

In the case of the bag collection system, closed plastic or paper bags filled with waste are removed, without being emptied, by ordinary trucks. Although this is a hygienic, dust and odour-free technology, it can be used only for certain types of waste, and full bags should be removed within a short period of time. This collection system is usually used at recreational areas during summer peak periods for removing excess waste.

The selective collection of municipal solid waste has come into the limelight in the developed industrial countries in the last 10-15 years. This is because the thrift of the overmechanised sorting-utilizing facilities that perform the numerous physical and mechanical sorting operations required for the traditional collection system was unequivocally questioned. Selectively collecting predefined material categories on the spot where the waste is generated and using the significantly simpler auxiliary post-sorting methods is cheaper, cleaner and results in better quality secondary raw materials being recovered from waste than when using central utilization facilities.

One significant change is that the new act on waste defines detailed regulations about the selective collection of wastes. Its primary goal is to minimize the generation of waste and to maximize the proportion that is utilized. This motivates the population to change its approach, and encourages people to collect waste separately according to category at their homes. This way, paper, plastic, metal, glass and biodegradable waste become utilizable. The aim is to minimize the amount of waste that ends up at landfill sites.

The advantages of selective waste collection:

- redirecting utilizable elements to the processing industry;
- through the separate handling of hazardous components, environmental harm caused by municipal solid waste can be reduced;
- saving disposal (landfill site) capacity.

During the development of selective waste collection systems one principle is that is should only be introduced at places where a traditional organized waste collection system is in operation, and the tools for collecting and transporting are already available. The most important factors to be taken into account when organizing selective waste collection are the following:

- it should be directly accessible to the residents involved, and construction shall be adopted to the local demands;
- waste collection containers that are harmonized with the local environment of the settlement with an aesthetic appearance shall be used.

In-house (in-site) collection points can be developed in the staircases, shared spaces and waste storage rooms, at the entrance or in courtyards of family homes. Practical space utilization, the use of cheap and simple technical solutions, easy accessibility, simple emptying and cleaning are all important features that must be considered. It is also important to ensure that the selective collection containers do not disturb the functional operations of residences.

Networks of recycling bins (road containers) in public places are the main forms of selective waste collection. For recycling bins placed in the vicinity of dwelling houses and in public places, it is essential to ensure the lockability of the containers, easy access and feeding, that the original functions of the public place is undisturbed and that they are aesthetically pleasing and harmonized with the environment, but at the same attention must be drawn to their appearance (colourful, labels, etc.) and easy access assured for collection vehicles. In this respect, simpler and more economical technical solutions should be preferred (see Figure I.4.4).

Only components that may be used as secondary raw materials can be collected at recycling bins:

- paper,
- plastic bottles and foils,
- coloured and white glass,
- metal beverage cans (see Figure I.4.5).

Hazardous wastes (dry batteries, paint cans, etc.), degradable organic wastes and other wastes harmful to health or the natural environment cannot be collected at recycling bins.

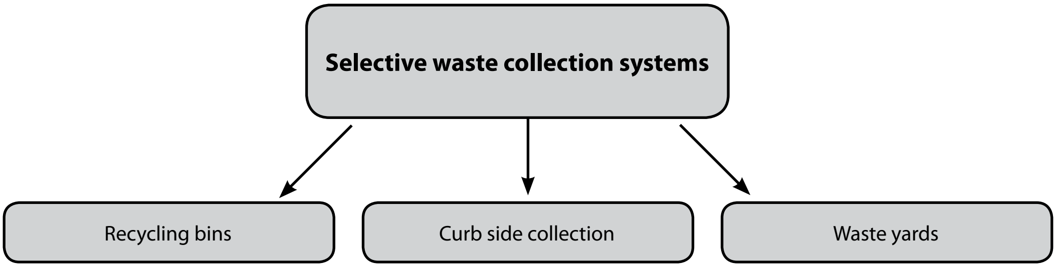


Figure I.4.4: Types of selective waste collection systems

Figure I.4.5: Selective waste collection island in a public place *(www.obuda.hu)*

I.4.2.2. Waste collection containers and tools

In modern waste removal systems, only standard containers that fulfil specific technical, environmental, occupational and work safety requirements can be used.

Standard containers (see Figure I.4.6) used in modern waste collection systems have the following volumes:

- small-size bins (50, 60 dm^3);
- medium-size bins (90, 110, 120, 240, 360 dm^3);
- small-size containers (660, 1100 dm^3);
- containers (above 1.1 m^3).

For external areas and the smaller settlements where the semi dust-free collection-transportation systems are still used, the manual emptying and the use of standard containers of 50, 90, 110 and 120 litres capacity is common, and can take into account further automatization opportunities.

In the case of housing estates, institutions, larger retail and catering units or smaller industrial facilities the use of 1100 dm^3 storage containers and the use of dust-free collection systems is common. In most cases, 1.1 m^3 sized containers cannot be placed in narrow streets or gateways. In these cases, plastic bins with a volume of 240 litres are especially useful. The space requirement of a 240 litre bin only slightly exceeds that of a bin of 110 litres volume. By using such bins, the time that is required for collection can be decreased by 50%. 110 litre bins may be practically used in residential areas with family houses and gardens.

Figure I.4.6: Municipal waste collection containers
(www.nidimpex.hu)

Different-sized containers have been developed due to the volume fluctuations in municipal solid waste mentioned above, and for the simplification and the enhanced automatization of work processes. Containers of different volumes are made of galvanized steel sheet or aluminium sheet with fibreglass reinforcing. Under the current conditions, lockable containers of 1.5 m^3, 2.5 m^3, 5 m^3 or 8 m^3 volume, made of steel sheet or aluminium sheet with proper reinforcement, are an appropriate method for institutions (e.g. hospitals, department stores) and production or marketing enterprises where a larger amount of waste needs to be removed at regular intervals. For the handling, transport and automatic emptying of containers special container transporting vehicles are used.

Waste collection plastic bags are special, single-use collection tools. For the storage of bags simply constructed fixed or rollable stands are used. Bags are hung on them with their open ends facing upwards, and they also have a lockable cover. Bags can be easily taken off the stand, and can be simply replaced. Under Hungarian conditions, coloured plastic bags of 50 or 100 litre volumes and a wall thickness of at least 0.08 mm are used. After their single use, bags also become waste. Plastic bags are an alien, non-degradable material and can harm some waste processing methods (e.g. composting). Their use, however, is a simple and hygienic technology for recreational areas during peak periods and in places where waste is only periodically generated (international fairs, events).

I.4.3. Collection and recollection of hazardous wastes

For activities that lead to the generation of hazardous wastes, or are connected to waste prevention, minimizing the hazardousness and maximizing the utility of such wastes shall always be top priority. Regulations on waste stipulates stricter data provision commitments. Waste producers, collectors and those performing disposal activities have to operate accurate recording systems. The traceability of the waste and its controllability shall be ensured, and the pollution of the environment and the appearance of health-damaging impacts have to be prevented.

Hazardous waste should be always collected separately, irrespective of its place of origin (residential, institutional, municipal from public places, industrial, etc.). The transportation and disposal of hazardous waste can be carried out exclusively by those collection and disposal companies that have special licences for such activities. The owner of the hazardous waste can dispose of it only by following the methods defined in the act, and in the case of illegal disposal or abandonment the owner of the waste or the user of the property will be held responsible.

I.4.3.1. The collection of residential hazardous wastes

About 1% of municipal waste is harmful to human and animal health, and – due to lack of oversight – can damage the natural environment because of its components. Such hazardous waste that requires special treatment includes dry batteries, accumulators, paints, inks, glues, discarded household utensils, fluorescent lamps or used cooking oil and fat.

Hazardous wastes generated in households should not be collected together with communal waste. These wastes can be securely stored in places inaccessible to children and pets for a shorter period of time before being taken them to collection points or to places of treatment. These wastes can be brought to waste yards, which is an opportunity that is open to everyone. Here, people can get rid of their hazardous wastes in an environmentally sound way throughout the whole year, free of charge.

The organization of collection days is an occasional solution for disposing of hazardous wastes at predefined dates and places once or twice per year. Collection is undertaken by companies that have relevant licences and special staff and equipment prepared for such activities.

I.4.3.2. Collection and temporary storage of industrial hazardous wastes

Government Decrees on the conditions for carrying out activities related to hazardous waste stipulates that the owner of hazardous waste is obliged to securely collect hazardous waste generated during its activities, at its place of origin or at its current location as long as it is has not been claimed by a hazardous waste management company.

With the exception of households, the producer of hazardous waste is obliged to:

- make a technological material balance about all its activities that generate hazardous waste (including the amount and composition of input materials that enter the given production technology, the amount and composition of products that are manufactured and also the amount and composition of hazardous wastes);
- keep a logbook about the operation of facilities and equipment used for the storage and management of hazardous wastes;
- keep records, and to provide data to the regionally competent environmental inspectorate.

The producer of waste may collect hazardous waste directly on the spot where it is generated (e.g. at a workplace collection point in a container that excludes the chance of environmental pollution in an amount not hindering the undisturbed operation of the activity for a period of 1 year, maximum).

If the delivery of hazardous waste to the hazardous waste management company is not directly carried out from the workplace collection point, the producer of the hazardous waste is obliged to collect it at a plant collection point situated on site. Plant collection points have to be established by taking into account the planned management activities and should exclude the chance of environmental pollution or damage. Hazardous wastes can be stored at such points for a period of maximum 1 year.

The storage places of wastes always have to be marked with clearly visible signs in order to avoid unauthorized persons or those wearing no protective equipment coming into direct contact with the hazardous materials.

During the establishment of storage places, basic environmental requirements have to be fulfilled, and environmental pollution has to be prevented by all means (see Figure I.4.7).

Figure I.4.7: Plant hazardous waste storage place *(www.glastronic.hu)*

During the establishment of storage places the following requirements have to be taken into account:

- the place shall be accessible via a paved road;
- it shall have a chemically resistant, stable and liquid-tight foundation;
- it shall be protected against unauthorized entry;
- rainwater shall not enter the storage place from the outside.

Requirements to be taken into account during the operation of collection points:

- wastes shall be separated by category;
- the name and the EWC code of the waste should be marked on the collection container in a clearly visible way;
- wastes should arrive and be stored in chemically-resistant, liquid-tight wrapping;
- the escape of volatile components into the natural environment shall be prevented by the use of closed systems;
- it is compulsory to ensure the proper ventilation of the container so as to avoid the unintended accumulation of gas.

I.4.4. The establishment and construction of waste collection points

The storage of hazardous wastes is carried out by using different containers and buildings. According to Government Decrees on the conditions for carrying out activities related to hazardous waste, the producer of waste has to ensure the regular collection of waste by using one of the following collection points.

- Workplace collection point: Collection point established on the spot of hazardous waste generation by taking into account the environmental hazardousness of the wastes. Smaller plants and construction work areas usually establish workplace collection points.
- Plant collection point: Area or building situated within the site for the collection of hazardous wastes originating from own activities. This can be established by the practical conversion of an existing storage room, or by using a part of a building which is currently not utilized. Larger production facilities usually have plant collection points (see Figure I.4.8).
- Special collection point: Collection point used for the collection of specific residential hazardous wastes for environmental protection or public health interests, based on separate regulations. For example, collection points situated at points of sale (in pharmacies or in department stores) that are used for the retake of expired medicines, run down batteries and accumulators belong in this category.
- Waste yard: Facility used for the collection of hazardous wastes of residential origin and those generated at producers in smaller amounts.
- Storage site: Facility for the storage of hazardous wastes which cannot be stored at plant collection points any longer, which cannot be further utilized due to a lack of appropriate technology, or which cannot be disposed of.

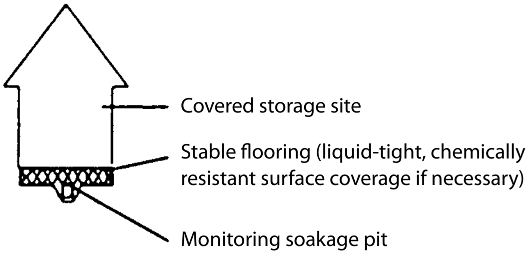


Figure I.4.8: Covered plant collection point *(www.tankonyvtar.hu)*

Waste yards are the complementary elements of the selective waste collection system where people can get rid of separately-collected utilizable waste components that are regularly generated in households, and hazardous wastes. Periodically generated large-size wastes (demolition and building waste, bulky items) can be also disposed of at waste yards. Here only the handing over of wastes happens; physical pre-treatment activities (shredding, baling and sorting) are carried out by the waste utilization company after the waste is transported elsewhere. After a short selective storage period (lasting a maximum of a few weeks) wastes get transported to the site of utilization/disposal. Wastes stored for a longer period without any reason take up storage capacity and room unnecessarily, which is obviously unfavourable from an economic perspective.

The following types of wastes can be collected in waste yards:

- components which can be used as secondary raw materials (paper, glass, plastic flasks, foils, metal wastes, metal beverage cans, waste wood, textile wastes),
- bulky wastes (tyres, household objects and utensils, electronic wastes, end-of-life vehicles),
- hazardous wastes of residential origin (dry batteries, accumulators, residues of medicines, paints and varnishes and their wrapping, cooking fat, pesticide residues, fluorescent lamps and bulbs),
- building-demolition wastes of residential origin.

Traffic generated by the operation of waste yards originates only from the residential delivery of wastes and the transportation of selectively-collected wastes, so it does not lead to heavier traffic than trade in general. In central, densely built-up areas it is advised to locate waste yards in bystreets that open from main roads. For suburban centres it is advised that they are built close to municipal offices, institutions or shopping centres.

During the establishment of waste yards the following considerations shall be taken into account:

- they shall be located in a more densely-populated area of the settlement, where they are easily accessible (from the point of view of residents and transportation);
- public utility connection points that are necessary for operation shall be provided;
- distance from the regional waste management facilities and the magnitude of road traffic;
- the size of the reception building and the covered closed building;
- the space requirements for containers placed under a roof or left outdoors;
- space needed for the undisturbed handling and transportation of containers and the waste deliveries of residents;
- area needed for the placement of supplementary facilities and tools (e.g. sand container, forklift storage space);
- space needed for further possible expansion.

As a general rule, it can be stated that the minimum space requirement of a waste yard is ten times as big as the space required for the containers, but at least 400 m^2.

I.4.5. The implementation of the transport of waste

The aim of the transportation of waste is to move waste from the place of generation to the disposal facility in an organized way with special vehicles, without the further pollution of the environment, and by paying attention to the characteristics of the waste that is transported. The transportation of wastes can be carried out through single-stage or double-stage methods as already described under Chapter I.4.1. This chapter presents details about the organization of waste collection, and shows the structure of special machines and the course of a modern waste collection process.

I.4.5.1. Organization and planning of communal waste collection lines

The most frequently-used method for the collection of municipal solid waste is based on containers placed at different households or industrial/trading sites which are regularly emptied by waste collection vehicles in an organized way (based on a planned route, with proper machines and experienced staff). One of the most widely-applied methods of collecting of municipal solid waste is when the vehicles that are performing collection activities visit service points one-by-one in order to empty containers or to remove collection bags placed there. If the tank of the collection machine is filled up, it visits the nearest landfill site, and empties its cargo. Then the transportation task starts from the beginning again.

During the organization of work it is a basic requirement that the given task can be finished within the available shift hours (by taking into account the amount of time needed for both collection and transportation). The availability of necessary basic information is an important part of the organizational work.

Such basic information includes the following:

- the characteristics and composition of waste to be transported;
- the characteristics of collection points (method of recollection, accessibility of the place, etc.);
- the characteristics of transportation routes (characteristics of transport and traffic, the proportion of paved and non-paved roads, transportation distance, etc.).

By having basic information, the following can be defined:

- the number, type and capacity of collection vehicles,
- data about the collection districts (time needed for collection, turnaround time, waiting time, idle operations, etc.).

After gathering all the necessary data and information regarding the removal of waste, collection lines need to be planned. By applying the so-called line editing method of operation research, the optimal mode of transportation can be defined with the help of linear programming.

Lines can be defined as routes including more stops (points) that are scheduled for waste collection. The activity of planning lines is called line editing. During the planning of lines sometimes the routes are given, and only the timetables have to be drawn up, while in other cases the optimal route needs to be defined. Since there is no uniform solution for the planning of the different lines, a unique method or model usually has to be developed according to the features of the given task.

Line planning is usually used for the implementation of transportation tasks among more service points according to some predefined objective function.

The objective function can be:

- transportation distance (from the point of waste loading to the disposal facility);
- speed – time;
- material handling work;
- capacity and loadability of the vehicle;
- pollutant emissions, etc.

Figure I.4.9 presents a pre-planned waste collection line from the point of loading to the landfill site (red arrow and yellow circle). In addition, the route of the line, the already driven distance and fuel consumption also can be tracked using the online system.

As a result of line planning in waste collection, the route of the lines can be optimized, fuel consumption can be reduced, and the capacity of collection vehicles can be maximized - or in other words, service provision can be made more cost effective.

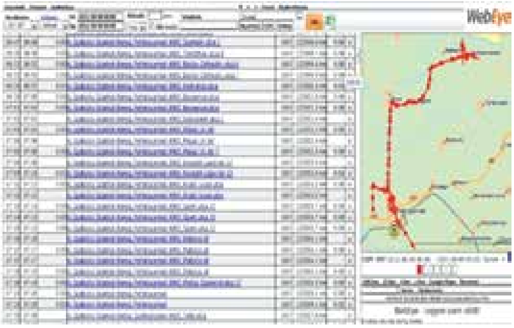


Figure I.4.9: An example of communal waste collection lines *(www. webeye.hu)*

I.4.5.2. Vehicles and tools that take part in recollection

The collection and transport of the municipal solid waste generated is a fairly complicated and expensive logistical task. Collection and transport have to be arranged without causing further environmental pollution. For this reason, containers precisely fitting the feeding mechanism and the type of waste are needed.

The following requirements have to be fulfilled by vehicles in order for them to be suitable for the transportation of communal waste:

- closed superstructure (tank) equipped with a compaction mechanism designed to fully utilize the tank;
- simple, durable and fail-safe design;
- fast feeding and emptying;
- noise and dust-free trans-shipping and emptying;
- the vehicle shall be mounted with equipment and parts necessary for safe transportation;
- the vehicle shall fulfil the requirements of the Highway Code.

The transport of communal wastes can be carried out in a semi dust-free and a dust-free way.

Dust-free waste collection and transport

Closed system dust-free collection and transport vehicles are used for emptying standard containers (and have a volume of 90, 110 or 120 litres) perfectly fitting the feeding mechanism. These special machines have a tank, and are also mounted with compaction equipment. According to the design of the compaction equipment, two kinds of vehicles can be distinguished:

- one with a revolving drum (see Figure I.4.10) and
- another special waste collection and transportation machine mounted with a compaction plate (see Figure I.4.11).

Figure I.4.10: Rotopress type special waste transportation machine (with a revolving drum)
(www. topola.com and www.classicrefusetrucks.com)

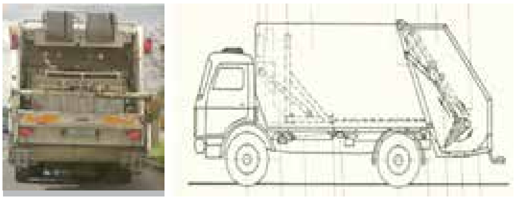


Figure I.4.11: Variopress type waste collection vehicle (with a compaction plate)
(Szász and Szénich, 1984)

The vehicle with a superstructure mounted with a revolving drum has a tank of about 20 m^3. Solid waste is compacted into the closed cylindrical tank situated on the longitudinal axis of the vehicle next to the driver's cabin through the cover closing (fitting) the back of the cylinder that contains the special container emptying mechanism. Within the revolving drum a so-called extruder screw brings the waste towards the closed part at the foreside using a spiral movement during which the waste is crushed and mixed through rotation. The revolving drum is operated by a hydraulic engine. Emptying can be carried out by opening the back door and by reversing the direction of drum rotation. The proportion of compaction possible by these special machines reaches at least 1:3–1:5.

A collection vehicle mounted with a compaction plate has a tank of 10-20 m^3. For these special machines the feeding mechanism and the constructional elements that receive, collect and forward the solid waste into the tank can be found at the back. Compaction is carried out by a plate that moves up and down along a diagonal plane. The fly situated at the end of the compaction plate is moved by two hydraulic cylinders. The function of the fly is to push the waste into the compaction chamber. The compaction ratio also reaches 1:3-1:5(8) in this case. Emptying is carried out by lifting up the cover frame at the back and by the operation of the compaction plate. The compaction plate is operated hydraulically and moves in a prismatic space, having a quadrilateral cross section. There are also collection vehicles that are capable of cleaning the bins by spraying them.

Semi dust-free waste collection and transport

Semi dust-free collection is carried out in containers where dust may be generated during feeding and emptying, but transport is carried out in a closed tank. During container transport the container is both the receptacle and the cargo hold of the transporting vehicle at the same time. Containers have a volume of 4–8 m^3 and they are equipped with a closed tank into which waste can even be fed manually through 4-8 feeding holes (see Figure I.4.12). Emptying is carried out by tilting after opening the closing wall on the back side. The different-sized containers are lifted onto the chassis of the vehicle, and are emptied by tilting by a vehicle equipped with a special lifting mechanism that is connected with the engine of the basic vehicle through an auxiliary power unit that includes a hydraulic system.

Figure I.4.12: Closed container equipped with feeding holes

Based on the design of the lifting mechanism, the following types can be distinguished between:

- lever-type lifting,
- lifting hook-type lifting and
- winch-type technologies.

Container transporting vehicles usually have a lifting mechanism that lifts in a backwards direction. The material collected can be building debris, bulky items, garden or hazardous wastes, etc.

I.4.5.3. The application of modern technologies in waste collection

The concept, classification and fields of use of the RFID based identification system

Basically, the RFID (radio frequency identification tag or intelligent tag) system consists of a reader device and tags that are appropriate for the storage of information and for the transmission of data. The RFID label can be as small as a grain of rice or as large as a brick, depending on the surface of the antenna and/or the size of the energy source. The tag consists of an antenna, a microchip that is connected to it and the base, including both. The reader device takes data from the tag that enters the radio frequency field, and transmits it to the computer that operates the system. There are also kinds of tags on which information can be written by the reader device. The great advantage of the

RFID system is that, when gathering information from the tags, the reader device does not need to be closely situated to them. Even the information content of tags fixed on the products located in loading units can be read, which of course depends on their depth of penetration.

Using the RFID system during the collection of wastes

Similarly to the payment of public utility services, through the introduction of the RFID technology people also pay according to their actual consumption – that is, after the number of emptyings – in waste management.

The system consists of the following elements:

- The RFID tag that is fixed on waste collection bins or containers. The RFID tag can be fixed in a hole formed within the bin (see Figure I.4.13) or in the middle of the cover, but in this case it is advised to put a protective foil on it in order to prevent damages during emptying.
- With the help of the RFID reader device fixed on the back wall of the waste collection vehicle, the identification number stored by the chip fixed on the bin is recorded during emptying (see Figure I.4.14). Since the identification number is assigned to the client, this way the owner is automatically identified.
- Weighing of the waste collection bin. Load cells fixed on the chassis of the vehicle define the weight of the waste that is collected into the bin with an accuracy of 1 kg.
- The truck that performs collection activities is connected to a complex satellite vehicle tracking system based on a so-called WebEye mobile communication. This is important for knowing which bins have been already emptied. The vehicle tracking system can be also used to help draw up and monitor the line plan (the movement of the vehicle, fuel consumption and the location of the client can be all observed), this way eliminating the undue use of vehicles.
- The computer (located in the driver's cabin of the waste collection vehicle) called the "communicator" is connected to the office (central) computer through a wireless connection and registers the above-mentioned collected information.

Figure I.4.13: RFID tag fixed under the hinge of the cover of a plastic bin *(Rácz, 2010)*

Figure I.4.14: RFID reader device located on the back side feeding mechanism of the waste collection vehicle
(Keszthelyi and Vönöczky, 2009)

Figure I.4.15 presents a simplified diagram of the modern waste collection process.

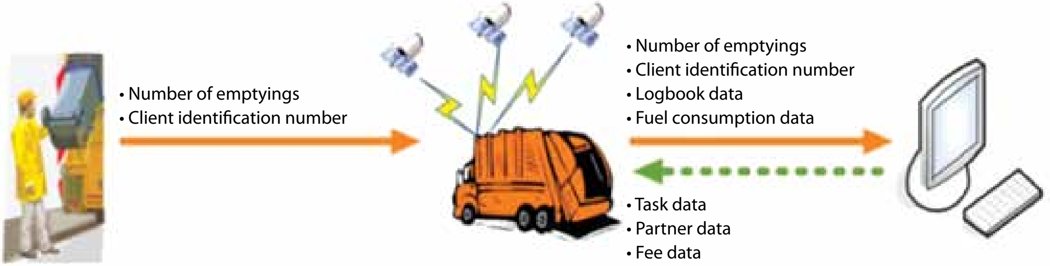


Figure I.4.15: The online information system for household waste collection *(Romhányi and Lovák, 2011)*

During waste collection, identifying the bin, recording its emptying and also GPS coordinates (showing the place and time of emptying) and taking measurements about fuel consumption are undertaken, and then all this information gets transferred to a central database. Data collected here become the basic data for issuing invoices. By up-to-date statistical analysis it can be shown when and how many times the client has used the service in the given month. Finally, the central office creates the actual invoice for the consumer. The RFID system can be also further developed to ease the process of waste collection and utilization. An RFID tag that is fixed on products during manufacturing may make the process of recycling easier, and could identify the product in the waste stream; this way, labour-intensive waste processing could become simpler in the future. Additionally, RFID technology also makes it possible to disassemble and recover still usable components from the waste.

I.5. The treatment and utilization of wastes

(Katalin Mozsgai, Péter Simándi)

The amount of waste entering the natural environment can be significantly decreased by utilization. According to the law, the main point of utilization is the replacement of natural resources with wastes or materials and products recovered or manufactured from waste, therefore the implementation of sustainable development is unimaginable without the utilization of waste. It is also important that by utilizing waste the amount of waste finally entering the natural environment can be significantly reduced, this way environmental pollution will be lessened, and costs related to the disposal and disposal of waste can also be reduced. It is a basic rule that all utilizable waste components should really be utilized, this way minimizing the amount to be disposed, and that energetic utilization shall be applied only with wastes which cannot be further utilized by other means. With utilization, efforts shall be primarily made towards the development of reprocessing and preparation for reuse according to the hierarchy of waste management.

The selective collection of the different waste streams is a precondition of utilization. It is a basic requirement during the utilization of waste that the product manufactured through utilization shall not cause more environmental harm than a product manufactured from primary raw materials, the technology for its utilization shall not endanger human health or the natural environment, and it shall not lead to excess economic impacts compared to a new product. Waste can be and shall be utilized if it is ecologically advantageous, technically feasible, and economically well-founded.

I.5.1. The classification of waste utilization technologies

Waste utilization methods can be classified from several perspectives.

Changing of the material quality of waste during the utilization of waste

- Utilization without transforming the material (the original features of the material are not significantly changed) – reuse[1];
- Utilization by transforming the material (by changing the composition, structure, quality, etc. of the original material) – recycling.

According to the organizational features of waste utilization

- Waste utilization on the premises of waste generation;
- Waste utilization outside the premises of waste generation within a specialized organizational framework (as a secondary raw material).

According to basic technological mechanisms

During the utilization of the different types of wastes, technological elements and their combinations presented in the following table (Table I.5.1) are used. Similarly to waste management, a systems approach should also be applied in the field of waste utilization. The different methods and basic technological mechanisms should not be applied independently, but together, by combining them with one another.

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[1] Reuse is not one of the waste management categories since it can be found in the category of prevention in the waste hierarchy, but preparation for reuse shall be listed among the categories of waste management. For more detail, see Chapter I.2 'The International and Hungarian legal system of waste management' (Figure I.2.1).

Process	Preparation	Separation	Utilization
Mechanical	Shredding Screening Compaction Mixing	Screening Air pneumatic sizing Flotation Ballistic separation	As filling material: mixing embedding Needle felting
Hydromechanical	Cleaning, washing Pulping Wet milling (deflaking)	Sedimentation Pulsation sedimentation Wet flotation Flotation Heavy medium separation Filtration Centrifugation	Expansion (loosening) Hydrostatic extrusion Mache production Felting
Electric	High frequency drying	Magnetic separation Magnetohydrodynamic separation Separation based on conductivity Infrared technology Optical electronic separation Electrostatic separation	Electrostatic dust and fibre application
Thermal	Cryogenic milling Drying Pasteurization Thermal shocking	Defrosting Cauterization Cracking Calandering	Smelting Hot pressing Injection moulding Extruding Calandering Vulcanization Disintegration in a pressure cooker Cracking (pyrolysis) Burning
Chemical and biological	Sterilization Neutralization Chemical cleaning	Elution Dissolution Extraction Hydrolysis	Chemical decomposition Hydrogenation Addition processes Enzymatic fermentation Yeast treatment Composting

Table I.5.1: The preparation, separation and utilization of wastes according to basic technological mechanisms *(Árvai, 1993)*

I.5.2. Paper

I.5.2.1. Characteristics of basic materials

Paper is of natural origin, it degrades relatively quickly, and, accordingly, it can be regarded as an environmentally friendly substance. On the other hand, its production causes severe environmental impacts:

a) harvesting of wood: 2-3.5 tons of wood (about 10 trees) are required for the production of 1 ton of paper. About 19% of total global wood consumption is used in the production of paper. 42% of trees harvested for "industrial" purposes (i.e. all that are not used as firewood) are used in paper production. The harvesting of wood generates significant environmental impacts and problems: harm to ecology, the water cycle, the carbon cycle, climate change, soil erosion, etc.

b) energy consumption: Paper production is responsible for 4% of global energy consumption. Using waste paper radically improves the energy balance of paper production:

• energy demand for primary production of grey kraft paper:	52.4 GJ/t
• energy demand for primary production of bleached sulphite paper:	53.4 GJ/t
• energy demand of products manufactured using waste paper:	7.0 GJ/t

c) water consumption: The paper industry uses more water per 1 ton of product than any of the other industries. Due to the need for substantial bleaching and washing, the production of office paper requires the highest amount of water.

d) water contamination: Numerous chemicals may enter natural waters from paper mills (e.g. paints, solvents, etc.). Their removal is necessary from the perspective of environmental protection and this increases the cost of production.

Within primary basic materials (that originate from the harvesting of wood, or sometimes from straw or textiles nowadays) so-called PEFC (Programme for the Endorsement of Forest Certification Schemes) and FSC (Forest Stewardship Council) certified basic materials and production processes can be distinguished. The main characteristic of these materials and processes is that their primary fibres originate from sustainable silviculture.

For paper production a significant amount of material and energy is needed. The production of recycled paper requires a significantly smaller amount of environmental resources and energy and generates proportionately less waste. Table I.5.2 presents the differences between the material and energy consumption of white paper and grey recycled paper:

White Paper	**Grey Paper**
417 m^3 of water	100 m^3 of water
1700 kg of wood	1150 kg of black-and-white newspaper
717 kWh of energy	300 kWh of energy
181 kg of limestone	
87 kg of sulphur	
6 tons of steam	3 tons of steam
60 kg of chlorine	

Table I.5.2: Materials and energy necessary for the production of 1 ton of paper
(http://www.kvvm.hu/szelektiv/hasznositas.php)

I.5.2.2. The utilization of waste paper

After selection, collection and sorting, the use of recycled waste paper can be divided into two main fields: utilization in the paper industry and utilization for other purposes (see Figure I.5.1). Waste paper is most commonly used as an input for further paper-making, and this is based on recollection. This is a fairly widespread method in all countries. Paper fibres can be reused in paper production 6-8 times.

The production of recycled paper (paper products manufactured from secondary fibre materials) is similar to the process mentioned above, with the only difference that instead of cellulose being produced from primary fibre materials, fibres recovered from waste paper are used in this case. The quality and appearance of the recycled paper that is produced is defined by the com-

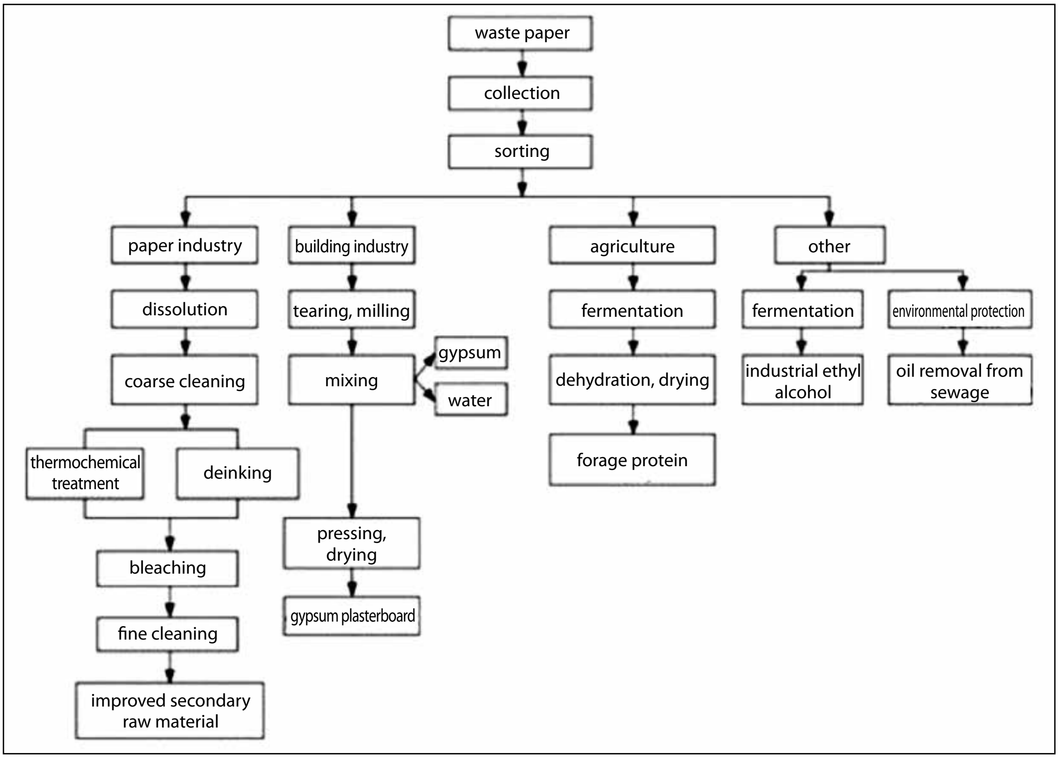


***Figure I.5.1: Opportunities for using waste paper** (Árvai, 1993)*

position, contamination and the age of this waste paper. Waste papers of different compositions cannot be equally well utilized by paper mills. The most valuable secondary raw material is waste that only consists of clean, selected and homogenous papers or cardboards. The different utility characteristics of waste papers are also reflected in their purchasing prices. Secondary raw material refers to the fibres that originate from recycled paper.

The first steps in its utilization (preceding the processes in the paper industry) are the following: selective collection, sorting, baling and transporting. The paper industry process starts with the preparation of waste paper. The majority of waste paper is prepared without chemical treatments or by a wet or semi-wet process, combined with chemical treatment.

As a first step, waste paper is leached in water in a pulper, and after the fibres are loosened it is broken down to individual fibres with the help of machines of different construction. Undesired contaminants (strings, wires, plastics, etc.) are removed from the pulp that is produced by different sorting production lines (vibrating screens, deflakers, hydrocyclones, centrifuge separators, etc.). The produced, cleaned pulp can be processed using traditional thickening and sheet-making methods.

In the last part of the process, effective defibring and deinking have been the main tasks for the paper industry. Papers produced from waste paper for ordinary use are grey. Deinking is carried out by washing or flotation. Both methods are designed to remove ink from the fibres.

During washing, ink is dissolved by chemicals, and is finely dispersed in the diluted medium so that fibre material and liquid-containing ink can be separated by the pressure suction of water moving through a colourless screen.

Flotation is an enrichment method based on the differences in the surface adhesion characteristics of materials, originating from the fact that the surfaces of the various materials adhere differently to air and water. By adding adequate reagents, the adhesion properties of water or air on the surface of solid molecules can be modified: it can be enhanced or mitigated, or even reversed. By dispersing air bubbles in the slurry, aerophilic or hydrophobic molecules adhere to them, and float to the surface of the slurry with the bubbles. By adding adequate reagents, the bubbles do not burst immediately but stay on the surface of the slurry for a shorter or longer period of time, forming a more or less stable foam layer. Molecules made hydrophobic can then be selectively collected into this foam, while aerophobic or hydrophilic molecules stay dispersed in the slurry.

During flotation, paper and dissolved contaminants are separated by pumping air into the water and by adding chemicals. In this case, gas dispersed into the emulsion draws hydrophobic ink molecules to itself, and this forms a separate phase at the top of the liquid. This way, at least half of the ink content is collected at the top of the pulp, from where this contamination is removed. Since the size of gas bubbles is determinative from the point of view of the effectiveness of the process, different methods are used to develop gas bubbles that disperse most finely (electrolysis, periodic gas injection or the release of dissolved gases).

After this, filling materials, coating substances and other additives are added to the pulp, and then comes the process of bleaching (the application of chlorine or hydrogen peroxide). Finally, water is removed from the pulp by pressing, the paper goes through drying equipment, and then the ready-made paper is put on reels. Paint sludge containing fibres and filling materials (the by-product of the process) will either be incinerated, treated by wet oxidation, or will be disposed. Zimmermann announced a patent for the regeneration of sulphide-containing alkalis of paper or cellulose industry origin generated through wet oxidation. The process is carried out at a temperature of 300-325°C and at a pressure of 2-20 MPa.

Recollected waste papers are primarily sorted according to their material (newspaper, cardboard or multi-layer policoated paperboards used as drink packages). Papers recollected by their material can become the secondary basic materials of A., paper products or B., multi-layer policoated paperboard-based final products (see Figure I.5.2).

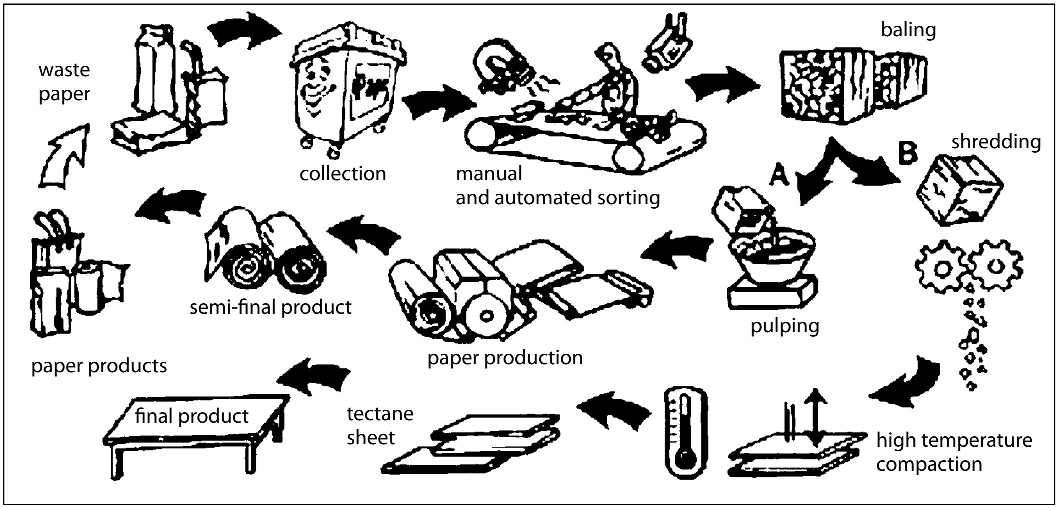


Figure I.5.2: The process of the utilization of paper *(http://www.kvvm.hu/szelektiv/hasznositas.php)*

A., Paper recollected for the production of paper products is first pulped, and then semi-final products are manufactured from it through the traditional processes of paper production. A wide range of final products is manufactured from the semi-final products of recycled paper origin.

B., For the production of final products, recollected multi-layer policoated paperboards used as drink packages are first shredded, then the pieces are compacted at high temperature and so-called tectane sheets are produced from this extremely compact material, which are then used for the manufacturing of final products.

The areas for waste paper utilization:

- corrugated cardboard from recycled paper;
- edge protectors and paper tubes from recycled paper**;**
- cardboard furniture;
- office papers and envelopes

Multi-layer policoated paperboards used as drink packages

Multi-layer policoated paperboards used as drink packages have a special place among the utilization of waste papers. Multi-layer policoated paperboards are so-called composite wrapping materials, since they are composed of three types of materials. Their components are the following: at least 75% paper, plastics (polyethylene) and aluminium foil. The basic materials of the different multi-layer policoated paperboards used as drink packages are as follows:

- Aseptic drink wrappings (UHT):

The weight of the 1 litre boxes is 28 grams, (75% paper, 20% PE, 5% Al);

- Non-aseptic drink wrappings:

The weight of the 1 litre boxes is 29 grams, (91% paper, 9% PE).

The advantages of multi-layer policoated paperboards used as drink packages:

- the cardboard ensures rigidity, and hinders the penetration of light;
- polyethylene protects against humidity and separates the foodstuff from the cardboard and the aluminium;
- aluminium protects the product from oxygen.

The disadvantages of multi-layer policoated paperboards used as drink packages:

- the production, reprocessing and utilization of such drink wrappings is an extremely energy consuming processes.

Utilization

Recollected multi-layer policoated paperboard drink containers can follow two different paths. The first version occurs with those packs recollected separately from waste paper. These packs (drink containers) are transported to two foreign paper mills that use special technology that has been developed for such waste. There, the blades of the pulping tank shred the packs, then pulp is generated from the cardboard that is soaked in water, while the plastic and aluminium layers are separated from the fibres. The pulp is separated with the help of a filter cylinder, and then it is processed into recycled paper through the traditional process. Remaining materials are energetically utilized either in incinerators or in cement factories. There is also a method during which, after the shredding of the packs, boards used in the furniture industry or for use as insulating materials are manufactured through the process of hot pressing.

The second solution has been introduced due to the increased amount of recollected waste experienced over the last years. In settlements where multi-layer policoated paperboard drink containers are collected together with waste papers, they are utilized together with waste paper by applying a simple paper production technology.

Several useful products can be made from recycled packs: wrapping paper, toilet paper, kitchen towels, egg containers, office products, message boards or cable drums for industrial use, etc. Plastic and aluminium that remains from multi-layer policoated paperboard drink wrapping is used as a source of renewable energy.

The other utilization possibilities for paper

The building industry is one of the other reusers of waste paper. Waste paper can be used for the production of insulating plasterboard. During production, waste paper is torn into palm-sized pieces by a willowing drum equipped with combs, and then it is broken into almost fibre-sized pieces through a dry process in the factory. The basic material is then mixed well with the addition of gypsum and water, then it is pressed, and the pressed boards are dried.

From the cellulose content of waste paper fodder, pet food mixtures or in some cases ethanol can be produced through fermentation.

After the special treatment of cellulose fibres, absorbing materials appropriate for removing oil from wastewater can be also produced.

I.5.3. Metal

I.5.3.1. Characteristics of the basic material

The primary basic materials of metals are ores (e.g. iron ore, bauxite, copper ore) from mineral raw materials. However, in addition to metals excavated from ores a huge amount of mining waste (rocks without economically removable metal content) also remains. For the excavation of one ton of aluminium, four tons of bauxite is needed, and during the process one ton of red mud – requiring special storage facilities that fulfil environmental requirements – is also produced. Iron and copper are melted from ores under reductive conditions in smelters which requires a significant amount of energy, while aluminium is primarily produced from alumina made from bauxite. Castings are produced from molten metal, which are further processed by rolling, stamping, forging, etc. The variety of final products made from metal is virtually infinite: the machine, vehicle and the packaging industry are all significant users. The most widely-used type of metal is steel made from crude iron with the help of alloying additives, while aluminium is the light metal with the greatest industrial importance, since it is easy to form, and it is durable as the same time. Metal containers are usually made of aluminium, iron, sometimes copper and their alloys. Today, more than 50% of them are produced from recycled raw materials.

Collection

The collection of metal beverage cans, tins, spray cans and caps is carried out in metal waste collection containers. Used aluminium beverage cans can be collected at more and more collection points located in schools, institutions, catering establishments or filling stations. Metal cans contaminated with paint or other chemicals can be brought to waste yards, or can be discarded during hazardous waste collection events.

I.5.3.2. Utilization

Metal constitutes about 8% of household waste. It is practical to deal with containers made of metal by dividing them into two groups. Different methods are used with materials made of aluminium and non-ferrous metals, and for those mostly containing iron (steel).

Recycling methods for aluminium based wrapping material

Beverage cans constitute to the majority of aluminium based containers. Besides these, screw-caps and aluminium foils can be mentioned in this category, although there is no data available at all about their total weight. Aluminium beverage cans can be utilized the most effectively without a loss of quality from all wrapping material.

At the beginning of the process, the collected cans are compacted, shredded, and the chips are separated by a magnet, then in the first step contaminants such as lacquers and paints are burned off by heating the material close to melting point (500-600°C, with the injection of oxygen). After this the material is smelted, slag containing further contamination is removed from the melt, and the pure aluminium is cast into blocks. These blocks are fairly valuable raw materials, and the costs of their production are counterbalanced by the energy costs of aluminium produced this way, which is only 5% of the cost of primary aluminium produced from bauxite.

Recycling of steel based wrapping material

The greatest amount of iron (steel) based wrapping materials are used by the canning industry in the form of tinned steel cans. After cleaning, the steel cans that have been separated out from waste using a magnetic process are detinned (through melting down, electrolysis, in an alkaline way or by the redox method). Tin recovered this way is also a valuable basic material.

Cleaning and detinning can be carried out within one single process. In this case contamination and the tin layer are burned or melted off, and are evaporated by a high temperature stream of gas. Slag originating from incinerators is treated by a magnetic separation process in order to remove iron. Detinned steel waste is compacted, baled, and then it is utilized in smelters. Figure I.5.3 is a general schematic about the utilization of metals.

Figure I.5.3: The utilization of metals

(www.hulladekboltermek.hu)

I.5.3.3. Methods used for the treatment of metal wastes

In most cases the majority of metal waste is a mixture or alloy of different metals, and also contains other materials, such as paper, plastic, glass, etc. The efficiency of utilization is based on the success of the sorting of waste. For this end, one of the methods presented under Table I.5.3 or a combination of them are utilized. This is often preceded by manual sorting, but the shredding of waste is a necessary step in all cases.

Figure I.5.4 presents a classification and categorization of shredders. Figure I.5.5 and Figure I.5.6 present one type of such equipment and the construction of the blades.

Figure I.5.8 illustrates one piece of technology that is used for separating metals. Shredded material sorted by material types is often briquetted (see Figure I.5.7). Metal briquetting machines can be used for the briquetting and compacting of metal scraps of aluminium, copper, steel and other origin. Metal briquetting has several advantages: the volume is decreased, there is no material loss during remelting, melting time is significantly decreased, soot formation is negligible during the melting process, etc.

In the next step, briquetted or shredded metal waste is melted in different types of furnaces (rotary drum furnaces or shaft furnaces). Figure I.5.8 shows the complex separation technology of metal mixes containing different contaminants.

Material properties	Industrial processes
Grain size	- sieving - fluid flow sorting
Form	- form sieving - sloped belt separation - ballistic separation - fluid flow separation
Density	- heavy medium separation - sedimentation - sluicing - table separation - ballistic separation - fluid flow separation
Electric conductivity	- electrostatic separation - eddy-current separation - electric sorting
Magnetic susceptibility	- megnetic separation - separation in magnetic fluid
Optical properties	- optical separation
Radiation	- radiometric separation - infrared separation - X-ray separation
Deformation properties	- bumping separation - Forming (e.g. with cylinders)
Mechanical, fracture mechanical properties	- selective shredding (and sorting) - weathering (and sorting)
Adsorption-adhesion properties	- flotation - selective flocculation - adhesion separation

Table I.5.3: Mechanical separation methods for the preparation of wastes containing metals *(Csőke, 2009)*

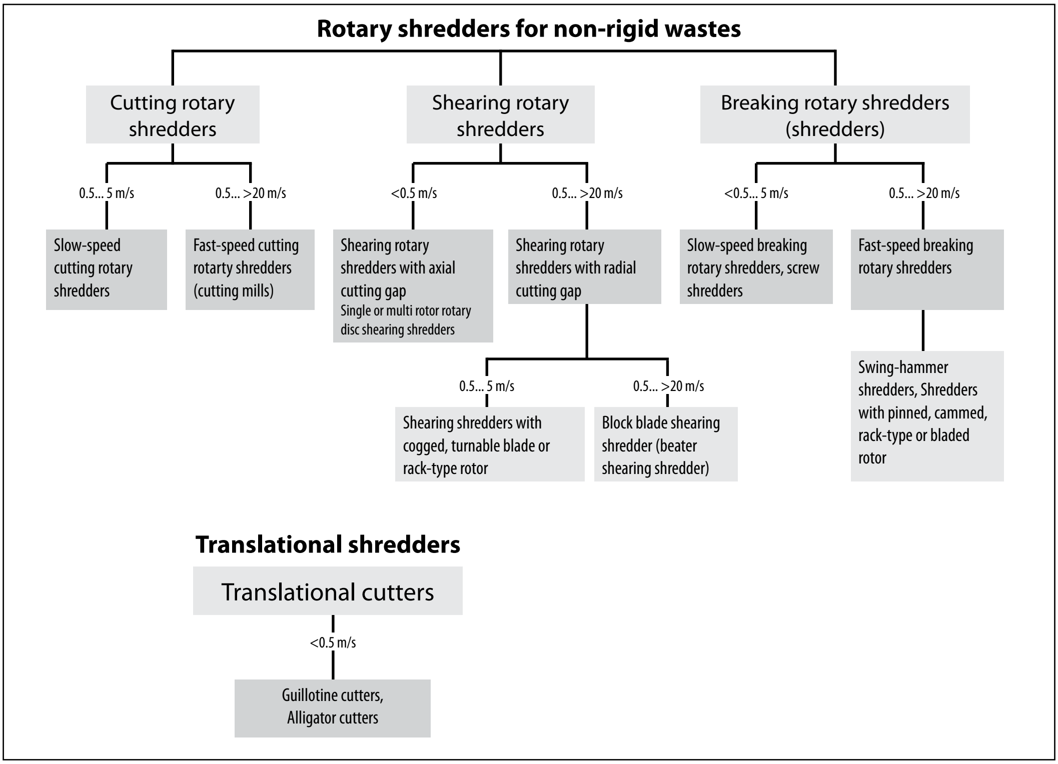


Figure I.5.4: Classification of shredders of non-rigid wastes *(Schubert, G. 2006)*

Figure I.5.5: Double axis shredder **(***Best Machinery Ltd.)*

Figure I.5.6: Different blades for shredders (*Best Machinery Ltd.)*

Figure I.5.7: Horizontal metal waste briquetting machine *(Best Machinery Ltd.)*

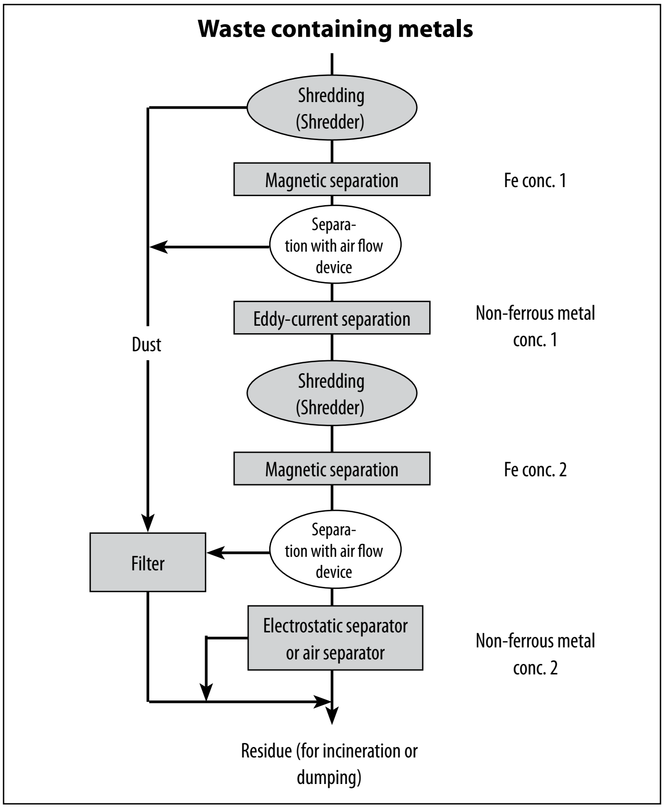


Figure I.5.8: Separation technology of wastes containing metals *(Csőke, 2011*)

I.5.4. Wood

Wooden packaging materials basically comprise pallets, furniture and boxes. They can be utilized for:
- producing repaired pallets,
- furniture production,
- woodchip production,
- briquette or pellet production.

Reaching the predefined proportions of utilization is difficult, since these used wooden products are usually taken home, and are used by the public.

Briquetting and pelleting are frequently-used methods for wooden wastes. Briquetting refers to a kind of compacting process that starts with shredding, and is carried out by the addition of binding material in some cases. A counter punching plate or the double roll presses of a horizontal layout are used for the production of briquettes. They should be chosen according to accurate knowledge about the characteristics of the material (chip size, composition, water content, etc.) and the amount of waste and the purpose of its utilization.

Pellets are fibrous and stringy materials pressed under high pressure, and held together by either their own material or by some binding material that is mixed in. Size may range from a few millimetres to material bars with a diameter of many centimetres. The wood pellets that are most commonly used in combustion technology have a diameter of 6 mm and a length of 2-5 cm. Since the water content of a pellet is only 10% compared to the 40% in wood, burning efficiency is higher than with firewood. Due to their being burned in a controlled combustion process, the emission of harmful substances is also lower.

The pelleting of solid organic wastes already prepared by shredding, sorting and drying is done in systems similar to presses. The majority of presses are equipped with a ring die and one, two, three or four press rolls, or sometimes with a flat die and conical or cylindrical Koller holes (see Figure I.5.9). The preconditions for pelleting include the shredding of material to the appropriate size, and the carrying out of necessary cleaning and sorting activities. These activities aim at creating a relatively homogenous and fine-grained material for granulation. Adjusting to obtain suitable water content is also important.

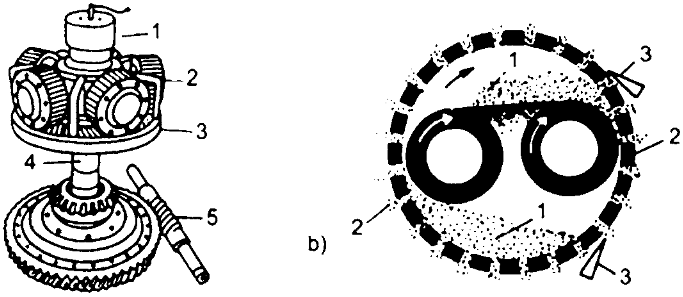


Figure I.5.9: The principle of pelleting presses *(Barótfi, 2000)*
a) the construction of a press working with a four-roll die (without casing) 1. hydraulic roll press regulator; 2. rolls; 3. main shaft; 5. screw gear
b) the principle of a press working with a two-roll ring die 1. material to be pelleted; 2. ring die with press holes; 3. blades

I.5.5. Glass

I.5.5.1. Characteristics of the basic material

Glass is an amorphous, crystalline, fragile material made of sand through an extremely energy intensive process that is primarily used in the packaging and the building industry. Accordingly, waste glass usually appears in household wastes and wastes originating from the building industry. On a human scale, glass virtually does not decay in the natural environment. Consequently, glass should be used in recycling systems (see deposit glass bottles). It can be regarded as an environmentally friendly packaging material only when it is it reused (refilled) and then reused as many times as possible. It does not decay in landfill sites, and it cannot be burned in incinerators either.

For its production, pure silica sand, soda, ground limestone, marble flour or lime marl, additives, carbon (during burning the sulphur content, sulphur-dioxide is produced) and 20-30% scrap glass is required, if possible. After mechanical mixing, ingredients are poured into tanks or melters, and are melted and silica is produced.

Melting starts at a temperature of about 800-900°C, and ingredients become liquid at 1300-1550°C. During clearing the melt becomes homogenous. Sodium-sulphate, arsenic-, antimony- or cerium-oxide or sodium-chloride are used as cleaning agents. Then the melt is rested until it cools back to a temperature of 1200°C. It is processed by blowing, pressing or pulling. Bottles are produced by blowing, glass plates, beer bottles and fruit jars are manufactured by pressing, while window glass is made by stretching.

Glass is the only remeltable material which can be reused in an unlimited way without its quality degrading. Scrap glass is an important basic material for glass production: it increases the thrift of production, and speeds up the process of melting. Raw material mixtures containing scrap glass can also be melted faster, since during the melting of scrap glass no chemical processes occur. Rapidly-melting scrap glass also has an active role in the digestion of other raw materials added to it (silica sand, dolomite, limestone, feldspar, alumina hydrate, soda, etc.). If scrap glass of appropriate size is used, the clearing of the glass melt will be also faster since it contains fewer gas bubbles than a melt produced using raw materials. A lower melting temperature means a lower energy demand for melting, which also increases the lifetime of the furnace. The colour of the glass will depend on the amount and quality of oxides that are added to the basic material. Mechanical and particularly automatized glass production is very sensitive to even small differences in the proportions of ingredients that are used; for this reason it is extremely important that the composition of glass remains constant.

I.5.5.2. The reuse of deposit glass bottles

The first step in waste utilization is prevention. This can be most effectively achieved with glass containers. Deposit glass bottles are multiway packaging materials, and their negative environmental impacts are negligible compared to those caused by single-use throwaway wrapping materials. The life cycle of this latter group is linear: materials exploited from nature, energy used for production, etc. are gone after a single use; in addition, the amount of waste increases during the process. In contrast, deposit glass bottles "go around the cycle"; that is, after appropriate cleaning they can be refilled several times, this way saving the material and energy used during their production for a long time. Water containing detergents used for cleaning and the transportation of one heavy reusable bottle still cause less environmental pollution than the production, transportation and disposal of 40 "throwaway" PET bottles (thus the use of 1 deposit glass bottle replaces the use of about 40 throwaway PET bottles of the same volume, since glass can be refilled about 40 times).

Collection

It varies settlement-by-settlement if white and coloured (green, brown, etc.) glasses are collected in common or two separate containers for collection. In the latter case, one of the steps of utilization (separation by colour) is even not necessary.

I.5.5.3. Utilization

It frequently occurs that, during collection, other materials are also mixed into the glass, such as stones, metals, plastics, etc. Since pure secondary raw material free of contamination is a requirement for utilization, first the different types of glass to be processed are sorted by their material types and by colour, and then they are mechanically cleaned. This can be carried out either manually, or by machines.

The recycling of waste glass is a two way process: some materials are redirected to the glass industry for melting, while others are used for different purposes (see Figure I.5.10).

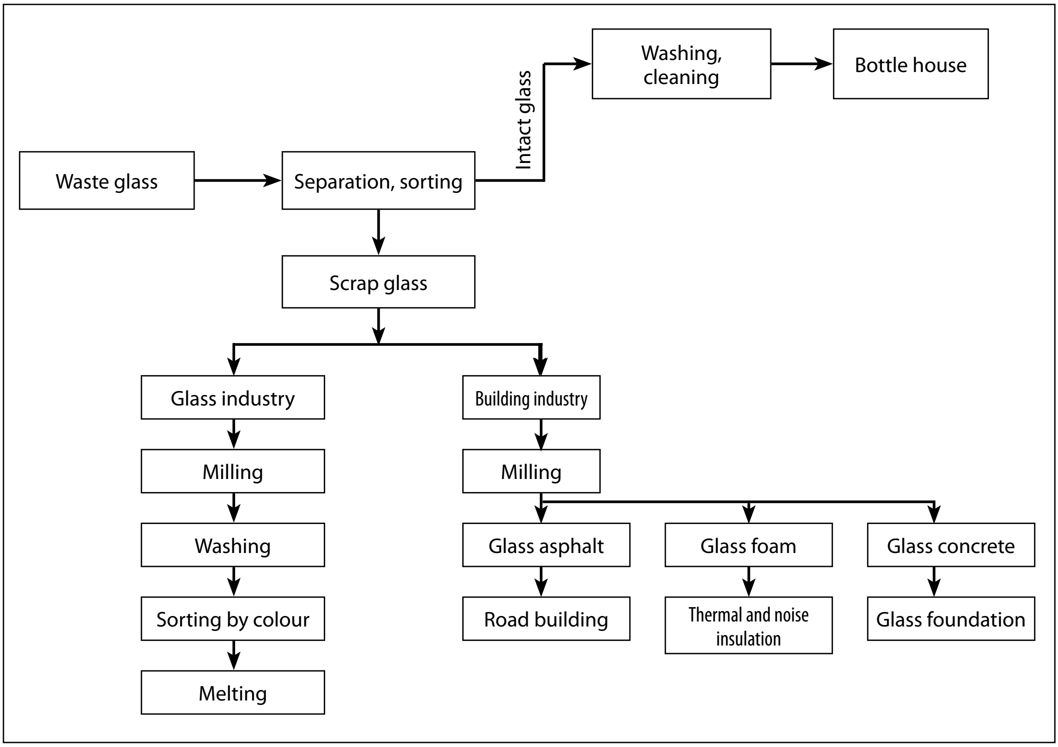


Figure I.5.10: Methods for the recycling of waste glass *(Barótfi, 2000)*

After cleaning, separately-collected glass is smashed into pieces, then metal scraps are removed from it by magnets, and other contaminants are also separated by different means in the separator. Scrap glass is sorted by size, while waste from mixed collection is sorted by colour (see Figure V.11). Optical separators work in three phases: first non-transparent contaminants (stones, ceramics, etc.) are removed from the mixture, then white glass is separated from coloured glass, and finally, brown glass is separated from green. Cleaning is carried out by washing with water in a rotary drum. Scrap glass needs to be broken into pieces before utilization. In most cases, a rebound crusher is used for such purposes. The appropriate, processable size ranges between 5-30 mm. In the next step ferrous contaminants are separated out. Magnetic separation can be carried out either using a band separator or a drum separator. Sorting is carried out with the help of a vibrator, while non-ferrous metals are removed by an eddy current separator, an air blast machine or by an air separator. The general scheme of the processing of waste glass is presented under Figure I.5.12.

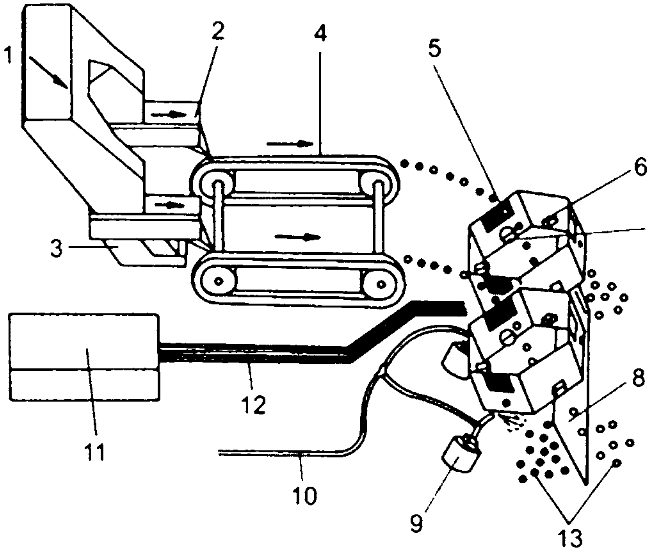


Figure I.5.11: Schematic diagram of an electronic optical separator *(Barótfi, 2000)*
1. material feeding; 2. vibration cradle feeder; 3. vibrator; 4. belt feeder; 5. background panel of standard colour;.
6. photocell uint; 7. source of light; 8. product separation board; 9. compressed air regulating solenoid valve;
10. residual compressed air; 11. electronic uint (amplifier, logical circuit, energy supply, signal device);
12. electric cord; 13. separated product

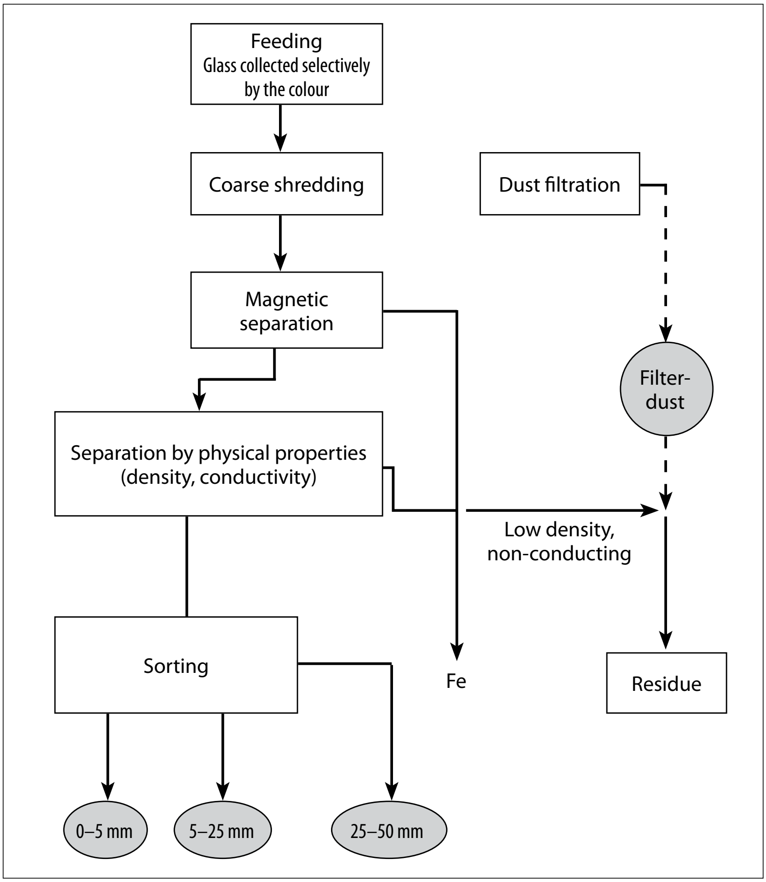


Figure I.5.12: The general technological scheme of waste glass processing *(Mucsi, 2011)*

At the glassworks smashed scrap glass is added to the mass melted from primary raw materials. Liquid glass reaches its final form with the help of moulding machines in packaging glass factories. In Hungary, the recycling of white waste glass is carried out in two glass factories (one that produces packaging glass and another that manufactures flat glass), both situated in Orosháza. Due to the lack of appropriate national utilization capacity, coloured scrap glass constituting about 50% of packaging glass wastes is transported abroad.

Scrap glass which cannot be economically utilized in glass production should also be used in the following ways:

- Scrap glass with a grain size larger than 25 mm can be used for the production of washable concrete paving blocks. Ground glass of various colours or with surface colouring can be also used for the decoration of concrete or building panels.
- By mixing ground waste glass with a grain size of 25-5 mm into asphalt at a proportion of about 50%, a high quality, water-tight and frostproof road building material can be produced. At the same time, glass also increases the friction coefficient of asphalt paving.
- After melting the waste glass and adding some additional raw materials, glass wool can be produced, from which high quality insulating and soundproofing panels can be produced.
- From ground and sorted glass grains, glass pearls can be produced with the help of a special gas burner through a so-called flotation process. This can be used for the reflecting surfaces of road signs, as a polishing material for industrial metal forms, the microforging material of steel structures, the carrier of colorants, the filling material of plastics, or for the cleaning of industrial waters.
- Ground and sorted scrap glass of an appropriate size can be used for the melioration of clayed, marly and sandy soils. It helps oxygen diffusion for plants in the soil, and with this scrap glass, the water retention of the soil can be also regulated.
- From a mixture of scrap waste glass of 0.5-7 mm size, and crystallizing materials with a proportion of 5-10% boarded, new marbled building material can be produced through the process of sintering (forming with pressing and thermal treatment) in a tunnel furnace, which is extremely rigid, and is well resistant to friction and weather conditions.
- Glass powder with a grain size of less than 125 µm can be used as a scrubbing agent or a water purifier. Ion replacement processes easily take place between the structural holes of the glass powder and the water, fatty acids and oleic acids, leading to a filtering-cleaning effect.
- By adding glass powder with a grain size of less than 125 µm to clay, china (which usually has three main components) can be made with two components. Chinaware produced this way can be transported well, can be treated at lower temperatures, has low-shrinkage and favourable mechanical characteristics.
- Foam gravel. Waste with a high glass content is ground to the appropriate grain size. It is homogenised with gas forming waste, the amount of which depends on the level of contaminants. It is granulated together at a melting point that reduces, and viscosity modifying additives. Granulates go through thermal treatment and then are covered by material with a large specific surface in order to regulate water absorption. After drying, they go through a thermal treatment process undertaken in an inclined rotary furnace, and then they are cooled. They can be used as (additional) insulating and soundproofing coatings and layers, step proof insulating elements (for underfloor heating), for the protection of flyovers against frost penetration or as lightweight concrete building elements or noise barriers.
- Cleaned scrap glass. Delivered scrap glass is weighed, qualified according to local standards, and then is processed. The production line cleans, breaks and sorts scrap glass (by colour). Cleaned scrap glass is then marketed as a final product with a quality certification.

I.5.6. Plastic

I.5.6.1. Characteristics of the basic material

Plastics are the most important representatives of large molecule synthetic and natural chemical compounds (macromolecules). In most cases, one of the polymers is only the main component of a plastic, so it also contains additives (stabilizing agents, mould lubricants, colorants and plasticizers, filling and reinforcing materials) besides this. Plastic is an artificial material made from crude oil (accounting for 4% of total crude oil production) with the help of additives. It decays very slowly, or it does not decay at all in the natural environment, and during its incineration hazardous substances are released.

The development of the plastics industry started in the 1960s due to the fact that consumer society started to prefer the use of plastics because they were cheap, convenient and because they came into fashion. Their application in the packaging industry has led to the generation of an incredibly large amount of waste packaging material.

The lifespan of plastic products is extremely varied and may last from a few days of use to many decades. Waste generation has to be taken into account also during the production, processing and use of plastics: packaging tools that have lost their function but which are of the same quality and worn out plastic products that require replacement will all become waste together with wastes generated during the thermoforming and confectioning of semi-finished plastic products. Figure I.5.13 presents one possible classification of plastic wastes.

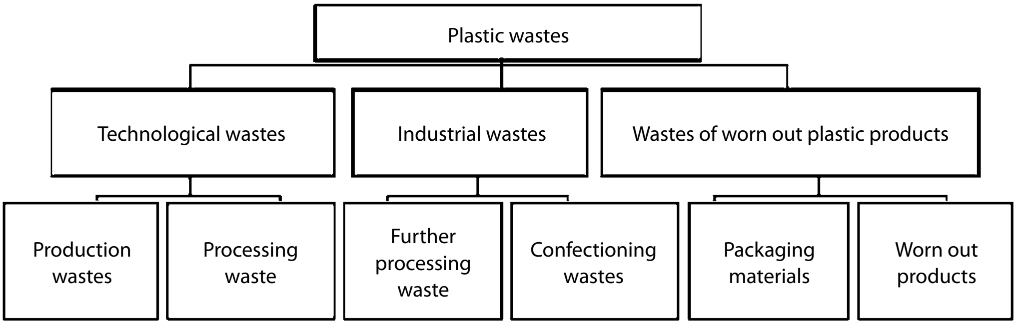


Figure I.5.13: Classification of plastic wastes *(Farkas, 2000)*

Currently, 50% of the yearly-produced plastic wastes are utilized in Europe: 60% of them are incinerated for the purpose of energy production, while the remaining 40% are recycled. The vast majority of recycled plastics have been recycled mechanically, and only less than 1% of them get recycled chemically.

Environmental impacts:

- Decomposition times of plastics are still unknown, they may last even for centuries under isolated circumstances;
- Carcinogenic substances are generated from the additives used during incineration (also causing respiratory diseases);
- Toxic by-products are generated during their production;
- They endanger the lives of many animals in nature;
- Additives mixed into PVC toys may enter the bodies of children.

I.5.6.2. The treatment and utilization of waste plastics

The reprocessing of waste plastics

Recollected plastic bottles (PET bottles) are sorted by colour by a sorting device, and then are baled through compaction. These bales are transported to utilization companies where ground material and granulate are produced from the homogenous plastic waste which is thereby made reprocessable (see Figure I.5.14).

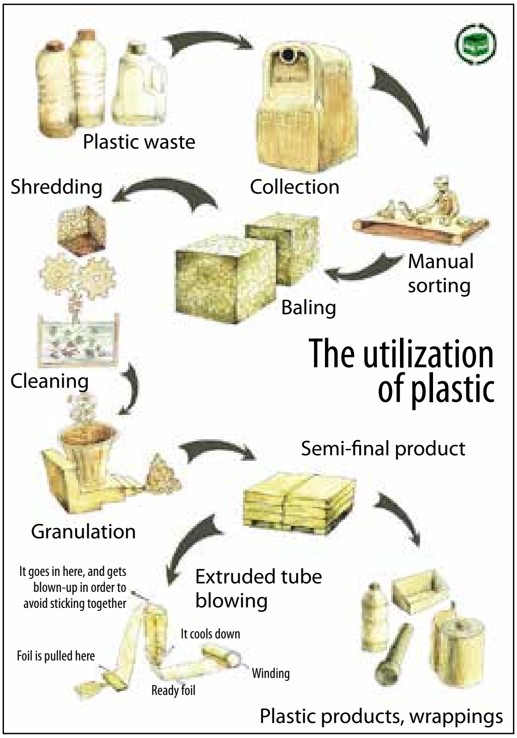


Figure I.5.14: The utilization of plastic
(www.hulladekboltermek.hu)

The reprocessing of plastic involves a sequence of mechanical operations where the order of the different technological steps and the type of the used equipment may differ by the kind of plastic and the type of waste. Utilization processes are partially the same, but they may differ according to the type of plastic. However, in general, they can be characterized the same way. The aim of mechanical utilization is to utilize the plastic in the material. The main technological steps in mechanical utilization are the following: selecting, shredding, washing, sorting, drying and granulation.

Mechanical utilization can be carried out for mixed plastic waste, or separately by using only one type of waste. If the process is designed to utilize the same types of components, mixed plastic waste shall be first sorted before processing. For large-size plastic wastes, sorting is done manually. The sorting of fine plastics is carried out by methods based on differences in density. Plastics with the same grain size that are chemically different (e.g. PE, PP, PVC) are usually separated after shredding and washing. Flotation can be used to separate mixed plastic wastes.

Mixed plastics can be also separated – with or without special surface treatment – by electrostatic separation processes. Electrostatic separation can be used for materials with different levels of conductivity, such as aluminium that is a very good conductor, and plastics that are insulating materials.

It is advised that shredding is carried out in a two-step process. The first step is coarse shredding, while the second one is fine shredding, following the processes of cleaning and drying. Depending on the type of plastic and the objects to be processed, different shredding and grinding equipment is used. Shredding can be carried out in a dry and a wet way at room temperature or during cooling. Hammer mills can be used for the shredding of larger-size plastic wastes. For the shredding of hard (duroplast) plastic objects, cylindrical grinders are used. Cutting mills are used for the grinding of technological plastic waste, while ball grinders are applied in the case of rigid, fragile plastic objects.

Washing is used to remove contaminants that have adhered to the surface of solid plastic wastes. The washing liquid is usually water containing detergents, but depending on the type of the contamination it can also involve an organic solvent. For washing plastic wastes of the same type, a simple heated washer duplicator equipped with an agitator can be also used. Plastic wastes of the same type that have been collected separately (e.g. PET bottles) can be also cleaned by special industrial machines that continuously operate. Flotation tank washing can be used even for the sorting of plastics. Hydrocyclones have greater separation efficiency than washing in flotation tanks. Before separation carried out with the help of a hydrocyclone, waste is leached away by a washing liquid. Efficient cleaning and separation can be achieved by the use of so-called friction washing-separating devices.

Sorting and washing are followed by the steps of water removal and drying. The majority of plastics are not hygroscopic, and they take in only a negligible amount of water; consequently, most of the water that remains on their surface after washing can be removed by mechanical means. The simplest way to remove water mechanically is to feed the wet plastics into a narrowing roller bed. Centrifuges are also efficient at water removal. Water that adheres to the surface of plastic scraps through adhesion cannot be removed by mechanical methods but only with the help of drying. For drying, cyclones and air circulating heater tunnels can be used.

Shredded, washed and dried plastic waste is too loose, and has a high relative volume. Correspondingly, it is unsuitable for further processing, and requires compacting and granulating. The simplest and most widely-used method for this is extrusion granulation.

Plastic waste of the same type produced after selection can be processed using traditional plastic processing equipment. From these methods injection moulding is most widely-used one (Szabó, 1974)

Chemical recycling

The aim of chemical waste utilization is to produce raw materials and decompose plastics to their monomers, or at least to recyclable materials with a small molar weight. Chemical utilization is practical when it is economical and easily feasible, when mechanical utilization is not effective, and where the waste is clean, and includes the same types of components. This process is still not widespread at the moment. The most important methods are the following:

- coking: production of hydrocarbons;
- cracking: production of hydrocarbons and crude oil;
- depolymerization: production of substances with a small molar weight which get re-polymerized;
- electrokinetic decomposition: production of industrial gases;
- hydrogenation: production of various chemical compounds during saturation reactions;
- transesterification: glycolysis, hydrolysis and methanolysis of PET and polyurethane.

Thermal utilization of plastic wastes

The oldest method of thermal utilization is incineration with the single original goal of disposing of the waste. Later, energy was produced from this process. Today, several other thermal utilization methods have become available besides incineration such as pyrolysis, gasification, metallurgical utilization or utilization in the cement industry.

During incineration the high energy content of plastic wastes can be utilized, which may also lead to problems at the same time (PE, PP and PS have higher calorific value than crude oil). Temperatures may rise to an excessive level which can damage traditional incinerators.

Pyrolysis is a kind of decomposition process carried out under lower-oxygen or anaerobic conditions during which first depolymerisation and cracking take place, and then the smaller molecules produced during this phase react with one another. Three phases are produced depending on the temperature and other conditions: a solid, a liquid and a gas phase, which can be used either for energy production or for synthesis.

Gasification is a kind of decomposition carried out at high temperatures with the addition of various gasification agents (oxygen, air, flue gases, water vapour and carbon-dioxide) or their mixtures.

During metallurgical utilization, synthesis gas is produced from plastics since they have a high carbon and hydrogen content. The synthesis gas that is produced can be used for the reduction of iron ore.

Utilization in the cement industry (co-firing) is the most common method used in the case of plastic wastes and tyres, but plastics containing chlorine are problematic (the following Chapter I.6. deals with the thermal treatment and utilization of wastes).

I.5.6.3. Explaining concrete technological processes through a few examples

PET bottle, PE foil and PP washing and processing line

Since during the collection, transportation and storage of plastic wastes a huge amount of contamination may adhere to the surfaces, a multi-phase treatment with water and detergents is inevitable after the process of coarse shredding. With the help of the friction washing machines and the leaching tanks 100% of the contamination and labels are removed. After cleaning, the washing liquid can be redirected back into the system and in this way the amount of sewage water/waste can be minimized (see Figure I.5.15).

After the cleaning phase, the cleaned plastic is transported into the drying unit in the form of coarse chips from where it will be forwarded to a buffer tank after water is removed.

The next – larger – technological process involves a granulating line, whose units perform the production of granules with predefined features after proper shredding and total water removal. This way, recyclable granulate can be produced from the plastic secondary raw material in the plastics industry. If the plastic granulate is intended to be used as wrapping material in the food industry, a further biotechnological unit that ensures sterility shall be also used in order to eliminate pathogens.

Figure I.5.15: Friction washing machines
(Best Machinery Ltd.)

The course of the processing of plastic and metal wastes from residential collection

During recollection activities, waste entering the site will be disposed in the outdoor storage area (and be measured using a platform scale). The feeding of material to the sorting and pre-treatment facility is performed by a feeding-buffer container which is continuously fed by a front-end loader. The basic material forwarded to the sorting facility first enters a pre-sorting station where large-scale cans, containers and other contamination located in the material stream (e.g. waste glass and waste paper) get separated out manually.

In the next step ferrous metals are removed from the pre-sorted basic material with the help of a rotating magnet. Waste iron separated this way is sold to specialized companies for further utilization. Pre-sorted basic material from which ferrous metals have been already removed is transported to the foil separator through an inclined belt feeder. Here waste foils get separated, after which they will be agglomerated and sold. In the next step, the material is forwarded to a vibrating table where smaller contaminants fall through the grates in the table and leave the material stream. Also, this vibrating table helps to evenly distribute the basic material on the conveyor belt.

After passing the vibrating table the mostly clean waste stream goes through an optical mechanical sorting process. The "heart" of the optical sorting devices is an optical sensor (the "red eye") that emits a beam of light onto the waste that includes plastic bottles, flasks and aluminium beverage cans that are passing fast below it. From the reflections of light the device can determine the characteristic material and colour of the given waste. After this identification process a set of nozzles located behind the optical sensors blows materials with the predefined sorting characteristics out of the material stream with compressed air in a fraction of a second. The first optical sorting device blows out PET bottles from the material stream; this way HDPE, PE and PP flask and aluminium beverage cans can be separated and later sold to partner companies for further pre-treatment. The second optical sorting device basically picks out PET bottles according to their colour. This colour-based sorting process is carried out according to market needs, but it can be stated that, in general transparent, blue, green and multi-coloured (yellow, brown, black, red, silver, etc.) bottles are separated out. In order to maintain perfect quality a manual post-sorting operation is also carried out after mechanical and optical sorting. After sorting by colour, bottles will be granulated separately colour-by-colour.

For the next step of the process unwashed PET granulate is forwarded to the PET granulate washing facility. During the washing process, based on colour, the material is first washed in cold water and then by warm water. Between the different washing phases and after them the granulate goes through granulate flotation tanks, centrifuges and metal and colour separation devices (see Figure I.5.16). After the washing and sorting technologies, the final product – washed PET granulates – is put into big-bag sacks. The product is either sold or further processed from the final product storehouse.

Washed, ground PET that enters the granulating facility (see Figure I.5.17) first goes to the drying device. After being dried according to requirements, the material can be extruded. The fritting of PET is carried out by an extruding device. Fritted material is cleaned and filtered in a vacuum. Granulating is carried out after cooling (see Figure I.5.18). Finally, the material is crystallized and packaged. Figure I.5.19 illustrates the process of the processing equipment which has a capacity of 2 tons per hour.

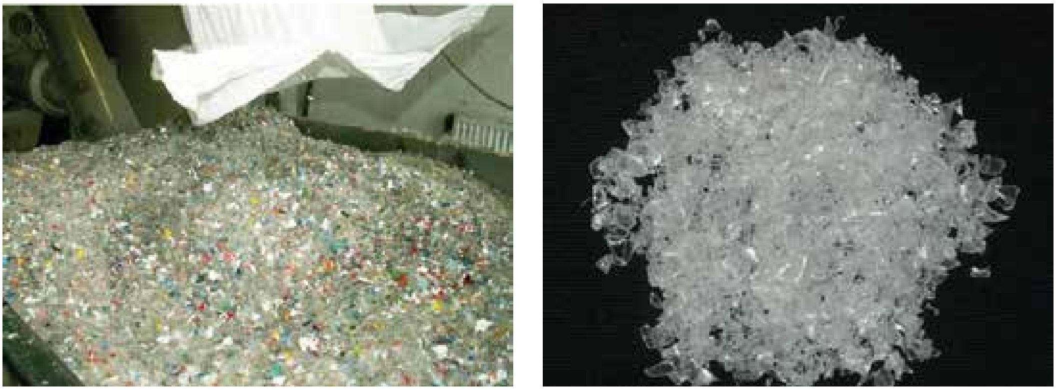


Figure I.5.16: Unwashed and washed transparent ground material *(Fe-Group Invest close corporation)*

Figure I.5.17: Granulating factory
(Fe-Group Invest close corporation)

Figure I.5.18: Transparent granulate
(Fe-Group Invest close corporation)

A few examples of secondary products manufactured from different types of plastics

PVC	tubes and coating materials, after grinding into dust,
PET	parts of bottling machines, e.g. in the Netherlands bottle lifting units are produced, bottle-to-bottle: producing bottles from bottles,
Polyester	carpets, etc.,
PE	agricultural foil, garbage bags,
PS	injection moulded products, insulation, etc.,
PU	POLIOL oil derivative, through a catalytic process, rigid foams with isocyanate,
Composite materials	paper fibres, aluminium.

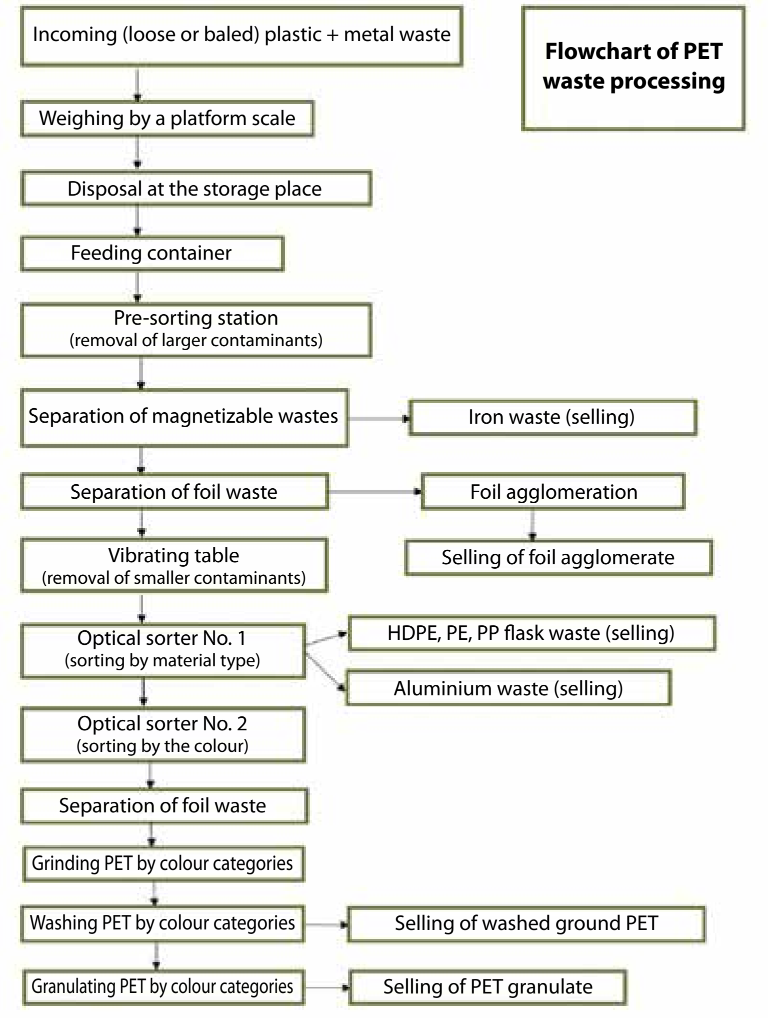


Figure I.5.19: The process of the PET waste procession *(Fe-Group Invest close corporation)*

I.5.7. Rubber

When the rubber industry first came into operation, the only elastomer was natural rubber. This latex is diluted before coagulation, and then the isoelectronic point where coagulation takes place is reached by the addition of organic acids (acetic acid or formic acid). Water is pressed out of the coagulated natural rubber, and then it is washed. During the production of 1 ton of natural rubber, 2.5-3 m^3 wastewater is produced. However, this technological process was used only at the beginning. Current technologies are based on polymers of crude oil origin.

I.5.7.1. Strengthening materials

Textiles

Cotton fibres used to be used to strengthen rubber structures for a long time. They were later replaced by viscose-based artificial silks which are still in use today.

Steel cords as strengthening materials play a significant role in the rubber industry, especially since the appearance of steel radial tyres. The production of fibres is carried out by drawing steel cords, leading them through diamond-based tools, and by adjusting their final diameter. For the warm and then the cold drawing system a huge amount of water is used. On the one hand, water is used to provide the necessary cooling effect, and by the addition of stearates it also works as a lubricant on the surface of the cord that is lead through the tool rings.

Penetration method

In order to reach the necessary level of adhesion between strengthening cords and rubber, textiles are impregnated with solutions that enhance adhesion. Today, exclusively water-based penetration-based methods where the textile is lead through an aqueous solution mostly containing latex, resorcinol and formaldehyde are used, and then the material is dried and thermally treated.

Filling materials

The majority of rubber products contain soot as a filling and strengthening material. Soot is produced in closed systems by the incomplete combustion of crude oil products. If the soot escapes from the system, it may become dangerous. Industrial soot is neither harmful to human health nor the natural environment, but if it enters the air it can pollute huge areas.

Plasticizers

In order to create the necessary characteristics and to improve processability, a few percent of plasticizers is added to rubber. Some kinds of these chemicals are totally indifferent from an environmental perspective (e.g. paraffin oils), but it is primarily oils that contain a huge number of aromatic compounds (e.g. extraction oils) that are carcinogenic and environmentally polluting.

Chemicals used in vulcanization systems

For the vulcanization of rubber sulphur, different isocyanates, peroxides, amines, carbamates and other carbon compounds containing sulphur and nitrogen heteroatoms are used. Except for sulphur, which forms cross-links and constitutes less than 3% of the material, none of the other components reach 1% in volume. During vulcanization these components are either built into the rubber or decompose. Accordingly, due to their small quantity and their being built into the material, their environmental impact is negligible.

I.5.7.2. Opportunities for utilization

Composition of tyres

Materials:

natural rubber	23.0%
synthetic rubber	24.0%
soot	25.0%
steel lining	14.0%
textile lining	4.0%
other	10.0%
Total	100.0%

Elements:

carbon	73.00%
hydrogen	6.00%
oxygen	4.00%
nitrogen	1.40%
sulphur	1.30%
chlorine	0.07%
zinc	1.50%
iron	13.50%

Re-capping: This refers to a process of reuse. The worn out cap (upper layer) of the tyre is renewed. The process is used in 10-15% of all cases, primarily for truck tyres.

Reprocessing – product manufacturing: The basic material of product manufacturing is ground rubber or rubber flour that is produced during the treatment of waste tyres. Through the different processes waste tyres are usually mechanically shredded, milled and ground, during which ground rubber of various grain sizes is produced, and the steel and textile that is built in to the tyres is removed. Milling is done by a special production line that removes 99.99% of metals, textiles and minerals, this way achieving the main goal of processing: production of clean rubber granulate of various grain sizes (usually 0.1-1 mm, 1-2 mm and 2-4 mm). Shredding can be carried out at normal temperatures or at low temperatures, which is known as cold shredding (or cryogen shredding). This latter technology is mostly used in the case of materials which cannot be shredded, or are difficult to mill at normal temperatures, and whose quality would be reduced by the heat produced during normal grinding. Cold shredding is primarily used during the processing of waste rubbers and plastic wastes. Liquid carbon-dioxide or liquid nitrogen is used as a cooling medium. Ground rubber (or rubber flour) produced this way can become the basic material for several products, such as fall protection rubber tiles at playgrounds, sports grounds, football fields with artificial grass coverings or stable mats. The materials produced are usually coloured and pressed into the desired form by mixing with glue.

The proportion of rubber which can be recovered from tyres is generally 60-65%. In Hungary, the actual value ranges between 55-60% because car users usually wear out tyre caps to a greater extent. For tyres with steel or textile frames, the remaining part consists of 25% textile and 10% steel respectively. The global proportion of utilization in the form of ground rubber reaches about 10-30%.

Reprocessing – technical application: One opportunity for technical application is utilization in the building industry, where the traditionally applied grit or gravel layer is replaced by rubber in the foundations of lower class roads or paving. During the process, tyres are first shredded into 10-30 cm sized pieces (treatment), and then they are used in the appropriate layer of the foundation of the given infrastructure. The advantage of the method is that the water permeability, flexibility and frost resistance of the rubber layer is significantly higher than the traditionally used stone-gravel layer. The use of fine ground rubber as an asphalt modification agent (in the introductory phase in Hungary at the moment) is also a way to use waste rubber. The mixing of fined ground rubber into bitumen under proper circumstances not only leads to the environmentally friendly utilization of tyres, but also to the production of high quality rubber bitumen for road building. A further method of utilization in material is when whole waste tyres are used to support the insulation material layer of non-hazardous landfill sites, according to relevant regulations that are in possession of the proper official licences.

Energetic utilization

Incineration is the most economical way of utilizing waste tyres today. This is also the only final solution for the total liquidation of this kind of waste. Since, due to their high hydrocarbon content, the calorific value of rubber products is high (28-32 MJ/kg) – the same or even higher than the calorific value of fossil fuels –, they can be even used as fuel.

Emissions are not a greater problem than, e.g., during the firing of coal. Since the energy consumption and energy costs of ground rubber production is fairly high, during energetic utilization the calorific value of rubber is utilized, and energy is produced without using external energy for the process (see Table I.5.4).

Component	Mass percentage
Carbon	70-77
Hydrogen	7-7.5
Sulphur	1.3-1.7
Oxygen	5
Nitrogen	1.5
Zinc	1.1-2.1
Iron	5-15
Other	5

Table I.5.4: The chemical composition of an average tyre *(Csőke, 2011)*

Three types of energetic utilization processes:

- utilization in clinker burners in the cement industry,
- combustion in firing equipment (steam or electricity production),
- pyrolysis: gas, fuel oil, soot or other use.

Waste tyres are often burnt in cement furnaces where 10-20% of the fuel demand can be met with this kind of material. During the process, tyres fully burn up, and steel and sulphur get bound into the raw cement. The addition of steel as an additive is necessary during cement production in any case. Residues that require further treatment are not produced during combustion at all.

Pyrolysis

During the process the ground waste tyre breaks into pyrocoke, gas fractions, pyro oil and the steel cords that formed the frame of the tyre at high temperatures (the following Chapter No. 6 deals with the process of pyrolysis).

Utilization during road building

Annual asphalt demand is ten times as great as the yearly-produced amount of waste tyres. Asphalt can be also recycled. By adding ground rubber and ground glass to it costs can be reduced, and the quality can be improved, since this way flexibility and resistance to heat and loading are increased.

Noise reduction

A small amount of unvulcanised or poor quality rubber is mixed into the waste rubber and boards are rolled from this mixture. If a metal net is put into the rubber the result will be a fairly flexible, corrosion resistant board with low thermal conductivity which can be fixed on the surface of machines and equipment.

Utilization as filling material

Depending on the grain size, ground rubber is worked into asphalt or into rubber tyres. Coarsely ground rubber is used when building playgrounds and parks. Fine granules of rubber can be used as a filling material in new rubber products. The finer the grain size, the more ground rubber can be added to the pure raw material without degrading the characteristics of the final product.

Development of banks and embankments

Walls founded and strengthened with ground rubber are more stable than those filled up with sand. At the same time, by using ground rubber 81-85% of material costs can be also saved.

Devulcanization

This is the process of mixing material produced during the devulcanization of ground rubber into pure raw material. In this case, the devulcanized product can be mixed in at significantly higher proportions than modified or surface modified ground rubber.

I.5.8. Textile

Textiles of natural origin have been used by the people for thousands of years. Their wastes do not pollute the natural environment, because they decompose relatively "fast". However, modern textiles often contain artificial materials, and the amount used is far greater than in the past.

The raw material of textiles can be of natural plant origin (cotton, flax, hemp, jute, etc.), of natural animal origin (wool, natural silk), of mineral origin (asbestos), of artificial organic origin (regenerated, synthetic) or of artificial inorganic origin (glass fibres). Synthetic textile can be produced from selectively-collected plastic bottles (e.g. polyester) by drawing the fibres.

I.5.9. Electronic waste

The most residential electric and electronic waste (e-waste) is generated from the following categories of electric and electronic devices:

- large-size household utensils (washing machines, fridges, ventilators, dishwashers);
- small-size household utensils (vacuum cleaners, kettles, food mixers, coffee makers);
- IT and telecommunication devices (computers, printers, telephones, faxes, mobile telephones);
- consumer electronics devices (radios, televisions, hifi-towers, DVD players, home cinemas).

According to the principle of extended producer responsibility, the producers and dealers of electric and electronic devices are legally bound to recollect, utilize and dispose of electric and electronic devices that become waste. People can return electric and electronic devices that are waste free of charge at waste yards and at traders who distribute electric and electronic devices, meaning the place of purchase where similar type e-wastes are taken back, free of charge.

It is important to recollect e-waste from people in an organized way, as mentioned above, or by other means, because parts containing hazardous components can be found in older e-wastes (lead, hexavalent chromium, cadmium, mercury, etc.) (see Table I.5.5).

Harmful component	*Carrier (examples)*
Polychlorinated biphenyl (PCB)	- condensers in washing machines - heat resistant oils in electric radiators
Polybrominated diphenyl ether (flame-retardant agent in plastics)	- back-wall of televisions - computer casing - electronic building units (raw material of guide plates) - switches, filling compounds
Heavy metals, semi-metals and their compounds	- luminescent materials - electronic building units - surface coating on building units and on the case

Table I.5.5: Environmentally-damaging components of electrotechnical and electronic wastes *(Csőke et al. 2011)*

Today, one of the most valuable secondary raw material sources is waste with a high metal content. This includes used electronic waste, vehicle accumulators and batteries. These not only contain valuable structural materials (aluminium, copper, iron, gold, silver), but also rare metals that are lacking in Europe, and the so-called "critical elements" meaning the metals of the platinum group (Pt, Pd, Ru, Rh, Os, Ir) and rare earth metals (Ce, Nd, Eu). Although substantial basic processing capacity (electronic waste and end-of-life vehicle shredding facilities) has been established in Hungary, the most valuable structural materials in received waste (Fe, Cu, Pb, Zn, Pt, Au, Ag, precious metals, rare metals and rare earth metals) are recovered by foreign processing facilities. Consequently, the real profits from processing are lost to them.

I.5.9.1. Disassembly technology of used devices

The pre-treatment of e-waste is carried out using manual and mechanical methods. Although the cost of manual pre-treatment is high due to the labour intensiveness of the process, it totally fulfils the very strict requirements of pre-treatment. Mechanical pre-treatment is done by an appropriate shredder, but the latest state-of-the-art disassembly equipment includes a "chain crusher". For mechanical pre-treatment, the strict regulations can be fulfilled only if the e-waste had gone through professional manual pre-treatment before any mechanical processing.

The processing of waste devices requires a complete system that includes the following steps.

Recollection – pre-sorting

Disassembly (centralized or decentralized)

The main units and components that contain hazardous substances and units, and parts requiring further different processing are disassembled and separated here.

- The process starts with the recovery of units that contain hazardous substances (condensers, batteries) and hazardous materials (evacuating liquids, see fridges);
- Then, larger homogenous units are disassembled (e.g. screens, plastics and metal housing and other homogenous building elements in the case of electronic waste);
- The process continues with the disassembly of relatively larger electronic components (metal housings, cables, conductor boards, drivers, transformers, plugs, etc.) (see Figure V.20).

The further processing of materials separated and sorted this way is carried out by separate mechanical preparatory and/or metallurgical, chemical or thermal methods and technological processes.

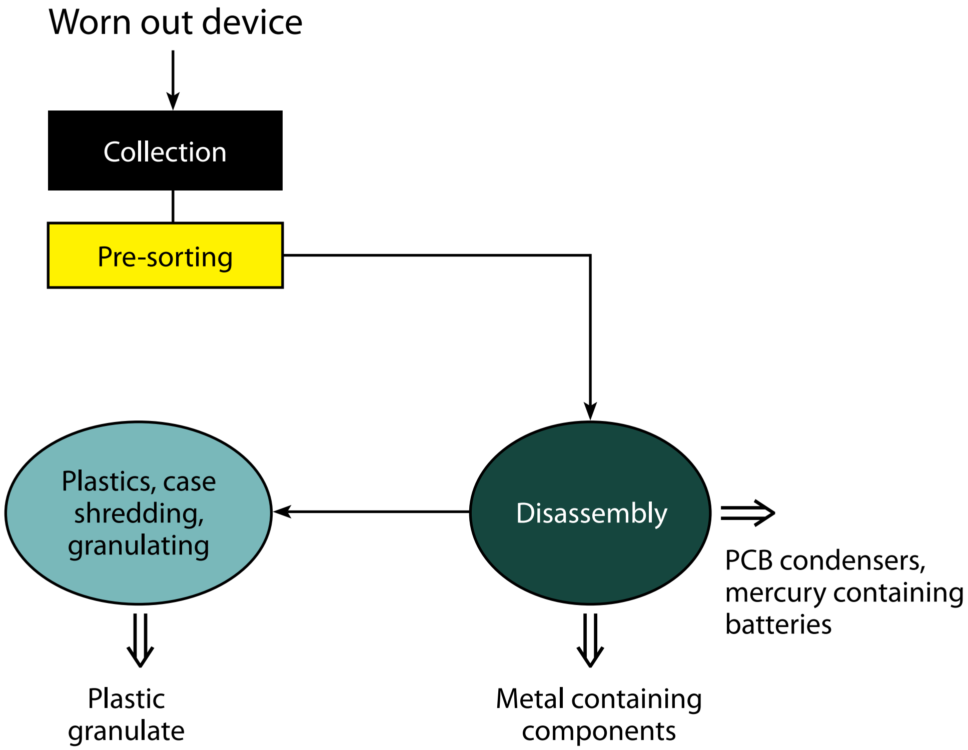


Figure I.5.20: Disassembly technology for waste objects *(Csőke et al. 2011)*

The course of processing is now illustrated through a concrete example: the case of a television (see Figure I.5.21).

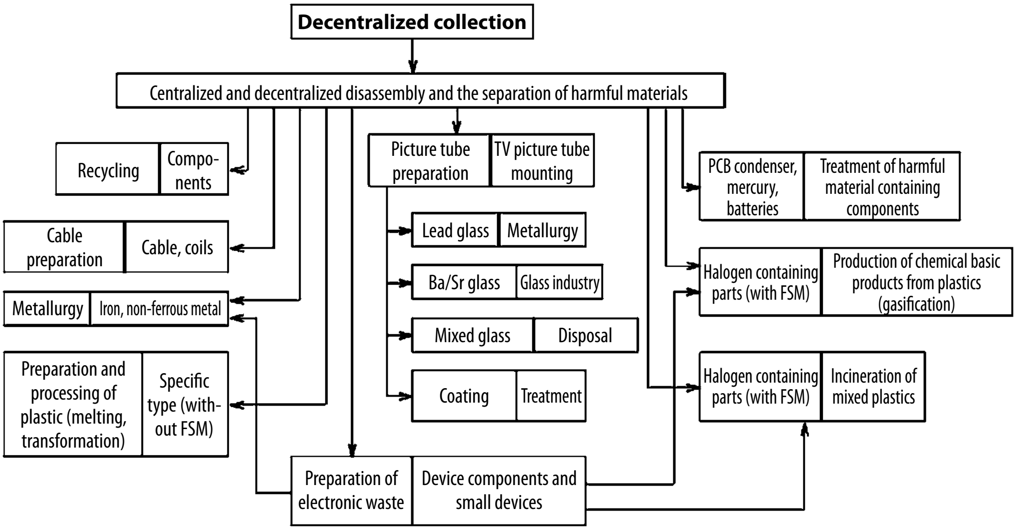


Figure I.5.21: Processing system for waste televisions *(Csőke et al. 2011)*

I.5.10. End-of-life vehicles

The global automotive industry produces more than 70 million motor vehicles per year, of which at least 20 million cars are manufactured in Europe. The majority of the motor vehicles are passenger cars, constituting 73% of all vehicles (in Europe this proportion is 85%, meaning 18 million passenger cars from the total 20 million).

An average motor vehicle includes more than 5000 parts and several structural materials. Due to the rapid exploitation of raw material and mineral sources and continuously-increasing environmental pollution – closely related to the amount of vehicle fuels consumed – the generation of more economic motor vehicles with smaller engines has gradually gained ground in the automotive industry. This is mainly achieved by the implementation of the principles of light construction during manufacturing.

However, this change leads to the use of more light metals and plastics, which are more difficult to recycle from an environmental point of view compared to traditional iron and steel materials. As a result they create new problems regarding their incineration and landfilling.

Depending on the living standards of the given country, passenger vehicles are typically used from 5-6 years to even 18-20 years, but then they become end-of-life vehicles, meaning that they become waste. After becoming waste, an average end-of-life vehicle can be regarded as a structural material complex of about 1000 kg from which about 70% is metal, 15-20% is organic material (plastic and rubber parts) and about 10% is made up of other inorganic materials (glass, textiles, etc.). These materials should be redirected back into the cycle of structural materials to the greatest possible extent (see Figure I.5.22). If end-of-life vehicles are unprofessionally handled, their fuels (oils, cooling agents and mediums, brake fluids, accumulator acids and antifreeze windscreen washing agents) are particularly liable to enter the natural environment and pollute living waters and the soil.

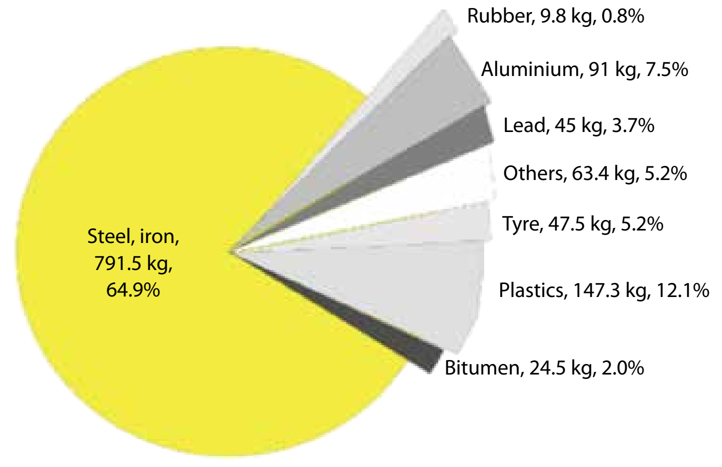


Figure I.5.22: Structural materials of cars *(Csőke and Nagy, 2011)*

I.5.10.1. Treatment and utilization of end-of-life vehicles

The professional treatment of end-of-life vehicles can be guaranteed only if they are forwarded to registered car scrapyard or waste management facilities. These actors remove fuels in an appropriate way, and treat them separately.

In terms of utilisation, the target value is 95% by 2015. The most important requirements for utilization are that structural materials (metals by type, plastics by type, paper, textile, glass, etc.) should be separated according to type for further processing and utilization.

The different components can be separated in three ways:

1 – selective disassembly, separating components by material type (carried out manually on a disassembly table or on a conveyor belt),

2 – selective mechanical separation after shredding,

3 – combined process, applying disassembly and mechanical separation at the same time or after each other (disassembly by units).

Separation usually consists of the following steps: shredding, classification according to component size, cleaning by washing, granulating, compacting, baling and briquetting.

The technology for pre-treatment includes the following main processes:

- shredding before separation (by a hammer shredder to a size of < 60 -100 mm) and separation using a magnet;
- classification according to size (by a drum screen);
- production of 3 density fractions using a dry or a wet method:
  < 2 kg/dm^3: plastic, rubber, wood, tar,
  2-3 kg/dm^3: glass, aluminium,
  > 3 kg/dm^3: heavy metals;
- aluminium recovery from the medium density fraction using electricity (eddy current or electrostatic type).

Parts remaining after disassembly which cannot be directly marketed are usually pre-treated by mechanical methods in so-called shredding facilities. The main goal is to create a pure final product, and – if possible – to avoid generating transitional products which have to be further cleaned, treated or disposed elsewhere, and to prevent environmental pollution that may be caused by them.

The biggest problem is caused by the remaining mixed waste, since the mixture of plastics, rubber and glass remains are difficult to use for any purpose. This amount is about 250 kg of mixed waste per car. Figure I.5.23 illustrates the disassembly processes of cars.

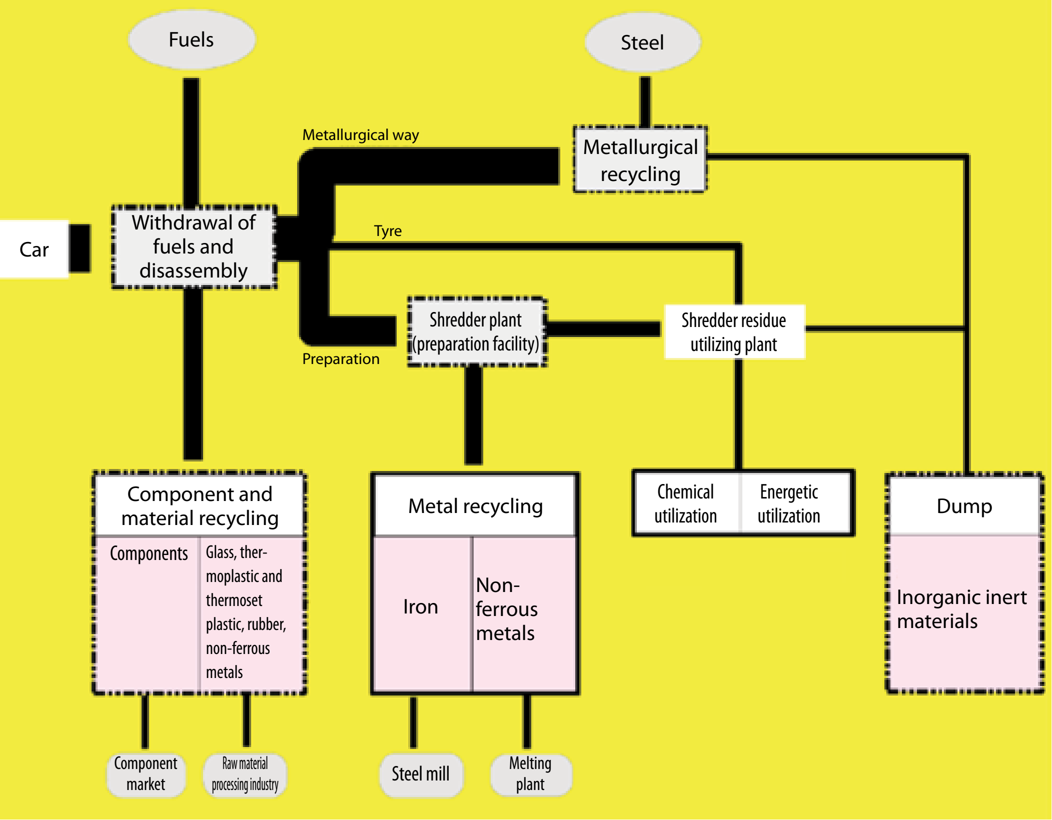


Figure I.5.23: The process of the utilization of cars *(Csőke and Nagy, 2011)*

I.5.11. Building-demolition waste

Building-demolition waste includes excavated soil, concrete debris, asphalt debris, waste wood, metal waste, plastic waste, mixed building-demolition waste and the waste of building materials of mineral origin produced during the construction of buildings by the building industry. Their composition refers to their sources of production (see Table I.5.6).

However, a significant fraction of all building-demolition waste ends up at municipal landfill sites. This is partly due to the fact that landfilling technologies require the disposeion of such wastes (for stability, providing access and other functional roads), but often these wastes are disposed only because of the existence of shorter transportation distances and lower transportation costs.

During the utilization of building-demolition waste, two cases can be differentiated between. In the first case, waste is used at the place of its generation, while in the second, it leaves the area of construction and becomes a product after a given treatment process (see Table I.5.7).

Name	**Composition properties**
Excavated ground	Natural mineral containing residues generated during building activities, which do not contain disadvantageously changing loose and hard stones.
	Their ratio is the highest among building wastes.

Building debris	Solid materials generated during the partial or total demolition of buildings, whose components are mostly of mineral origin, and building materials used in architectural and foundation engineering.
	Their composition greatly varies depending on the way of construction, the age and the function of the given building.
Road demolition debris	Solid mineral containing residues generated during road related building or demolition activities.
	Their components include concrete with hydraulical binder, bitumen bound materials, asphalts, slabs and border stones.
Mixed building-demolition wastes	Any mixed waste generated during the different building or renovation activities.
	Its major components are light materials (mostly paper, cardboard, foil, packaging materials, wood and plastic wastes, often paint residues, sometimes asbestos insulating materials) mixed with various debris of mineral origin. Usually, it is treated together with municipal solid waste. Most often it is collected and transported in containers.

Table I.5.6: Typical building-demolition waste *(NWMP, 2014)*

Processed waste	Source	Recycled product	Fields of application
Concrete debris	roads, bridges, industrial facilities	crushed concrete debris	Road foundations without a binder, panels for inferior roads. Cement-bound road panels. Agricultural roads, additive during concrete production, filling material, drainage layers.
Asphalt debris	roads	crushed asphalt debris	Upper road foundation without a binder, bottom road foundation. Road foundation with a binder. Agricultural roads. Additive during asphalt production.
Asphalt and concrete debris	roads, bridges, public domains pavements	crushed mixed concrete, asphalt, natural stones	Upper road foundation without a binder, upper road foundation with a binder, agricultural roads.
Building debris	buildings, industrial facilities	building sand, crushed building materials (brick content lower than 25%)	Stabilized bankings and foundations. Foundations of sports fields.
Brick debris	houses, buildings	building sand, crushed building materials (brick content higher than 25%)	Additive during the production of building blocks. Additive for concrete and light concrete. Stabilizations. Banking, foundation. Floorings.

Processed waste	Source	Recycled product	Fields of application
Mixed building debris of mineral origin	buildings, houses, industrial facilities	crushed building materials of mineral origin	Bankings, foundations, bottom layer of sports fields, drainage.

Table I.5.7: Utilized building-demolition waste *(NWMP, 2014)*

I.5.12. Hazardous wastes: oil, battery, accumulator, medical wastes, etc.

Hazardous wastes are a direct or a potentially enhanced danger to wildlife, people and also to the elements of the natural environment. Toxic, infectious, flammable, explosive, mutagenic (mutation causing), carcinogenic (cancer causing), teratogenic (causing developmental disorders), irritating, corrosive, etc. materials belong in this category. Hazardous wastes include, for example, dry batteries, accumulators, used oil, chemicals and their containers, waste medical tools, alkalis, acids, etc.

Although (hazardous) wastes that require special treatment are primarily generated during industrial and agricultural production and utilization activities (e.g. washing waters containing metallic salts, paint residues, acids, alkalis, oils, sludges containing heavy metals, pesticides, wastes of animal husbandry and slaughterhouse origin) such wastes are also produced in households, including, for example, bleach, accumulators, batteries, glue, medicines and paints, solvents, etc.

I.5.12.1. Oil wastes

The majority of this is oil from industry, used in machines and in vehicles. Large lubricant dealer companies have established and operate their own waste oil recollection systems, usually with the help of external companies, to carry out transportation, collection and treatment tasks.

In waste yards waste can only be collected separately; consequently, hazardous waste is collected also this way, including – among other types – household utensils, electronic wastes, dry batteries, accumulators, paint and varnish residues, cooking fat, pesticide residues, fluorescent lamps and bulbs, used oil and containers contaminated with hazardous materials.

In some member states of the European Union, the level of utilization reaches 60-70% of the amount of recollected oil wastes. The current utilization practice prefers energetic utilization instead of regeneration. Since, according to the principles of the waste hierarchy, utilization of material should precede energetic utilization, it would be practical to prefer the promotion of regeneration processes and technologies. This is also supported by regulation on the environmental product charge, since it can be reclaimed only in the case of utilization of material.

The possibilities for reusing waste oils include their utilization as lubricants or use as fuel oil. In both cases pre-treatment is necessary, primarily meaning the removal of contaminants by different filtering methods.

I.5.12.2. Battery and accumulator wastes

For batteries and accumulators, total take back is required by regulations. From 1st July 2009 take back should be offered at every retail unit that sells such electrical devices. Recollected batteries and accumulators shall be fully reprocessed with an efficiency of 50-75% depending on their type. Regarding the wastes of portable batteries and accumulators, the obligatory recollection target value is 25% by 2012, which should reach 45% by 2016 (the European Union directive defines collection proportions for the period ranging from 2008 to 2016).

The utilization of motor starting accumulators

In developed industrial countries, secondary lead covers 40-60% of lead demands. The average composition of used lead-acid accumulators is presented in Figure I.5.24.

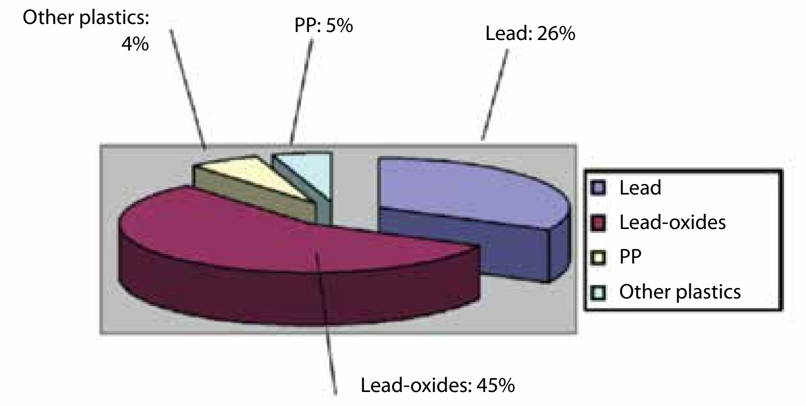


Figure I.5.24: The average composition of used lead-acid accumulators *(Csőke, 2011)*

The technology

The process for dealing with lead-acid accumulators consists of two main parts:
preparation:
- reception and feeding of the material,
- coarse crushing and deacidification,
- shredding and the separation of structural materials;

smelting:
- melting,
- refining and casting (see Table I.5.8).

Product	Reycling ratio (%)	Life cycle (year)
Accumulators - Passenger car - Truck - Fix installation	80 -90 ~ 100 ~ 100	3 - 4 5 - 6 5 -15
Plate	95 – 100	100
Pipe	70 -80	50
Cable covering	50	40

Table I.5.8: Recycling of lead *(Csőke, 2011)*

Preparation (Figure I.5.25): Accumulator waste is loaded from the collection vehicle to bunkers in the ground from where it is forwarded to the silo by an excavator. During these processes accumulators are crushed and the acid can be pumped out of the sump that is located at the bottom of the bunker. Then, an excavator loads the material onto a vibrating conveyor where iron is removed by magnets, and further sprinkling with water is carried out. For the next step waste is shredded in two phases: first a spiked roller pierces the boxes in order to remove the remaining acid, and then it is further shredded by a (rotary disc or hammer) mill. Then the chips that are produced are classified: paste is removed by a vibrator, and then is densified and filtered, while the coarsely screened refuse – bars, poles and plastics – are separated by a hydro-separator or a dense medium device (see Figure I.5.26). The removal of PVC from plastic waste is an important step in the separation process.

Smelting: This process consists of basic melting and cleaning melting. In the process of basic melting paste, dust returned from the screens, the light floating fraction from refining and slag are melted. During the process, slag-forming and reducing agents (sand, iron chips, soda and coke) are added. The necessary temperature is ensured by a gas burner using oxygen. Lead is drained and poured into metal dies below a suction hood, and then the blocks are forwarded for refining. During this process blocks, separated bars and coarse lead waste is refined. The complicated refining of lead (that involves many steps, typically used in metallurgy) is not necessary, since removing copper and antimony is usually sufficient. Then cleaned lead is cast into blocks. The final products of the technological process are lead blocks of the desired composition, while the by-products, including polypropylene chips, recovered alloys and iron waste can be further utilized. Unmarketable by-products and those regarded as hazardous wastes are disposed.

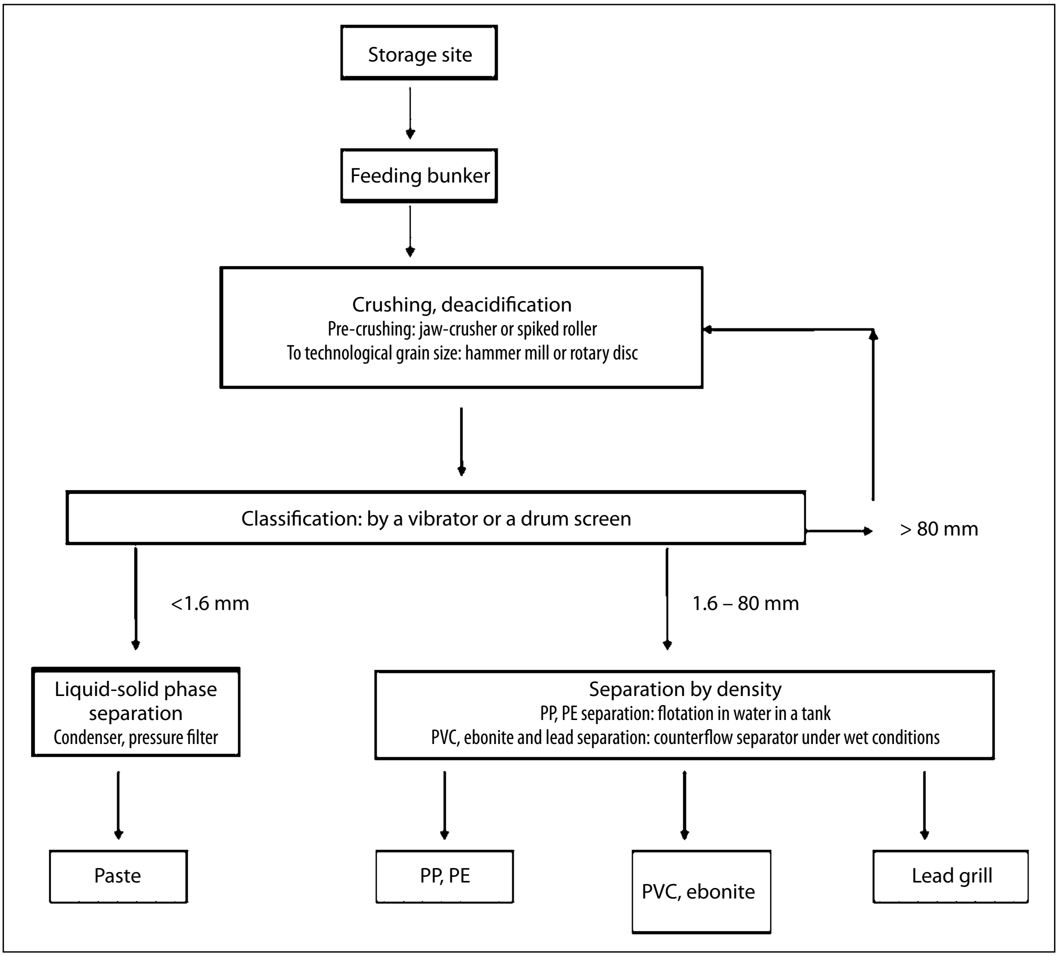


Figure I.5.25: Preparation of lead accumulators *(Csőke, 2011)*

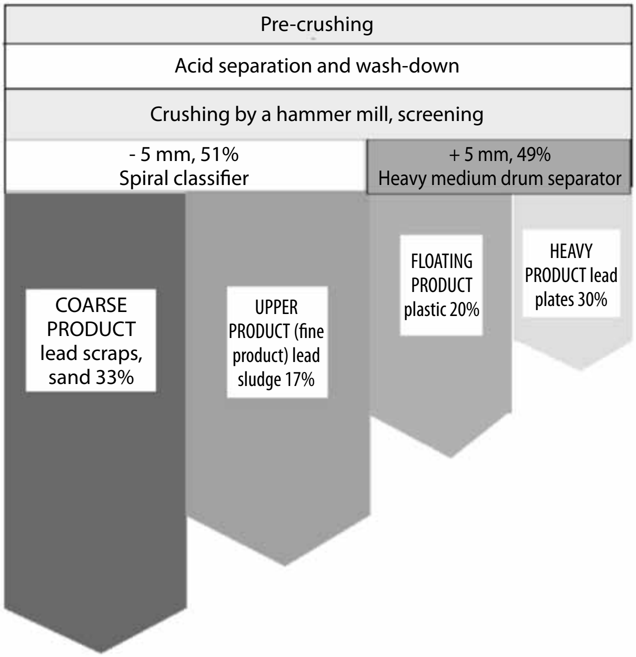


Figure I.5.26: Preparation technology for lead accumulators *(Csőke, 2011)*

Utilization of batteries

Main types of small-size batteries/cells

The main types of single use (non-rechargeable) household dry batteries/cells are the following:

- Carbon-zinc batteries/cells, used in small-size tools with a lower power demand such as torches, watches, razors and radios.
- Zinc-chloride batteries/cells, used similarly to the previous category.
- Alkaline manganese batteries/cells, used in tape recorders and walkmen. They are less prone to puncturing and leakage compared to the above-mentioned two types, and they also have a longer lifetime.

Button cells

- Mercury oxide button cells, used in hearing aids, pacemakers and cameras.
- Zinc-air button cells which are a type of mercury oxide button cells. They are used in hearing aids and pagers.
- Silver-oxide button cells, used in electronic watches and calculators.
- Lithium button cells, used in watches and cameras.

The general utilization of rechargeable dry batteries/cells is similar to that which takes place with the batteries mentioned above, with the addition of the small nickel-cadmium, nickel-metal hydride and lithium ion accumulators, which are used in larger capacity tools, cordless devices, mobile phones, etc. A few examples of the latter can be seen below:

- Nickel-cadmium (NiCd) batteries have been the fastest growing types on the market for rechargeable cells for a long time. They are used in high capacity cordless tools, walkmen, portable telephones, laptops, razors, motorized toys, etc. Their lifetime spans about 4-5 years.
- Nickel-metal hydride (NiMH) batteries are not as dangerous to the natural environment as NiCd batteries and their lifetime is also longer.
- Lithium ion (Li-Ion) batteries have a larger energy storage capacity than NiCd and NiMH batteries.

Figure I.5.27 shows the average composition of the batteries.

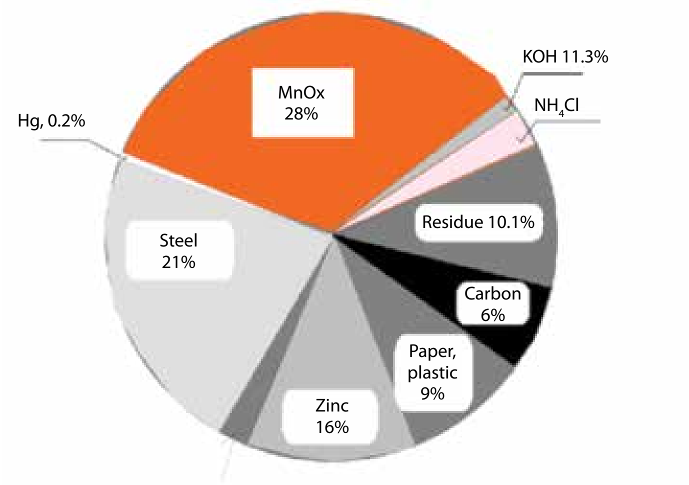


***Figure I.5.27: Composition of batteries** (Csőke, 2011)*

The processing-preparation technology of used batteries is usually based on a combination of mechanical, chemical and thermal methods (see Figure I.5.28 and Figure I.5.29).

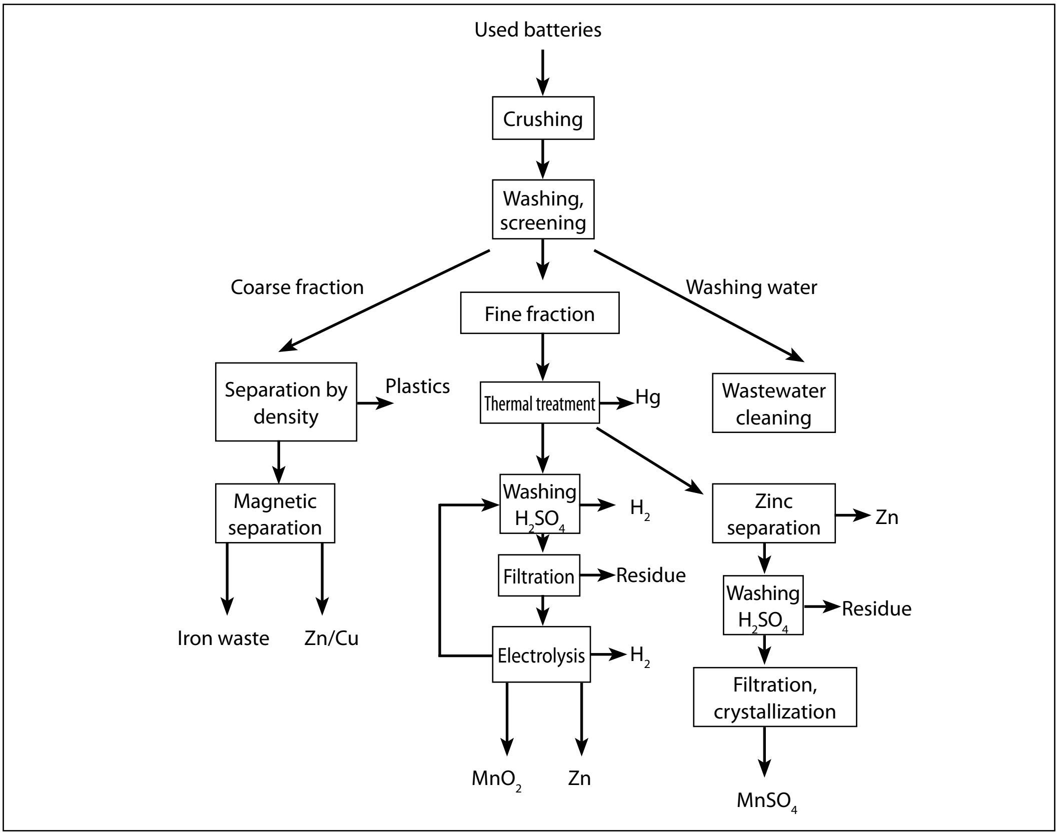


***Figure I.5.28: Preparation technology for used batteries No. 1** (Csőke, 2011)*

I.5.12.3. Medicine and medical waste

Medicine waste shall be separately collected from municipal waste using a closed system, and should be disposed of by thermal methods. The recollection and treatment of medicine waste is the responsibility of their producer, according to which public and branch pharmacies and shops that have a licence to sell medicine out of pharmacies take back medicine waste, and after their recollection transport them to waste incinerators.

According to widely-used practice, infectious waste is treated using two methods: 40-45% of it are disposed of by incineration, while 55-60% of this waste is sterilized using steaming technology, and then is either disposed as municipal waste (about 40%), or incinerated (about 60%). Lately, microwave sterilization has started to become popular. This refers to steaming sterilization where the steam is generated by the energy of microwaves. With the help of a magnetron, high voltage energy is converted into microwave energy, which warms up the waste, and converts its water content into steam.

The residues of waste incineration are slag, fly-ash and filter dust. Basically, these wastes are hazardous wastes which should be disposed without polluting the natural environment. The most common solution is to dispose of them at hazardous waste landfill sites, but embedding residues into cement and disposing them, or utilizing them after residues have been vitrified (glassification at high temperatures with the addition of agents) is also becoming more common. Glassification can be carried out in incinerators that operate using plasma technology.

The extractive treatment of solid incineration residues is also undertaken. This involves dissolving heavy metal pollutants out of residues using acids, this way mitigating or reducing to zero their hazardousness.

In the case of medical wastes the proportion of the utilizable fraction is very low due to the characteristics of the waste. The only exception is the silver-containing solution produced during the development of x-ray films from which silver can be economically recovered.

I.6. Thermal waste treatment

(Péter Simándi)

Treatment carried out at high temperatures is one of the possible methods for the utilization or disposal of organic wastes, or wastes mostly containing organic materials produced in huge amounts. Such treatment processes include:

- incineration,
- pyrolysis, and
- gasification.

Waste incineration is an exothermal process where oxidation is complete. It can be ensured through providing an appropriate amount of air ($\lambda > 1$).

Pyrolysis or cracking is an endothermic chemical process carried out in an environment lacking air or oxygen ($\lambda = 0$) with the help of an external source of heat. During this process waste is decomposed to simpler but more stable chemical compounds with lower molar weight. During the technological process, gas, liquid (tar, organic acids, oil, decomposition water, etc.) and solid final products are created. Final products are primarily utilized as energy sources, and they are partially used for heating the reactor, this way compensating for the heat used during the endothermic reaction. On the other hand, they are sometimes used in the chemical industry as secondary raw materials (e.g. during methanol production).

During gasification partial oxidation is carried out using a small amount of air ($\lambda < 1$). Through this process the highest possible amount of combustible waste material is transformed into energetically utilizable gas, and what remains is a small amount of coke or molten slag in the case of complete gasification.

I.6.1. Incineration

Incineration is a thermal method for disposing of wastes that is the focus of environmental research all over the world in terms of complex assessments of its numerous advantages and disadvantages. Judgements about waste disposal by incineration are not the same. It has both supporters and opponents.

The advantages of wastes incineration:

- a significant reduction in volume and weight (this way fewer material handling operation are required, and less landfill space and land area);
- the heat energy that is produced can be utilized, and its marketing is not exposed to the fluctuations in the market;
- during incineration wastes get mineralized and inertized, and the treatment is ideal from the perspective of hygiene;
- modern efficient incineration and flue gas purification technologies ensure the efficient protection of the environment.

The disadvantages of waste incineration:

- incineration causes secondary environmental pollution (air pollution, problems during the disposal of fly-ash and slag);
- it is ecologically unfavourable, since thermally-decomposed material leaves the natural cycle;
- investment and operational costs are significantly higher compared to traditional methods (compost, biogas, landfilling).

During incineration the organic material components of waste react with the oxygen content of the air, and become transformed into gases, mostly carbon-dioxide and water vapour, and leave the incineration system as flue gases. Non-combustible inorganic material becomes residue in the form of slag or fly-ash. Wastes of different composition and states of aggregation can be also incinerated.

For perfect combustion,

- appropriate temperatures,
- appropriate flow conditions,
- the retention time,
- and the feeding of enough air to exceed the stoichiometric level are required.

According to Decrees from the Ministry of Environmental Affairs on technical details and emission limits of waste incineration, incineration facilities shall be planned, developed, built and operated in a way that the temperature of gas produced during the combustion process shall reach 850°C for at least 2 seconds of retention time at authenticated and predefined points in the combustion chamber (as defined by the environmental protection authority) even under the most unfavourable conditions after the last injections of combustion air, through the application of proper control and homogenization. During the combustion of waste that contains more than 1% organically bound halogens (expressed in chlorine units) the temperature shall reach 1100°C for at least 2 seconds of retention time. In the case of complete oxidation combustion technology, waste is intensively mixed with combustion air that exceeds the stoichiometric air demand by 1.5-2.5 times, and is oxidized with a combustion efficiency (CE) of 90 - 99.99% (see Figure I.6.1).

$$\boxed{\text{CE}} \quad \text{EH} = \frac{CO_2}{CO_2 + CO} \text{x} 100$$

The combustion efficiency (CE) indicates the efficiency of oxidation carried out in the combustion chambers or furnace cavities through the proportion in the gas mixture of carbon-dioxide and carbon-dioxide-carbon-monoxide that leaves at the end of the process.

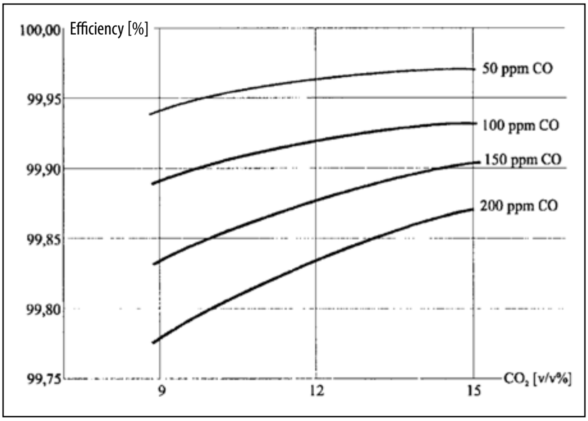


Figure I.6.1: The efficiency of combustion at 50-200 ppm CO content according to the CO_2 content of the flue gas *(Zimler, 2003)*

During the combustion of hazardous wastes, the minimum requirement is that the efficiency of combustion reaches a level of CE = 99.9%. In addition, there is a further requirement for the efficiency of decomposition (DE). DE can be calculated by recording the mass flow of material that enters the combustion chamber and that which leaves it unchanged:

$$\boxed{DE + G_{in}, G_{out}} \qquad LH = \frac{G_{in} - G_{out}}{G_{in}} x100 = \left(1 - \frac{G_{out}}{G_{in}}\right) x100$$

G_{in}: the mass flow of main hazardous organic components entering the system;
G_{out}: the mass flow of material emitted into the air through the flue gases of the incinerator;
G_{in}-G_{out}: the difference between the mass flow of main hazardous organic components decomposed (burned + separated) in the incinerator.

The efficiency of decomposition is dependent on the whole combustion technology and it is a factor which is very difficult to measure. Usually, it is defined for the most stable chemical compound that is burned, or for the component with the lowest emission limit (e.g. 99.9999% elimination in the case of dioxin). For hazardous wastes, the required efficiency of decomposition is achieved in the post-combustor by ensuring the correct waste retention time (see Figure I.6.2).

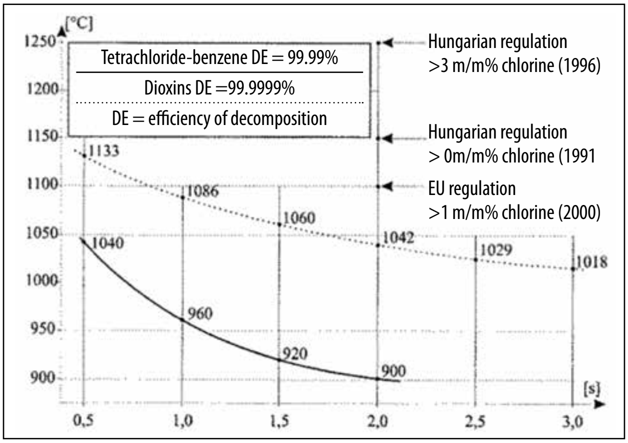


Figure I.6.2: The decomposition of dioxin and tetrachloride-benzene *(Lábody, 2003)*

It can be clearly seen in the figure that the combustion temperature and the time necessary for combustion are inversely proportional, and do not have a linear relationship. Also, the concentration of materials influences the speed of the reaction. At the beginning of combustion, the concentration of combustible material and oxygen is high in the combustion zone, oxidation takes place rapidly, and many reaction products are generated. In the post-combustion chamber the concentration of combustible gas and oxygen decreases in the flue gas and the process of combustion slows down. The injection of secondary air increases the concentration of oxygen, this way speeding up the combustion reaction and improving upon the efficiency of combustion and decomposition.

During the combustion of waste with a low calorific value, the specified temperature – usually about 850°C – shall be provided by a supporting burner running on natural gas or oil fuel. It is required during the working and the operation of combustion chambers that the total organic carbon (hereafter TOC) content of the slag and the furnace cavity ash shall be lower than 3% at the end of the combustion process, or ignition losses shall be less than 5% of the dry weight of the above-mentioned residual material. For this end, appropriate waste pre-treatment methods should be used where necessary.

Flue gas still containing combustible gas and a volatile fraction at a level of 5-10% is fed into the post-combustion chamber, where combustion is completed at the desired efficiency. The flow of gas slows down in the post-combustion chamber, and – despite the mixing of secondary air injected at high speed – turbulence decreases. The specified temperature – usually 850°C or 1100°C – can be guaranteed only by supplementary firing based on oil or natural gas. Since the level of turbulence is different at different points of the combustion chamber, its local value cannot be calculated. The dimensionless Reynolds number (Re) provides information about how the flue gas viscosity experienced in a given combustion chamber at a specific temperature changes the speed of the gas, and at what level turbulence will occur.

$$R_c = \frac{v \times d}{\nu}$$

V = flow velocity [m/s]
d = diameter of the combustion chamber [m]
ν = kinematic viscosity of the flue gas [m^2/s]
(The viscosity of flue gas containing 12% of water vapour is 2.317×10^{-4} [m^2/s] at 1200°C.)
$R_e > 50\,000$

The critical value under which the flow stays linear is Re = 2 320. Although above Re = 10 000 flow becomes turbulent for sure in the combustion chamber, it is advised that Re should not exceed 50 000 in spaces where total oxidation is occurring. In combustion chambers with corners, laminar flow may develop in the corners even at such a value. This may lead to high levels of CO. In a micro environment local turbulence may be developed due to the occurrence of chemical reactions that lead to changes in volume (e.g. the oxidation of carbon-monoxide to carbon-dioxide).

Proper flow conditions can be ensured either by mechanical tools (moving grates, rotary furnace, stoker devices) or by aerodynamic methods (directing the moving flows of gas).

For most waste incinerators the temperature of the combustion chamber does not exceed 1050-1100°C due to the softening-melting characteristics of inorganic residues (slag, fly-ash). If combustion is undertaken at a temperature of 1200-1700°C, this is called slag melting waste incineration. In this case, solid residue is melted and leaves the combustion chamber as melt. During combustion the amount of solid residue depends on the amount of waste burned. In the case of municipal solid waste the amount of residue is about 10 v% or 30-35 m% (for slag melting combustion it may reach 15-25 m%), while during the combustion of liquid and sludgy wastes it is only 2-10 m%.

Information necessary prior to thermal disposal of wastes:

- state of aggregation (fluid, paste like, solid, mixed);
- chemical composition as determined by elemental analysis (carbon, hydrogen, oxygen, nitrogen, sulphur, water and ash content);
- composition determined by fast analysis (fixed carbon, volatile material, water and ash content);
- calorific value;
- density;
- the melting characteristics of ash;
- grain size distribution, maximum grain size and composition by material type in the case of solid waste;
- viscosity, ignition point and flash point, solid contaminant content and its maximum particle size and chemical effect in the case of liquid waste;
- halogen material content (chlorides, fluorides, bromides);
- heavy metal content (lead, cadmium, mercury, copper, vanadium, etc.);
- other metal content (iron, calcium, sodium, etc.);
- other toxic material content (PCBs);
- other specific material characteristics, if necessary (e.g. infectious characteristics, temperature, etc.);
- quantitative data (minimum, maximum and average values).

From the perspective of combustion technology, it is primarily calorific characteristics that are of great importance (calorific value, combustible material content, water content and ash content). These features are not independent of one another since they are closely related. Calorific value and combustible material content affect the thermal loading of combustion systems, processing capacity, the necessity for additional firing and the possibility of heat utilization. Water content affects the amount of necessary additional fuel and the quality of flue gases that are produced (dew point).

I.6.2. Pyrolysis

Cracking (pyrolysis) is the controlled chemical decomposition of waste containing organic materials by heat under lower-oxygen or anaerobic conditions – sometimes with the injection of an inert gas (e.g. nitrogen) – carried out in a properly-constructed reactor. As a result of this process, waste is decomposed to simpler but more stable chemical compounds with lower molar weights.

During cracking the following materials are produced from organic waste:

- pyrolysis gas;
- liquid product (oil, tar, decomposition water containing organic acids);
- solid final product (pyrolysis coke).

Their composition, proportion and amount depend on the composition of the treated waste and the operational conditions and structure of the reactor. The final product is primarily used as an energy source (fuel gas, fuel oil, coke) or sometimes as secondary raw material in the chemical industry (e.g. by converting the gas product into synthesis gas for methanol production), while at other times it is used for various purposes (soil amelioration for solid residues rich in carbon; wood preservation for aqueous residues; granulated slag melt as an additive in the building industry, etc.).

The conditions for the chemical conversion reactions are decisive during the process of cracking. Primary factors include temperature, heating-up time and reaction time, grain and piece size, the proportion of mixing and its efficiency. The temperature basically determines the composition and the proportion of the final product. Heating-up time depends on the characteristics of heat exchange and also affects the composition of products.

Pyrolytic processes work across a wide range of temperatures:

- low temperature pyrolysis: 450-700°C;
- high temperature pyrolysis: 700-1100°C;
- gasification: 800-1100°C;
- gasification with molten slag: 1500-1700°C.

Depending on the method of heating, reactors can be operated by:

- indirect (through the reactor wall or with the help of a circulating medium) or
- direct heating methods.

In the case of directly heated reactors, pyrolysis and partial combustion provide heat energy and are carried out in the same space. On the one hand, heat transfer through the reactor wall occurs at a poor level of efficiency, and such reactors are also susceptible to the quality of the fireproof walling, but they can be simply operated and regulated well on the other. Heat transfer through a circulating medium is fairly efficient, but such as system is more complicated to operate.

The best heat transfer conditions can be achieved by using the direct heating method, but in this case the carbon-dioxide, water and nitrogen-oxide content of gas products increase, and it is also more complicated to regulate the process. Depending on the relative direction of the flow of material processed in the reactor and the parallel current of pyrolysis gases, countercurrent and cross-flow methods can be identified. The direction of flow is an important factor and affects the difficulty of gas purification.

Solid residues can be processed in different ways after water bath separation (production of activated carbon after the removal of inorganic residues and then its direct burning, etc.).

For the separation and the purification of products that are in a gaseous state or in the form of steam a huge variety of gas purification and gas-steam separation methods and their combinations are used (e.g. cyclones, electrofilters, gas washers, post-combustion chambers or cracking reactors).

Pyrolysis is a complex mixture of physical and chemical subprocesses. Cracking methods are extremely complicated, but are very economical at the same time: their greatest advantage is that the resulting products are marketable aliphatic and aromatic hydrocarbons, and their impact on air pollution is significantly lower than that caused by waste incineration.

Disadvantages:

- requires enhanced preparation of materials;
- gas purification is more complex and more complicated than the purification of flue gas produced during combustion;
- washing water is heavily contaminated, and requires complex cleaning processes;
- the chance that imperfect combustion products that can only be degraded with difficulty will be created is quite high. For this reason energetically utilizable gas can be burned only at extremely high temperatures.

Low and medium temperature methods have been developed for the processing of specified product groups (e.g. plastics, waste tyres, production waste) in order to recover raw materials (see Figure I.6.3 and Figure I.6.4). High temperature technologies are primarily suitable for the processing of communal waste, and final products can be used for energy production.

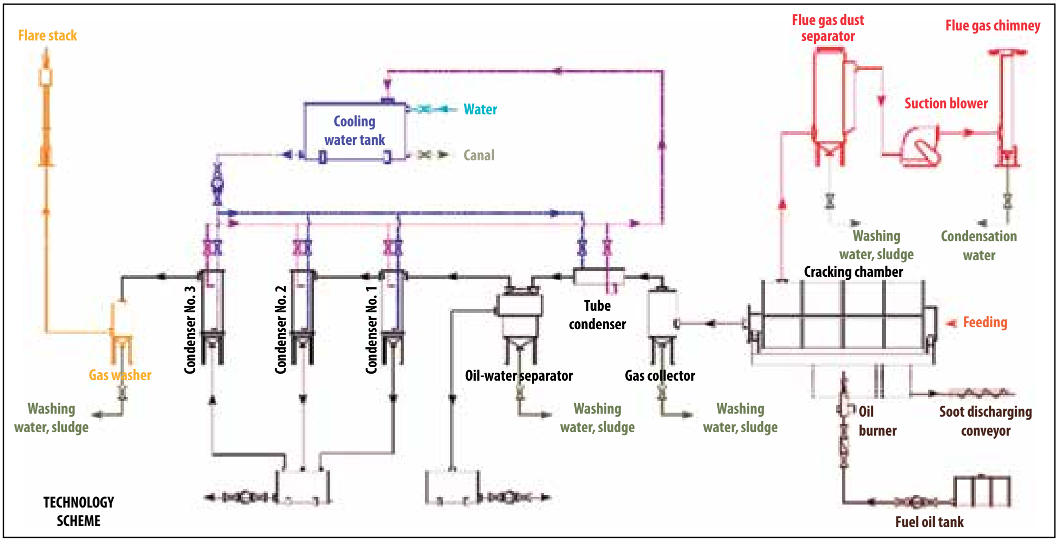


Figure I.6.3: Flowchart of a low temperature pyrolysis technology (Environ-Energie Ltd.)

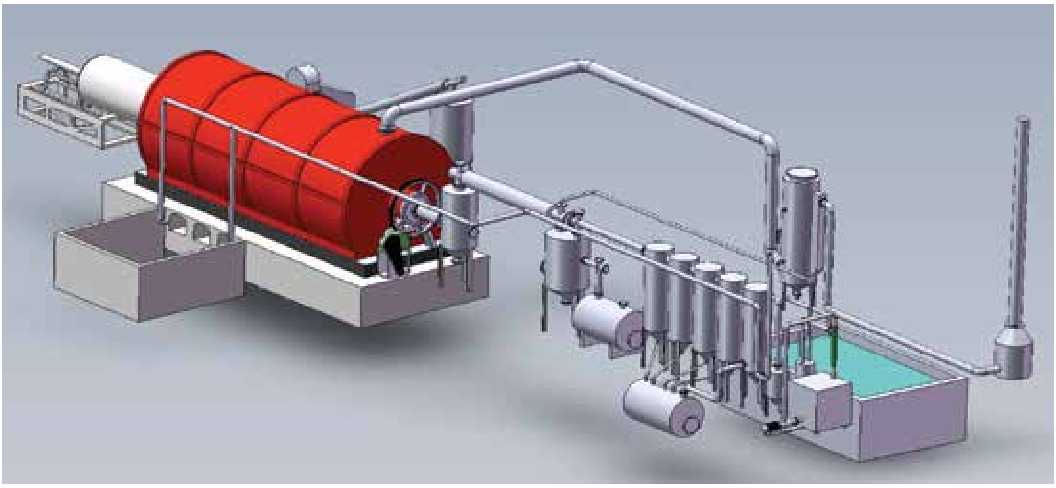


Figure I.6.4: Three dimensional view of low temperature pyrolysis equipment *(Environ-Energie Ltd.)*

Pyrolysis is the first phase of the processing of wastes. If it is designed to recover raw materials to be further transformed by chemical technologies into final products then it can be regarded as a chemical industry sequence of operations as a whole, and it can be categorized as waste recycling. If the final products (oil, combustible gas) are to be energetically utilized, then they go through a complete oxidation process (that is, they get burned) during the final phase of the process.

I.6.2.1. Typical chemical processes in pyrolysis

- Low temperature cracking is carried out at a temperature of 450-600°C. The final product is low-temperature carbonization oil, low-temperature carbonization tar and a high carbon content solid residue. Little gasification occurs.
- During medium temperature pyrolysis (between 600-800°C) the proportions of oil, tar and solid residue significantly decrease, while the proportion of gaseous products increases. Aromatic hydrocarbons and benzene derivatives are produced, and the process of thermal cracking becomes more intensive.
- High temperature cracking is carried out at above 800°C. Between 800°C and 1200°C short-chain hydrocarbons (mostly methane) are produced during the process of thermal cracking, and due to the huge amount of hydrogen released, water gas is produced and a final solid product is created: graphite.
- If the solid waste also contains organic materials, between temperatures of 1200°C and 1700°C they will soften and fuse and silicates will be created, while metal oxides will be reduced.

I.6.3. Gasification

Partial oxidation is carried out by using little air and a quantity of air of $\lambda<1$. During the process, raw gas (that requires later purification) and molten inorganic residue are produced. A gasifying medium containing water vapour, oxygen or carbon-dioxide is used in the process. If possible, the total combustible material content of the waste is converted into combustible gas during gasification and this can be energetically utilized: all that will remain is a small amount of coke or molten slag in the case of complete gasification. The special process called "hydrogenization" belongs to this category. During this process the organic material content of waste is mostly converted into oil and tar and a relatively small amount of gaseous and solid final products in the presence of CO under high pressure (70-450 bar) and low temperatures (250-450°C) in an aqueous medium.

I.6.4. Plasma jet firing

During cracking with a plasma jet, gases or gas mixtures heated up to high temperatures are used. Cracking can be a pyrolytic process when waste is broken into its components (N_2, CO, HCl, etc.), but it can be also an oxidation process, similar to combustion. Plasma, produced by a plasma generator, is developed by heating up gases or gas mixtures that are lead through an electric arc that is generated between two electrodes to a high temperature. Figure I.6.5 presents the schematic layout of an internal electrode plasma generator.

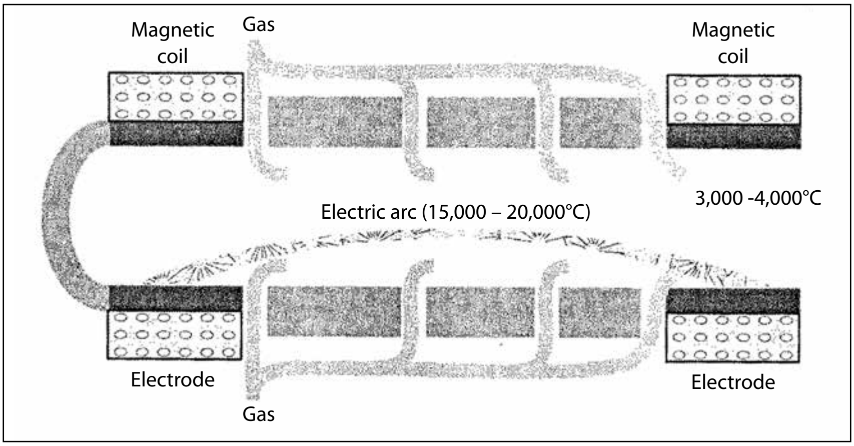


Figure I.6.5: Layout of a plasma generator *(Lábody, 2003)*

Gases containing both ionized atoms and electrons are called plasma. It is characteristic of the plasma state – often referred to as the fourth state of aggregation – that it can be maintained only at high temperatures. If we heat up a gas, then the molecules in the gas start to dissociate (meaning split into atoms) at a temperature of about 2000°C. At above 3000°C some of the gas atoms lose their electrons and become ions. This leads to a plasma state which is a mixture of free electrons, positive and negative ions and neutral atoms that result from disintegration.

The electrical energy of the high-voltage (greater than 1000 V) electrical arc at thousands of A of current intensity which is created between the two electrodes of the plasma generator is transformed to heat energy of 15 000 - 20 000°C and heats up the plasma-forming gas to the required temperature of 3000 - 10 000°C. For example, for the breaking of stable chlorinated chemical compounds – such as polychlorinated biphenyls (PCBs) – that are difficult to dissociate, slow relative burning at high temperatures in an air plasma flame of 5000-8000°C is used, while for the pyrolyization of easily-degradable wastes using plasma with a lower temperature level of 3000 - 5000°C will suffice.

Plasma forming gases can be:

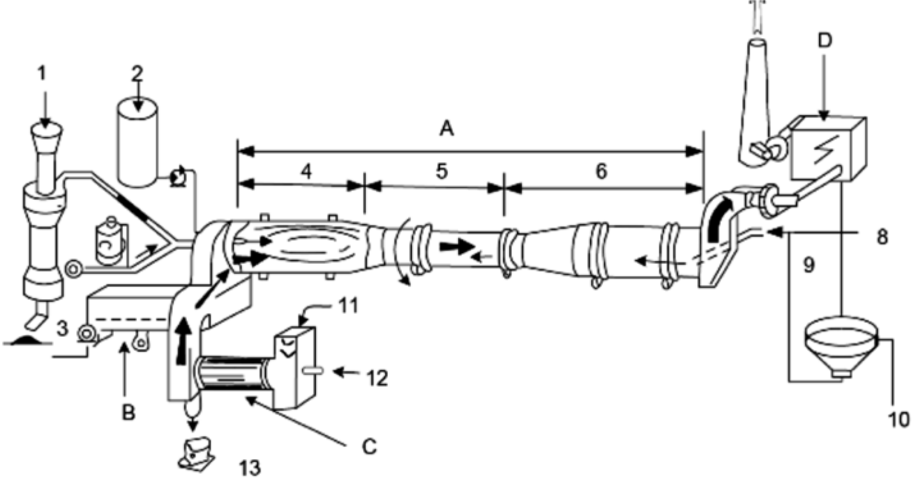
- neutral – e.g. argon, nitrogen, carbon-dioxide, helium, etc. – for pyrolytic breaking;
- oxidative gases – oxygen, air – for oxidative combustion in the cooling recombination phase;
- reducing gases, e.g. hydrogen, carbon-monoxide, etc.; such gases are used in the metallurgical industry for the recovery of metals from their ores and for the melting of metal wastes (mostly metallurgical flying dusts).

If gases are cooled, they return to their atomic and then molecular states again; that is they recombine. But these gases may be different ones, containing totally different molecules than their initial chemical compounds. After pyrolytic cracking, combustible gases, such as carbon-monoxide, methane, propane, etc. can be also produced. During oxidative cooling processes carbon-monoxide, water vapour, nitrogen, hydrochloric acid, oxygen, sulphur-monoxide, etc. can be produced. The advantage of this method is that the volume of gas is only 30-40% of the gas produced in traditional incinerators. This gas practically contains no dioxins or furans and its nitrogen-oxide content is also low. The efficiency of decomposition is greater than DE = 99.999 996%, but it may even reach 99% to the 9th place. Figure I.6.6 illustrates the technology of a liquid halogenated waste plasma jet facility.

I.6.5. Incineration in high temperature industrial technologies (co-firing)

For technologies with a high energy demand, some of the fossil fuel can be substituted by using combustible waste, making operations much cheaper. In practice, co-firing of waste is usually undertaken in industrial energy-producing boilers and in the clinker furnaces of the cement industry. The cement industry primarily burns waste tyres.

According to the law, the co-firing of waste shall be licensed only if firing or co-firing is designed to produce electric or heat energy or is used for cement, brick, tile or ceramics production in the building industry. Only wastes which cannot be utilized in other materials should be fired or co-fired in waste incinerators or waste co-firing facilities. Hazardous wastes can be burned exclusively in hazardous wastes incinerators.



A – clinker furnace; B – clinker cooler; C – pre-furnace of pyrolysis; D – electrofilter
1. primary fuel; 2. secondary fuel (liquid waste); 3. clinker removal; 4. sintering zone; 5. calcination zone; 6. drying zone; 7. flue gas exit; 8. raw sludge; 9. removed dust;
10. water; 11. solid waste; 12. pastelike waste; 13. slag removal

Figure I.6.6: The co-firing of waste in a clinker furnace *(Árvay, 1992)*

I.7. Landfilling of wastes

(Mátyás Hartman, Péter Simándi)

The disposal of wastes represents the final stage of waste management, during which materials which cannot be further utilized under current economic-technological conditions are stored on or in the ground.

The environmental impacts of landfill sites

For a state-of-the art landfill site, three phases can be identified regarding the environmental impact: planning-licensing and construction, active filling (when the landfill site is receiving waste), and closing down (recultivation).

An operating landfill site has the following impacts on the natural environment:

- air pollution caused by traffic (transportation);
- dust, deflation;
- creation of leachate;
- noise pollution;
- surface water runoff;
- release of gases and odours;
- presence of birds, insects and worms;
- destruction of landscape.

Closed down landfill sites also create environmental impacts through leaving leachate, releasing gases and contaminating vegetation. This is why, by law, they have to be continuously monitored for 30 years after closure.

I.7.1. Processes that take place at landfill sites

Waste that enters landfill sites is extremely heterogeneous both in terms of its physical and chemical nature (size, form, weight, volume density, composition, water content, reactivity, etc.). This heterogeneous material is the starting point of a long homogenization process during which the material goes through mechanical, physical-chemical and biochemical transformations.

I.7.1.1. Mechanical processes

Mechanical processes include the mechanical stress (bending, cracking, breaking-up, shearing, compaction, etc.) created by waste consolidation, settling and surface movements. The consolidation of waste does not only refer to compaction processes caused by mechanical loading (the effect of its own weight), but also the result of decreases in volume often caused by the chemical-biological decomposition of the different compounds. The pace of settling usually slows after some time. In the initial phase, settling through its own weight is dominant (primary consolidation) and usually amounts to reductions of 5-30% of the thickness of the layer. The majority of settling takes place in the first year after filling.

Primary consolidation is followed by secondary consolidation: a long-term process that greatly depends on the processes that take place inside the waste. Deformation that occurs in the landfill site has to be taken into account during the sizing and development of both the final insulation system and the gas collection system.

Mechanical parameters

The density of waste

- Actual density of waste: the weight of waste per unit volume.
- Effective waste density: the total weight of waste and the covering material per unit volume.

The density of municipal waste varies greatly depending on the composition, water content and the level of decomposition of the waste, the thickness of waste that is added on a daily basis, the proportion of compaction and the depth of the landfill site, etc. (see Table I.7.1).

Waste component	**Density without compaction kg/m^3**	**Water content %**	**Ratio of compacted and uncompacted waste**	
			Normal compaction	**Intensive compaction**
Kitchen waste	128-480	50-80	2.9	3.0
Paper, cardboard	32-128	4-10	4.5	6.2
Plastics	32-128	1-4	6.7	10
Textile	32-96	6-15	5.6	6.7
Rubber, leather	96-256	1-12	3.3	3.3
Garden waste	64-224	30-80	4.0	5.0
Wood	128-320	15-40	3.3	3.3
Glass	160-480	1-4	1.7	2.5
Metal	48-1120	2-6	4.3	5.3
Ash, slag, dust	320-960	6-12	1.2	1.3

Table I.7.1: The physical parameters of some waste types *(Szabó, 1995)*

For well-operated landfill sites, the thickness of the different layers is about 0.5-0.7 m; accordingly, a volume mass of about 500-600 kg/m^3 can be achieved through compaction, on average. For thicker layers, only lower density layers will be created. The density of raw waste usually ranges between 150-300 kg/m^3, but in the case of light compaction this reaches 350-500 kg/m^3, while during heavy compaction this may be 800-1000 kg/m^3. With the help of some special methods, a density of over 1000 kg/m^3 may be created.

Parameters that greatly depend on density:

- e_0- porosity coefficient: For well compacted waste, this value is 1; without compaction it can be a maximum of 15.
- water content (water content per unit volume expressed in %): this can reach 10-15% in the case of loose wastes, while with well-compacted wastes it may reach 40%.
- water retentivity: the maximum water content which can be absorbed by the waste without gravitation filtration occurring.
- adsorption capacity: the difference between water retentivity and water content. Municipal solid waste can absorb water at levels of up to 140 l/m^3 and reach a maximum value at a density of about 600-800 kg/m^3.

The "particle distribution" of waste

The particle distribution characteristics of waste are fairly important parameters since they have a primary role in determining the relative surface. The characteristics of those components with a higher quantity in the waste are of great importance. For example, the presence of an ash fraction below 16 mm will greatly affect leaching processes, consolidation and the water balance of waste, while a larger size (e.g. paper) fraction and/or kitchen waste has a fairly important role in water storage and can significantly affect primary consolidation processes.

Solidity parameters

The level of consolidation (density) of the waste directly affects hydraulic and mechanical parameters, including, for example, shear resistance and compression parameters.

- internal angle of friction (φ): 25-26°
- cohesion (c'_{max}): 30 kPa

The loadability of waste

The loadability of waste is not significant even in the case of systematic disposal. It can range between 25-100 kPa. It is considered advisable to not exceed 25-40 kPa during sizing.

Slope stability

Filling slope stability is a crucial issue. Although a relatively high slope angle of 60° in the case of dry landfill sites may be permissible due to the low volume mass of the waste, a minimum safety slope ratio of 1:3 should be observed because of the risk of unfavourable events (high pore water pressure, gasification, etc.) occurring during sizing, and due to potential change in cohesion. Consequently, is generally accepted that a slope angle of a maximum 30° should be created.

I.7.1.2. Physical-chemical processes

Washing-out, leaching

Washing-out processes that take place at landfill sites can be physical or chemical, but they are closely related to each other. Besides the migration of particles caused by the movement of water, chemical reactions also take place. The two processes are balanced by the dynamic and chemical features of water.

Erosion is one special type of physical washing-out, and can include:

- external (surface) erosion: here, the transporting medium is rainwater that runs off the surface,
- internal erosion: linear erosion increases the pore space within the internal structure of the waste,
- contact erosion: erosion processes develop at the borderline of components with different particle sizes.

During washing-out only waste particles that are under a certain size are moved by flowing water. Similarly to erosion, this process can refer to:

- external washing-out ,
- internal washing-out ,
- contact washing-out .

Chemical wash-out (or leaching) is one of the most important processes that occur with porous wastes regarding the transport of materials. It refers to the process by which organic and inorganic chemical compounds are released from the waste complex by water leakage that enter the ground water. The migration potential of contaminants primarily depends on their solubility, but other thermodynamic factors (e.g. adsorption coefficient) and the charge of the diffusing particles also affect the migration of materials.

Adsorption

During the process of adsorption chemical substances become fixed on the surface of some kinds of material particles. As a result, the contaminant concentration of leachate becomes diluted. In contrast, during adsorption ion replacement phenomena the composition of leachate changes due to the replacement of ions. The degree of adsorption depends on the physical and chemical characteristics of the adsorbent (its relative surface, quality of surface functional groups, number and type of active centres, etc.), the features of the adsorbing substance (water solubility, polarity, functional groups, ionic state), the pH of the environment and other chemical characteristics. In terms of adsorption, materials such as glass, plastics, rubber, some metals, ceramics, etc. are not affected due to their surface charge states, particle size and particle structure.

Diffusion and dispersion

Diffusion and dispersion are mechanisms during which the contaminant concentration of the leachate that is produced is altered. With diffusion the ions and molecules of the leachate develop a new state of balance through transportation processes. During dispersion, different dispersal systems are developed.

Filtering

During filtering some components of the leachate that are moving in a downwards direction get stuck in the waste and stay behind in accordance with physical laws of nature. Filtering may stabilize through the gravitational movement of water until it slows down or stops entirely due to the narrowing or the blocking of pores.

Precipitation

Chemical precipitation is a process that leads to changes in phase or material exchanges between existing phases during which dissolved chemical components crystallize out from solution because their total concentration is greater than the solubility limit. The process depends on the pH, the redox potential, the temperature and the concentration of ions.

I.7.1.3. Biochemical processes

Disposed material is transformed due to environmental impacts and the consolidation of the waste mass. Transformation refers to a disintegration and decomposition process that is affected by the atmosphere (the presence or lack of oxygen), the amount of precipitation that falls on or enters the dump, the water content, composition and homogeneity of waste, the height of the storage yard, the development of the site and the activity of microorganisms. External temperature changes only affect the upper layers, since in the deeper ones the temperature is defined by biochemical reactions.

Biochemical processes take place only with the organic compounds of waste. Although the amount of disposed organic materials will continuously decrease, there is still a relatively large volume of it: consequently, the issue of the biochemical processes that take place in landfill sites has to be dealt with. Organic materials decompose under aerobic or anaerobic conditions with the help of microorganisms. These conditions define the speed and temperature of such processes. Some materials decompose easily, such as proteins, fats or carbohydrates, while others are hard to degrade, such as cellulose, lignin, wax, resin, etc. Since in landfill sites anaerobic processes are dominant, landfill gas, decomposition residues (biomass) and leachate are produced.

I.7.2. Degassing

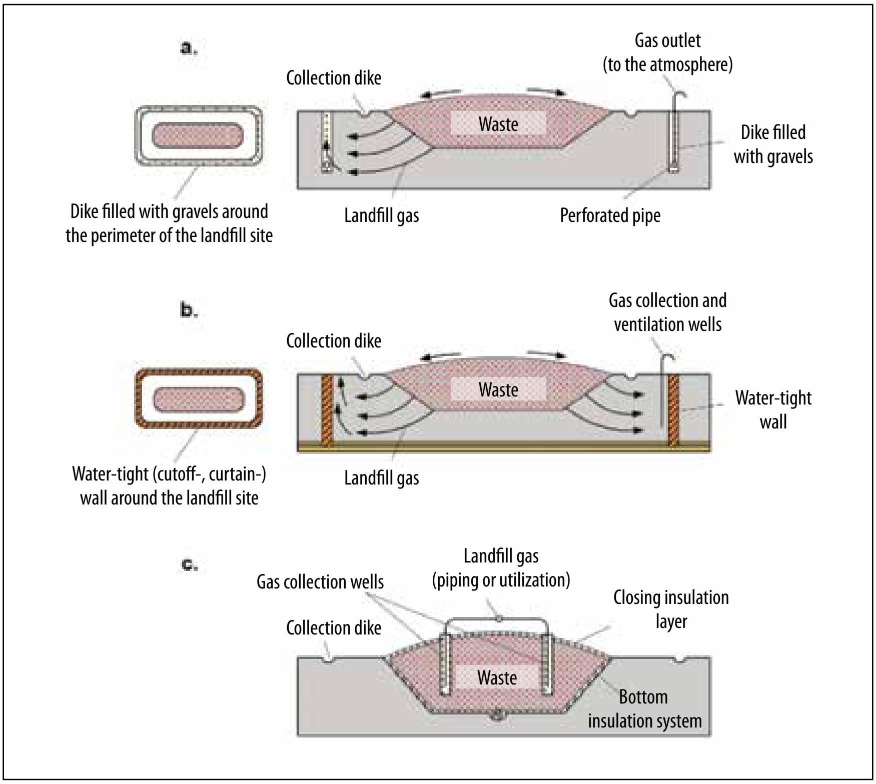
Ongoing monitoring and control of gasification and degassing are basic requirements for the correct operation of landfill sites in order to prevent the release of landfill gas into the natural environment (atmosphere and soil) (see Figure I.7.1).

Figure I.7.1: Pool with gas wells

The controlled collection and removal of any gas which is produced is important, because:

- a gas burst may happen at the landfill site;
- gas leakage may destroy surface vegetation, this way significantly increasing the danger of erosion occurring on the recultivated surface;
- it may have a toxic effect;
- long-lasting gas emissions may endanger the health of surrounding residents;
- it may have a bad odour;
- the methane that is produced forms an explosive mixture if mixed with air;
- the gas is a potentially cheap source of energy, therefore it is practical to collect it.

Gas monitoring and degassing systems can be active or passive. In the passive system the natural pressure of gas that is produced creates a flow of gas, while in the active system a vacuum has to be created artificially to remove the gas. The passive method can be used only if both methane and carbon-dioxide are produced in large amounts. The difference between pressure and diffusion drives methane to the air, out from the landfill site. Vertical shafts, dikes and layers filled with sand or gravel transport methane to the lowest level. Placing perforated pipes below the vertical or the covering layer is an efficient method for doing this (see Figure I.7.2).

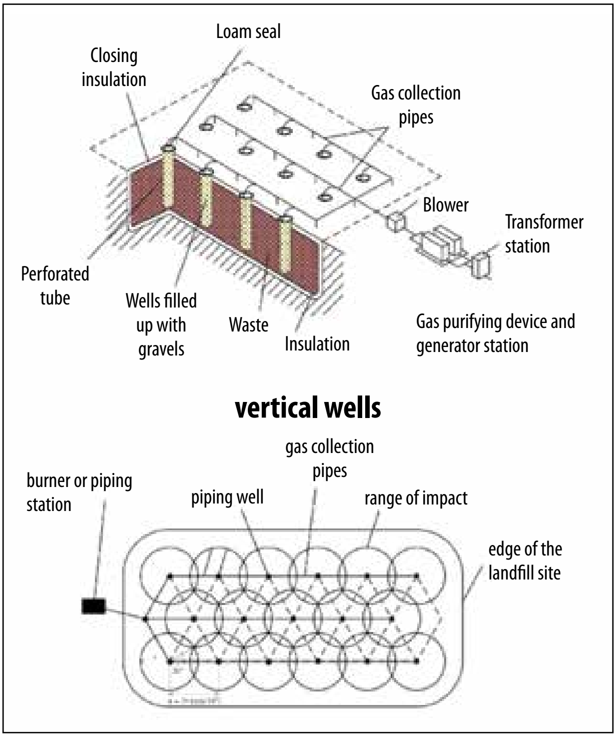


a. collection dike filled with gravels and perforated pipes, b. protection dike developed around the perimeter of the landfill site, c. gas collection wells

Note: version "a" and "b" are used at landfill sites without a bottom lining; version "c" is used at landfill sites with a bottom lining

Figure I.7.2: Schematic of passive gas monitoring and degassing system *(Tchobanoglous et al., 1993) – Landfill site*

From the perspective of environmental protection, an active system is more effective. Such systems consist of wells situated at the edge and within the landfill site based on a grid layout. Wells can be vertical or horizontal. The different wells and pipes are interconnected by a main line with a compressor at the end. A vacuum is created in the main line with the help of this compressor. Depending on the thickness of the dump and other local parameters the distance between the wells will be 8-20 m. For active systems, edge gas removal dikes are also used. These are built directly around the landfill site at a depth of about 8 m or less (see Figure I.7.3).



a. system scheme, b. layout of wells and range of impact

Figure I.7.3: Active gas collection system with vertical wells *(Tchobanoglous et al., 1993)*

I.7.3. The water balance of the landfill site

The water balance of the landfill site is very important, since the amount of leachate expected can be determined based on this. Calculating this volume is a complex task due to the heterogeneous material composition of waste and the particle size and structure – much more complex than for a natural geological formation. Besides the amount of rainwater that seeps in, the water content of the waste and water produced during biochemical reactions also positively affect the water balance. Evaporation and anaerobic decomposition processes counteract these processes and decreasing the amount of water in the landfill site. If influent water that arrives from the top and the bottom is not taken into account, then the water balance of an operating landfill site will be the following:

$$V_w + V_r + V_c = E + R + SR + S + L$$

V_w: - water content of transported waste (water produced by consolidation)
V_r: - seeping rainwater
V_c: - water produced during biochemical processes
E: - evaporation
R: - retention (water stored in capillaries for a short period of time)
SR: - surface runoff
S: - storage (in the form of adherent water)
L: - leaving leachate

The amount of water stored in a landfill site depends on the height of the site, the level of compaction of the waste, pore size and the distribution of pore size, original water content, the composition of waste and the status of decomposition.

Leachate

Perhaps leachate is the greatest environmental risk to communal landfill sites. The origin of water seeping through a dump is already known according to the above-mentioned information, but its composition is extremely diverse, and it can be of a toxic and/or aggressive character due to the high concentration of contaminants. A basic requirement for well-operated landfill sites is to collect and treat leachate.

The quality of the leachate depends on several factors, such as the material the waste is made of, the structural development of the landfill site, the climate, the weather, the season, the characteristics of biochemical processes, pH, the age of the landfill site, etc.

The composition of leachate and its changes provide valuable information about the biochemical and physical-chemical processes that are taking place in a landfill site at any given moment. As the landfill site gets older, the loading of leachate rapidly increases then gradually decreases, but even several years after the closing down of a landfill site a significant amount of contaminants can leave the site through the leachate (see Figure I.7.1).

Analysis of Hungarian evaporation and precipitation patterns indicates that that average leachate amounts to about 150-300 m^3/ha/month (5-10 m^3/ha/day), by calculating with a leakage level of 1 mm/day and a leakage coefficient value of $k = 10^{-8}$ m/s.

Table VII.3 presents the average values of contaminants in the gravitational water of household waste that originates from well and poorly-operated landfill sites. It can be clearly seen that for the alkaline conditions needed for anaerobic decomposition, the amount of organic material burden is high. The same facts are verified by data about modern landfill sites taken from two Hungarian settlements (Oroszlány and Tatabánya) (see Table I.7.2).

Values measured in the waste pile	Poorly-operated	Well-operated	
pH value	8.1	7.4	
Electric conductivity	4143	3212	μS/cm
Insoluble materials	390	172	mg/l
Dry residue	2812	2683	mg/l
KOI	2230	1922	mg O_2/l
TOC	587	1050	mg C/l
BOI_5	85	544	mg O_2/l
NH_4^+	162	83	mg/l

Values measured in the waste pile	Poorly-operated	Well-operated	
Na^+	522	180	mg/l
Ca^{++}	48	221	mg/l
Fe	5.8	3.5	mg/l
Mn	1.9	1.3	mg/l
Zn	0.9*	0.09*	mg/l
Hg	0.006*	0.006*	mg/l
Total hardness	19	30	mvai/l
NO_2^-	0.24	0.07	mg/l
NO_3^{--}	17.7	2.9	mg/l
Cl^-	727	208	mg/l
SO_4^{--}	74	146	mg/l
S^{--}	1.5*	0.8*	mg/l
PO_4 (total)	4.3*	3.7	mg/l

* calculated mean values by taking into account detection threshold

Table I.7.2: The average amounts of contaminants and other parameters in the gravitational water of household waste originating from well and poorly-operated landfill sites *(based on Volg, 1978, Odzuk, 1987)*

I.7.4. Requirements for landfill sites

Newly-built landfill sites can be divided into the following three main categories, according to the type of disposed waste:

a) inert waste landfill site (category A)
b) non-hazardous waste landfill site (category B)
- used for the landfilling of inorganic, non-hazardous waste (category B1b)
- used for the landfilling of mixed, non-hazardous waste (with a significant organic and inorganic material content) (category B3)

c) hazardous-waste landfill site (category C)

It is a general rule that only pre-treated wastes can be disposed of through landfilling with the exception of inert wastes and wastes whose pre-treatment cannot be carried out using the best available technology.

I.7.4.1. Site selection for landfill sites

While selecting the location for a landfill site, the following features should be taken into account:

- regional development,
- spatial planning and settlement development,
- landscape conservation,
- land as a natural element, especially the protection of arable land,
- geological and hydrogeological factors,
- the need to protect surface and subsurface water,
- prevention of air pollution,
- public health,
- nature conservation,
- waste management, and
- fire safety

During preparation and planning, special attention shall be paid to:

- the distance from the border of the landfill site to residential and recreational areas, waterways, channels, surface waters, agricultural and inhabited areas,
- the location and the presence of protected areas and protected areas which are sources of drinking water,
- the contamination sensitivity of the area,
- the geological and hydrogeological features of the area,
- the danger of floods, subsidence and surface movement (sliding),
- the conservation of natural and cultural heritage.

The protective distance between the property boundary of the landfill site and contiguous residential areas, residential buildings or other areas or facilities which should be protected cannot be less than 1000 m for hazardous waste landfill sites, 500 m for non-hazardous waste landfill sites, and 300 m in the case of inert waste landfill sites.

To operate as a modern landfill, the following features should be assured:

- a landfill basin equipped with technical protection elements, including a bottom, slope, cover and closing insulation,
- a leachate removing leakage and drainage system,
- a leachate collection pool,
- a machine room, biogas pump,
- a biogas suction well with delivery pipe,
- a biogas collection pipe,
- paper-catching net or plank,
- green vegetation,
- a management building with portal, offices, restrooms and toilets,
- an entrance and fence,
- a monitoring system (groundwater monitoring wells),
- a platform scale,
- a computerized waste registration system,
- an equipment shed, fuel storage building,
- a waste compaction machine (compactor),
- a collection hall for certain types of wastes that need to be wrapped or baled, and covered storage for hazardous household wastes,
- public utilities (water supply, including drinking, watering and fire-fighting water; communal sewage disposal and treatment; an electricity supply, outdoor lighting; a telephone and fax),
- a container and vehicle washer equipped with sludge and oil traps,
- service roads and surface coverage,
- a collection yard for selective waste collection technology.

I.7.4.2. The construction of landfill sites

Landfill sites can be constructed in mine pits, holes, basins bordered by embankments, dumping areas developed by heaping (hill building technology) or in dumping grounds that are on the side of a slope (valley filling) (see Figure I.7.4).

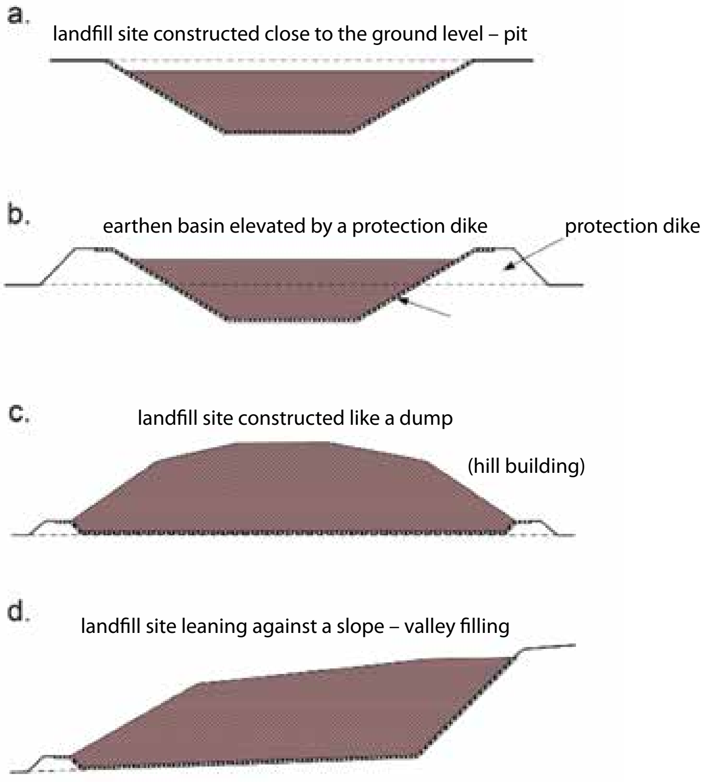


Figure I.7.4: Landfill site types according to filling *(Brandl, 1989)*

Rainwater that runs off the surrounding areas has to be diverted from the landfill site through bottom and interception dikes. Municipal solid waste can be disposed only in landfill sites with appropriate technical equipment. Protection shall be included on the whole bottom surface of the landfill basin and on the bordering slopes up to the height to which the area might get flooded if the seeping water drainage system gets blocked.

The filled landfill basin (basin part) shall be closed by an upper insulation system. The final closure of the waste shall be done in a way that rainwater runs off the surface quickly without seeping into the waste. During the final closing-down of the landfill site, the operator of the landfill site shall proceed according to the previously accepted post-management plan, and has to take measures for the recultivation and the post-management of the area of the landfill site.

I.7.4.3. Technical protection of landfill sites

Landfill sites should be planned and built with appropriate technical protection –taking the composition of waste to be disposed into consideration – ensuring that the natural elements, especially surface and subsurface waters, geological media and the air that are in the direct vicinity of the area do not get polluted during the whole lifetime of the landfill site.

The bottom and the sides of the basin of the landfill site shall be developed in a way that their geological insulation layer meets the requirements listed under Table I.7.3.

Landfill site category	Leakage coefficient (k; m/s)	Thickness (m)
Inert waste landfill site (category A)	$\leq 1.0 \times 10^{-7}$	≥ 1
Non-hazardous waste landfill site (subcategories B1b and B3)	$\leq 1.0 \times 10^{-9}$	≥ 1
Hazardous waste landfill site (category C)	$\leq 1.0 \times 10^{-9}$	≥ 5

Table I.7.3: Requirements for the subsoil and the side of landfill sites

(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)

If a natural geological insulation layer with the characteristics listed under Table I.7.4 is not available, a supplementary artificial mineral insulation layer having a minimum thickness of 0.5 m, and providing the same leakage coefficient as the above-mentioned natural layer shall be built in the case of all landfill site categories. The insulation layer can be made of natural and/or artificial materials.

The two insulation systems can be regarded as identical if the cumulative contaminant streams that develop are the same, meaning that they have the same contaminant retentivity.

- The clay mineral content of the material of the subsoil should reach at least 10% in the case of non-hazardous and hazardous landfill sites, and it also shall have a significant adsorption capacity. In the latter case it is particularly favourable if the cation exchange capacity of the subsoil is T>25 mekv/100 g, and sufficient if this value ranges between 15-25 mekv/100 g. If the value is T<15, the adsorption capacity of the subsoil is unfavourable, but this is not a defining criterion.
- The maximum groundwater level at rest or the maximum pressure level should be no more than 1.0 m away from the bottom level of the insulation layer of the landfill site for non-hazardous landfill sites, and 5.0 m in the case of hazardous landfill sites.
- The organic material content of the subsoil cannot exceed 5%.
- The subsoil of the landfill site shall have a load-bearing capacity that ensures that deformations caused by loading do not endanger the efficiency of the bottom insulation system and the stability of the body of the landfill site.
- It is unfavourable if there are weakly consolidated layers with low stability close to the surface because excess settling caused by the compaction of these layers has to be compensated for by lifting the bottom of the dump.

Table I.7.4 illustrates the layer system of side wall and the bottom insulation that should be developed in the basins for the different types of landfill site categories.

Elements of the insulation layer system	Landfill site category			
	Inert (category A)	Non-hazardous		Hazardous (category C)
		Inorganic (subcategory B1b)	*Mixed (subcategory B3)*	
Artificial insulation layer	optional	compulsory	compulsory	compulsory
Geophysical monitoring system (in the case of new landfill sites)	optional	optional	compulsory	compulsory
Drainage layer	optional	compulsory	compulsory	compulsory

Table I.7.4: The layer system of the side wall and the bottom insulation to be developed in the basins

(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)

Insulation of landfill sites

The insulation system of dumps consists of closing, slope (side) and bottom insulation systems, which wrap the whole mass of waste, and insulate it from the outside world. Wrapping is appropriate if the insulation effect of all of the three elements is long-lasting, and contaminants can leave only through the monitored leachate and gas collection and removal pipes. Figure I.7.5 and Figure I.7.6 illustrate the elements of the insulation system of landfill sites.

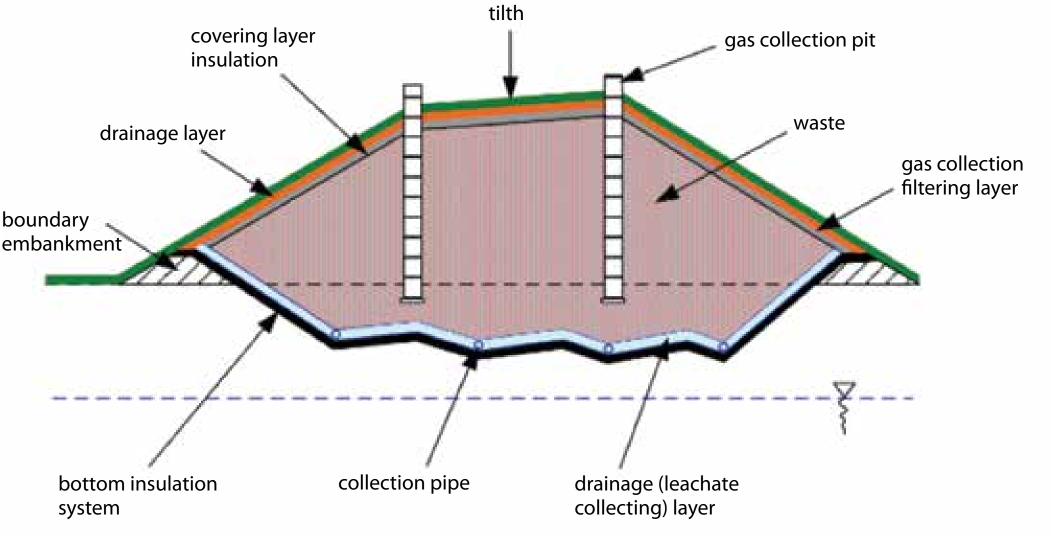


Figure I.7.5: Elements of the insulation system of landfill sites *(Szabó, 2011)*

Figure I.7.6: Building of a modern landfill site

Bottom and closing insulation systems have to fulfil the following requirements (Stief, 1985; Franzius, 1987) (see Figure I.7.9):

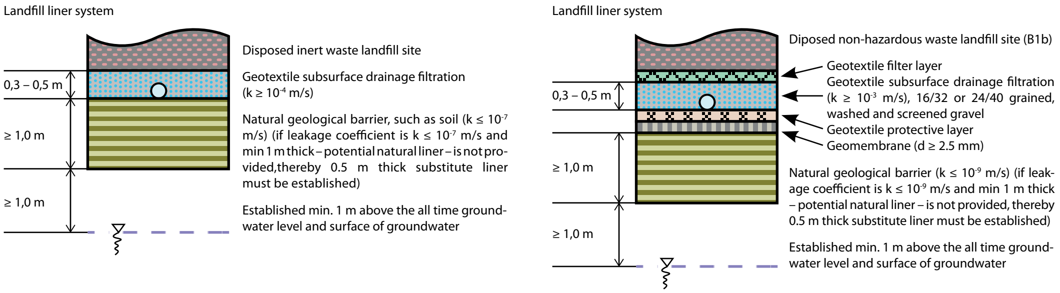
- waterproof construction against rainwater, heat resistance up to 70°C,
- provide insulation against landfill gases,
- resistant to landfill loading (mechanical, chemical, biological resistance),
- capable of bearing subsequent settling,
- resistance to drying out,
- resistant to microorganisms, rodents and the roots of plants,
- erosion and frost resistant,
- ease of use,
- allow compactness and insulation monitoring activities to be conducted in both the building and the operational phase,
- reparability in the case of damage and dilapidation,
- thrift.

Requirements for the development of bottom insulation for the different landfill site categories are regulated by Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste and landfill sites fulfilling the requirements of Council Decision No. 2003/33 of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 and Annex II to Directive 1999/31/EC.

Bottom insulation systems

The bottom insulation systems of landfill sites are presented in Figure I.7.7.

Inert waste landfill site **Non-hazardous waste landfill site (B1b)**



Non-hazardous waste landfill site (B3) **Hazardous waste landfill site (C)**

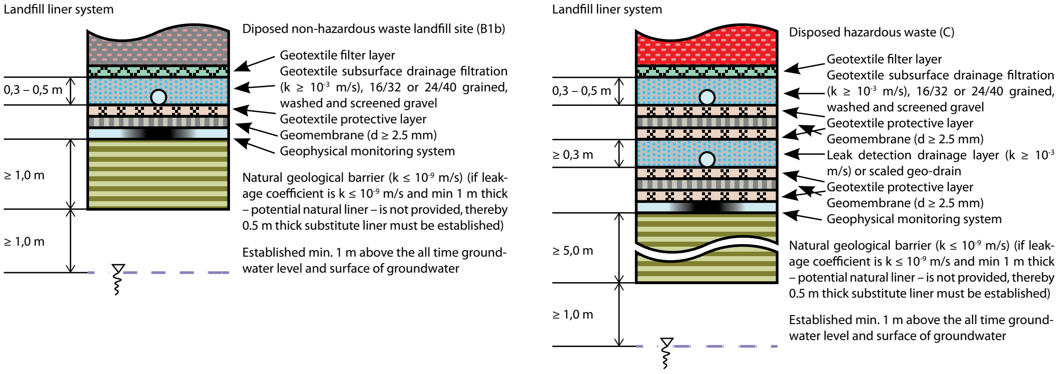


Figure I.7.7: Bottom insulation systems of landfill sites *(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)*

Slope insulation requirements for inert waste landfill sites

Insulation of the slope of cuts: the insulation layer shall have the same insulation capacity as a natural layer of a minimum 1 m thickness with a leakage coefficient of $k \leq 10^{-7}$ m/s. For artificial insulation the thickness of the layer shall reach minimum 0.5 m.

Insulation of the slope of embankments: insulation capacity shall be identical with the requirements set for the upper closing insulation layer.

Slope insulation requirements for non-hazardous waste landfill sites

Insulation of the slope of cuts: the insulation layer shall have the same insulation capacity as a natural layer with a minimum thickness of 1 m, with a leakage coefficient of $k \leq 10^{-9}$ m/s. With artificial insulation, the thickness of the layer shall reach a minimum 0.5 m.

Insulation of the slope of embankments: insulation capacity shall be identical with the requirements defined for the upper closing insulation layer (ground coverage can be mitigated by building in the artificial turf surface).

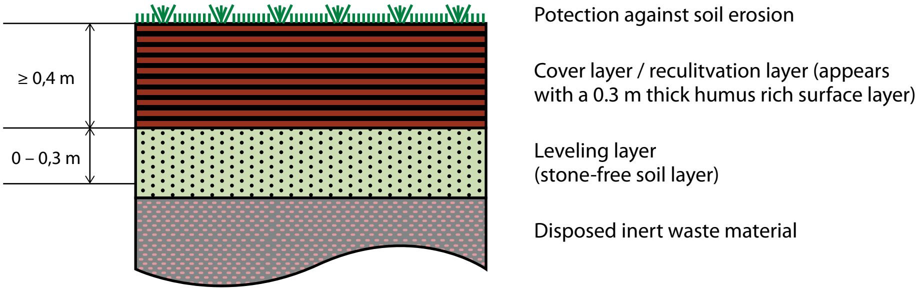
Slope insulation requirements for hazardous waste landfill sites

Insulation of the slope (or the side of the basin): the insulation layer shall have the same insulation capacity value as a minimum 5 m thick natural layer with a leakage coefficient of $k \leq 10^{-9}$ m/s. For artificial insulation, the thickness of the layer shall reach minimum 0.5 m.

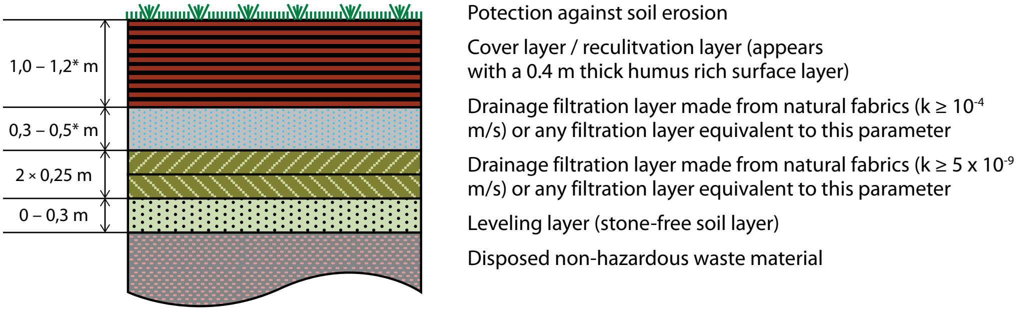
Insulation of the slope of external bordering embankments: insulation capacity shall be identical with the requirements defined for the upper closing insulation layer.

Final closing insulation systems (see Figure I.7.8)

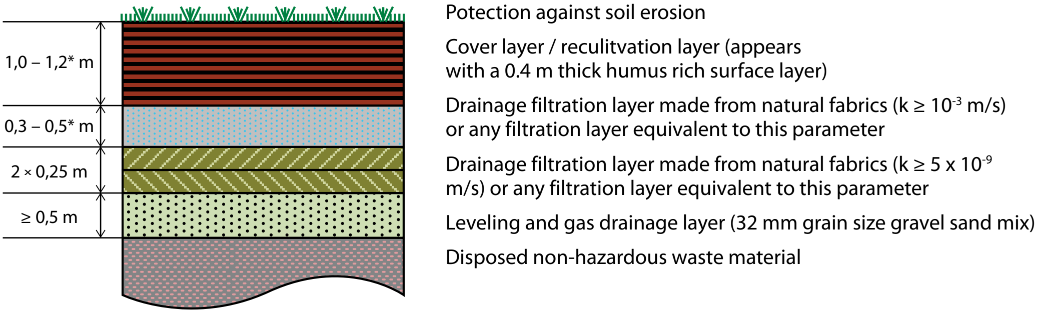
Inert waste landfill site



Non-hazardous waste landfill site (category B1b)



Non-hazardous waste landfill site (category B3)



Hazardous waste landfill site (category C)

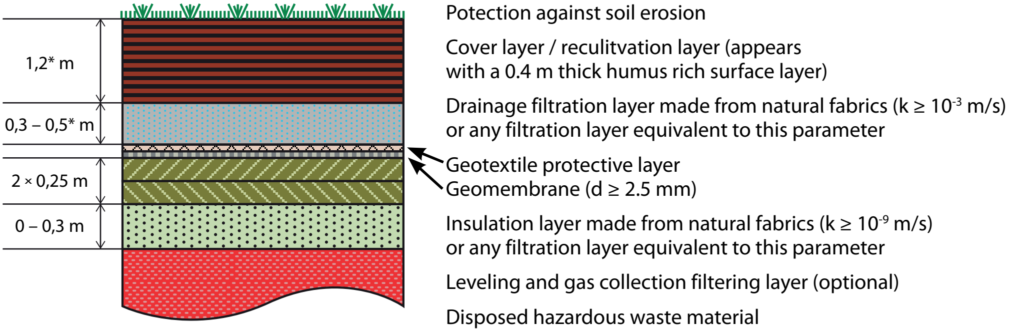


Figure I.7.8: Final closing insulation systems of landfill sites
(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)

I.7.4.4. Leachate collection system (drainage layer)

A 'leachate collection system' is the common name for the efficient drainage system used for the collection, drainage and monitoring of leachate. The thickness of the leachate collection layer is usually 0.5 m, which can be reduced to maximum of 0.3 m if justifiable. Layer thickness of less than 0.5 m should be sized. The leachate collection layer shall be built from a material containing rounded (soled) particles with a particle size of 16/32, having a leakage coefficient of k ł 10^{-3} m/s, and containing a maximum 10-20% of lime (see Table I.7.5).

	Inert waste landfill	**Non-hazardous waste landfill**	**Hazardous waste landfill**	
			Upper drainage layer	**Second control layer**
Thickness (m)	0.3 – 0.5	0.3 – 0.5	0.3 – 0.5	0.3
Material	16/32 or 24/40 gravel	16/32 or 24/40 gravel	16/32 or 24/40 gravel	-
k value (m/s)	$>10^{-3}$	$>10^{-3}$	$>10^{-3}$	$>10^{-3}$

Table I.7.5: Summary of requirements for the development of the leachate collection system
(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)

A drainage system (drainage blanket) placed between the waste and the first insulation layer shall contain at least two layers. The leachate collection and drainage system should be placed on the insulation layer, and a filtering-protecting layer needs to be built between this and the waste in order to facilitate the entering of leachate into the collection-drainage system, and to avoid the washing away of fine particles from the leachate, this way preventing blocking. Both layers of natural and artificial origin shall be sized. Also, the leachate collection system needs to be sized in order to prevent the development of a hydraulic gradient that exceeds the allowed limit at the insulation layer, meaning that the surface of the leachate should always stay within the drainage layer since and not be allowed to rise to the level of the waste layer.

For landfill sites belonging to category C, two drainage layers shall be established. Geodrain (a filtration layer of artificial material) can be used between the two geomembrane layers as a drainage-monitoring layer; its efficiency has to be verified by hydraulic calculations. The second drainage layer is placed under the first insulation layer and also has two functions: the primary one is to monitor (by signalling the malfunctioning of the insulation layer), while the secondary one is to collect and drain.

Filtration systems (filtration layers, geotextiles, drain pipes) become less efficient, and may become blocked after some time even in the case of the most careful planning. Blocking can occur because of mechanical, physical-chemical and microbiological reasons.

Mechanical blocking is caused by leakage of fine particles. This can be avoided if the drainage layer has appropriate mechanical and filtration stability. In practice, mechanical stability means a layer with an appropriate particle size, while filtration stability means a layer with a proper distribution of particles. For filtration layers with a particle size that meets requirements, mechanical stability can be guaranteed by observing the filtration rule.

Physical-chemical and microbiological impacts usually appear together with blocking, and lead to incrustation, when the effective pore space significantly decreases primarily due to the precipitation of iron-oxides and carbonates. The process can be slowed down if:

- current velocity is increased in the filtration layer;
- the pore size of the filtration layer is increased;
- the relative surface of the filtration layer is decreased.

I.7.5. The technology of landfilling

With the help of the predefined landfilling technology the inevitable pollution (dusting, odour, air pollution, unfavourable aesthetic impact) must be minimized, and the usability of disposed waste (e.g. biogas production, the recovery of materials for selective landfilling) does not deteriorate during the operation of the landfill site. As a part of the construction drawing process for ordered landfill sites, an operational plan has to be developed that includes all those activities which have to be carried out during the building and the operation of the landfill site and the disposal of waste among others.

Figure I.7.9: Compactor (*Best Machinery Ltd.)*

Compaction

The compaction of disposed waste is necessary for each landfilling technology. In this way the volume of waste can be decreased and the water balance, stability and the subsequent settling of the landfill site will be also more favourable. For the compaction of waste it is advisable to use a special machine – a so-called compactor – that has been developed for such purpose (see Figure I.7.9). For waste with density of 0.15-0.25 t/m^3, a density level exceeding 1 t/m^3 can be achieved.

Shredding

Through shredding the volume of the landfill site can be better utilized. This is more appropriate for significant amounts of lumpy waste. Small parts can be compacted well, and only a little air will stay within the waste.

Temporary covering

This is necessary for preventing environmental pollution, and for mitigating the production of leachate. Covering activities should be carried out by adding a 20-25 cm thick layer of waste that contains no organic materials or dirt after every 1.5-2 m layer of waste is disposed and compacted, at least once per shift.

Monitored landfilling using a prism system

For monitored landfilling with a prism system, waste is disposed in layers. Each layer is made of a network of waste 'prisms' (main prisms or cross prisms). At the crossing points in the prism network "aeration pits" or "aeration holes" are developed, which are filled up when the given layer is completed (see Figure I.7.10).

Divided channel system of landfilling

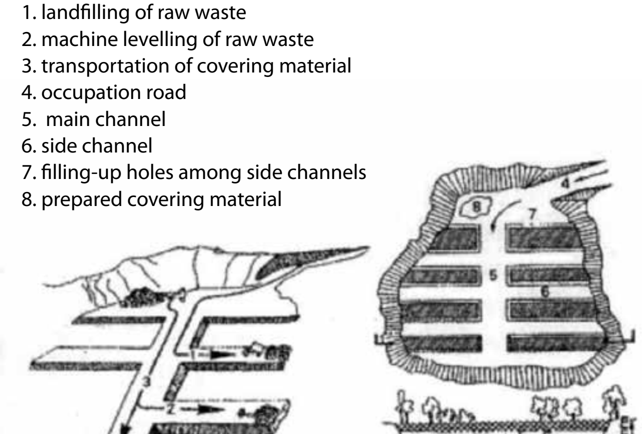

1. landfilling of raw waste
2. machine levelling of raw waste
3. transportation of covering material
4. occupation road
5. main channel
6. side channel
7. filling-up holes among side channels
8. prepared covering material

Figure I.7.10: Schematic of the prism system of landfilling *(Szabó, 1995)*

This approach can be used only at sites where natural conditions can provide appropriate protection. For this method a long but narrow channel is dug at the site with an average length of 25-80 m, a width of 4-5 m and a depth of 2 m. Waste is disposed at one of the sloping ends of the channel, it is then spread and compacted with the help of a special machine, and at the end of the shift it is covered with the previously-excavated ground. After the final filling-up of the channel, final surface insulation layer is put onto the block.

Frontal landfilling

It is advised that frontal landfilling is used with long and narrow sites. The prism is orthogonal to the direction of the landfilling front, and the width of the open, uncovered front can be adjusted to the amount of incoming waste in a flexible way. Since only one of the slopes and the plane of the top need to be covered, less covering material is required.

Circular landfilling

Circular landfilling is done using not too deep holes situated in a flat area at a prism height of 3-4 m. Landfilling is carried out in a circular way, starting from the edges and coming in towards the centre of the area. Here, only one of the slopes and the plane of the top need to be covered, so the amount of covering material in this case is also less.

Building artificial hills

Artificial hills are primarily built on flat areas. It is becoming more and more common that the filling of holes is continued even after reaching the original level of the ground by building artificial hills. With the help of this method landfill sites can be developed even in areas with a high groundwater level. They should be built in a way that the landfill site fits into the landscape. In fact, the method of building artificial hills is the reverse of hole-filling technology; this way the hill is made by putting layers of prisms on one another (see Figure I.7.11).

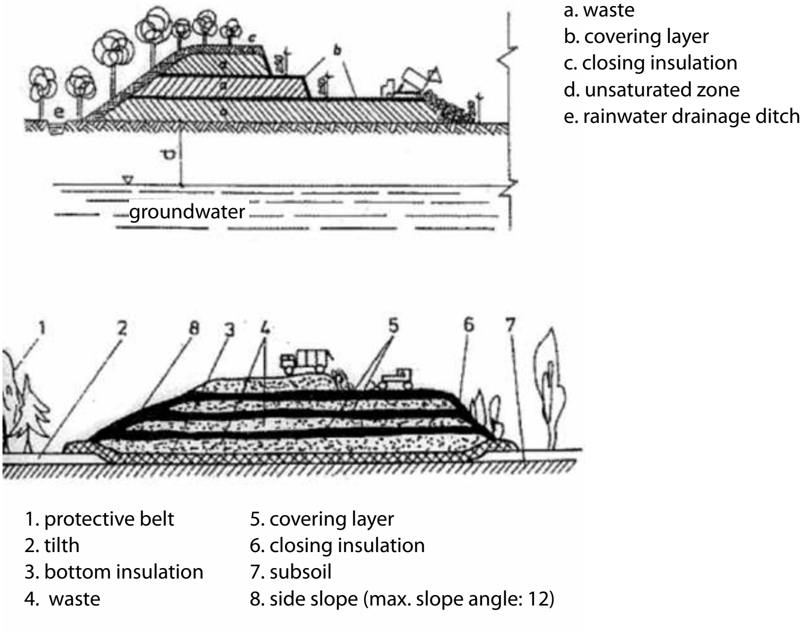


Figure I.7.11: Building of an artificial hill *(Árvai, 1993)*

I.7.6. The operation and monitoring of landfill sites

Through professional and careful operation the emissions of landfill sites can be prevented and minimized. Every operating landfill site shall have an operations plan that has been approved by the environmental inspectorate, which includes:

a) rules concerning the taking over of waste and the order of its registration;
b) details about the technological process of waste disposal;

c) the process of the treatment of landfill gas, leachate, communal sewage and sewage sludge and rainwater;

d) the process of the monitoring of safety facilities and measures, the operation of the environmental monitoring system and the registration of observed data;

e) staff number and tools necessary for the operation of the landfill site.

(The damage control plan and fire safety regulations also need to be attached to the operational plan.)

It is forbidden to mix or to dilute waste in order to meet the quality requirements of the given landfill site.

The landfilling fee should be defined by the operator so that it covers the total costs of the building, commissioning and operation of the landfill site, and the estimated costs of closing down and post-management for at least 30 years.

The operator of the landfill site has to keep a register of the amount and characteristics of disposed-of waste, including the origin, producer and owner of the waste, the time of delivery and the exact place of disposal in the case of hazardous wastes.

During the delivery of waste – at the first time in a series of deliveries – the owner of the waste has to verify that the delivered waste can be taken over by the given landfill site according to the conditions defined in the respective licence.

The basic characterization processes and definition of the basic features of waste are the duty of the owner. The same applies to compliance, meaning that the owner is responsible for ensuring that the characteristics of the waste transported to the disposal site are in compliance with those defined in the licence of the site in question.

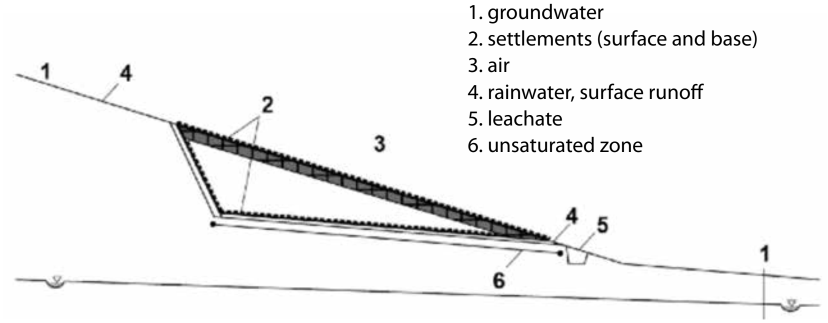
The operator of the landfill site has to perform on-site verifications. This includes fast verification methods that confirm that the waste is identical with that defined in the licence for the landfill site and with the waste mentioned in the accompanying documentation. The on-site verification check takes place at the entry point of the landfill site or the place of disposal and includes a check on the accompanying documentation, a visual observation of the transported waste, and a rapid check of the basic characteristics of the waste that are important from the point of view of takeover.

Landfill sites have to be continuously and regularly monitored (see Tables I.7.5, I.7.6, I.7.7 and I.7.8). The monitoring process includes checking:

- the technical and mechanical status and the changes in status of primary technological facilities and equipment (landfill site, storage places, landfill gas treatment system, structures);
- the condition of tools and equipment used for the monitoring the leakage and the leachate drainage system of the landfill site;
- the quality status of surface and subsurface waters through observing the components defined in the licence on a regular basis, within the defined area of observation also defined in the licence;
- the quality of sewage waters (e.g. leachate, contaminated rainwater) removed from the area of the landfill site;
- the condition of safety facilities and equipment, water drainage and water treatment systems.

Basically, analyses focus on two topics:

- the monitoring system that is connected to the operation and changes in status of the landfill site;
- the monitoring system that is responsible for observing the environmental impacts of the landfill site (see Figure I.7.12).



1. groundwater
2. settlements (surface and base)
3. air
4. rainwater, surface runoff
5. leachate
6. unsaturated zone

Figure I.7.12: The elements of the monitoring system of landfill sites *(Szabó, 2011)*

Aim of monitoring	**Frequency of monitoring**	
	in the operation phase	**in the post-management phase**
Changing of the mechanical structure and the composition of the waste body	every year	-
Settling of the level of the waste body	every year	test reading every year

Table I.7.5: The monitoring of mechanical changes
(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)

Data regarding the status of the landfill site include:
- landfill site capacity (volume) occupied by the disposed waste,
- the method/s of landfilling,
- the time and duration of landfilling,
- the level of compaction,
- the weight and volume of disposed waste,
- the composition of waste,
- free landfill site capacity (volume and weight).

Properties	**Frequency of monitoring**	
	During the operation phase	**During the post-management phase**
1. Amount of precipitation	every day	every day by adding the measured value to the monthly values
2. Temperature at 2 p.m.	every day	monthly average
3. Prevailing wind direction and wind force	every day	not specified
4. Evaporation (lysimeter)	every day	every day by adding the measured value to the monthly values
5. Atmospheric humidity at 2 p.m.	every day	monthly average

Table I.7.6: Collection of meteorological data
(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)

Aim of sampling	Frequency of sampling	
	During the operation phase	During the post-management phase
Defining the amount of leachate	every month	biannually
Defining the composition of leachate	quarterly	biannually
Surface water loading	quarterly	biannually
Defining landfill gas emission and atmospheric pressure (CH_4, CO_2, O_2, H_2S, H_2 etc.)	every month	biannually

Table I.7.7: Emission data: Monitoring of water, leachate and gas

(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)

Aim of sampling	Frequency of sampling	
	During the operation phase	During the post-management phase
Defining subsurface water level	biannually	biannually
Defining the composition of subsurface water	frequency depends on the location of the landfill site	frequency depends on the location of the landfill site

Table I.7.8: Analysis of subsurface water

(Decree No. 20 of 2006 (IV. 5.) of the Ministry of Environmental Protection and Water Management on certain rules and conditions concerning waste tipping and landfills)

After the closing down of the landfill site in the phase of post-management, other monitoring activities are also required, such as:

- monitoring the status of transportation roads and service roads used for reaching the landfill site once per week, and maintaining them at least once per year;
- the continuous monitoring and the necessary maintenance of structures (e.g. fences) in order to prevent unauthorised access;
- the maintenance of vegetation (grass mowing, cutting) if necessary, but at least twice a year;
- the weekly monitoring of water drainage and treatment systems (rainwater, leachate), and their maintenance, cleaning and sludge removal when necessary, but at least once per year;
- monitoring the landfill gas collection system at least once per week, and maintaining it if necessary, but at least once per year.

I.7.7. The recultivation of landfill sites

Recultivation and post-management consists of the following main subprocesses:

a) the elaboration and authorization of the project plan for recultivation and post-management,
b) the temporary and/or final development of the upper closing layer system of the landfill site,
c) the development and the operation of the landfill gas collection and treatment system,
d) the development and the operation of the leachate and rainwater treatment system,
e) the development and the operation of the monitoring system necessary for the post-management phase,
f) the formation of the body of the landfill site, the compaction of its surface layers, the develop-

ment of slopes, fitting the landfill site into the landscape by taking into account the further use of the area,

g) the demolition of equipment and buildings not intended for further use, and fitting the area occupied by them into the landscape,

h) performing maintenance and conservation tasks during the whole post-management period,

i) finishing post-management,

j) fulfilling reporting obligations.

The above-mentioned tasks shall be carried out with regard paid to the composition of the disposed waste, the availability of technical facilities present at the landfill site, and the fact that recultivation and post-management activities may apply to the whole area of the landfill site, or only to some part of it.

Of course, the development of the upper closing layer system also includes the development of the lateral closing layer system of the landfill site, when it is necessary (see the subchapter, "The insulation of landfill sites").

During the recultivation of existing landfill sites with no technical protection it can be necessary to examine (through a risk assessment and a cost-benefit analysis) if the recultivation of the landfill site is feasible, or whether this is not possible. If the landfill site contacts subsurface waters the only alternative is to eliminate it due to the danger of contamination entering into subsurface waters.

Figure I.7.15: Closed down, still not recultivated landfill site

Figure I.7.16: Not recultivated landfill site

II. FOOD INDUSTRY BY-PRODUCTS AND WASTES

II.1. Basic definitions (László Simon)

According to the European Union definition, waste means 'any materials or objects that their owner discards, intends to discard or is obliged to discard – this also includes food waste.

Food waste means materials which have been produced during food production and processing in factories, warehouses, restaurants and other units of the catering and commercial industry and also in households. These materials are either not suitable for human consumption or further processing or they are food products which have expired and/or were spoiled.

Biowaste means biodegradable green waste from parks and gardens, food and kitchen waste from households, restaurants, canteens and retail units and similar waste from food processing units.

Biodegradable waste refers to waste with organic content which degrades or can degrade biologically, either aerobically or anaerobically. Biowaste also belongs to this category.

The task of the food industry is to produce food – products suitable for human consumption. During their processing, in addition to foods as main products, most technologies also produce materials which, due to their ingredients, are not suitable for direct human consumption. These materials are, first of all, wastes from the food industry as, because of their modified physical and chemical characteristics, they are unnecessary products created by a specific technological process which must be removed. A significant amount of the removed materials, however, can be directly utilized and sold, and they can be used as primary materials or energy sources in other technological processes.

In primary food industrial technology, in addition to the main products, the by-products of the food industry are also utilizable and marketable in their original form. The related terms are secondary raw materials and secondary energy resources, which include materials from the food industry that can be used in other technological processes as raw materials or energy resources.

By-products are materials or objects produced during a production process that is not designed to produce such materials; their further use is assured and they can be directly used – without any further processing different to usual industrial practices. Their production is part of the production process and they do not harm either the environment or human health. Their further use meets legal regulations; that is, the specific use of these materials or objects meets all the requirements related to product, environment and health regulations.

Wastes are materials that their owner (producer) cannot or does not want to use or sell in the current social, economic and technical environment. Accordingly, they are removed from the environment. Management of the produced waste, however, must be ensured to avoid polluting the environment.

Waste collection means the collection of waste for transport to a waste processing facility. This includes the pre-selection and storage of waste materials. Waste collection is a technological process which concerns the collection of waste at the place where it is produced using well-organized processes that do not harm the environment, and ends when it is transported.

Transportation refers to the movement of waste outside the waste management plant.

Waste processing refers to utilization and disposal techniques and includes the preparation stage prior to utilization and disposal. Waste processing refers to a series of processes – which can be used in series or separately – aimed at the collection, transportation, reuse and disposal of the produced waste without causing any environmental pollution.

Waste utilization refers to any management processes which result in the waste being used by it replacing materials which have an existing function, or which prepare the waste so that it can serve such a function in a plant or in an area of the economy. Waste utilization is an activity which turns the useless materials that are produced during production processes into marketable and useful materials. Waste can be utilized directly (without modification) or indirectly.

Utilization in the original form refers to any form of reuse except for energetic utilization.

Energetic utilization refers to utilization processes that capture the energy content of the waste. This includes energy production from biodegradable waste and also processing the waste to turn it into fuel or fuel for heating.

Waste disposal refers to any processing that is not reuse, even if it results in secondary material or energy extraction. In addition to waste utilization, the food industry is also an important area for employing techniques that dispose of waste which cannot be used in any way. The goal of disposal is to prevent environmental pollution by modifying the quality of the waste material, or by isolating the waste from its environment.

A biowaste processing plant is a facility for the collection, pre-treatment and utilization of biowaste.

II.2. The reasons for and proportions of losses of food, and the production and amount of by-products and wastes of the food industry (László Simon)

On a global basis, nowadays the amount of food produced is enough to satisfy demand: however, the distribution and consumption of food is rather uneven. On the Earth, out of 7 billion people 850 million are affected by starvation or are undernourished, while 1.2 billion are overweight or obese. According to international recommendations, a person of average weight and activity needs 11.30-11.72 MJ (2700-2800 kilocalories) of food daily to maintain life and health. 'Overnutrition' is mostly typical for developed countries (whose individuals consume up to 5.86 MJ (1400 kcal) extra on a daily basis) and in the last 30 years the average weight of a person has increased, just as has the amount of unused, wasted food.

Poor harvesting practices, improper storage and transportation, strict sales deadlines, waste produced on the markets and waste produced by buyers (end-consumers) means that about one third of the food globally produced is wasted. Approximately 4 billion tons of food is produced annually. It is estimated that 30 to 50 percent (1.2 to 2 billion tons) is never consumed (2012 data). This means that both natural resources and energy are being wasted during food production, processing and consumption.

Agriculture is responsible for 22 percent of all greenhouse gases (animal husbandry is responsible for 18 percent of global emissions). Food production and processing result in significant pressure on soil, water use, energy consumption and CO_2 emissions. In food waste dumps – due to fast decomposition and decay – large amounts of methane gas (landfill gas) is produced, which has a much greater greenhouse effect than carbon dioxide. One unit of food waste leads to over four times as much CO_2 being produced during its decomposition.

The high level of food waste is already causing serious economic, environmental and food safety problems, which may lead to social tensions by 2050 when nine billion people must be nourished. The Environmental Programme of the United Nations recommends reducing unnecessary food waste and loss, reusing food waste and by-products and developing new technologies rather than further increasing food production. These measures may increase the energy efficiency of food production by 30 to 50 percent. If unnecessary food waste and loss could be decreased by 50 percent by 2050, food production would only have to be increased by 25 percent, rather than the 60 percent that is estimated today, to nourish the population that is expected to exist.

Food losses and unnecessary waste may occur at any stage of the food provision chain, illustrated in Figure II.2.1 – however, the reasons for the losses are different for the specific stages of the chain.

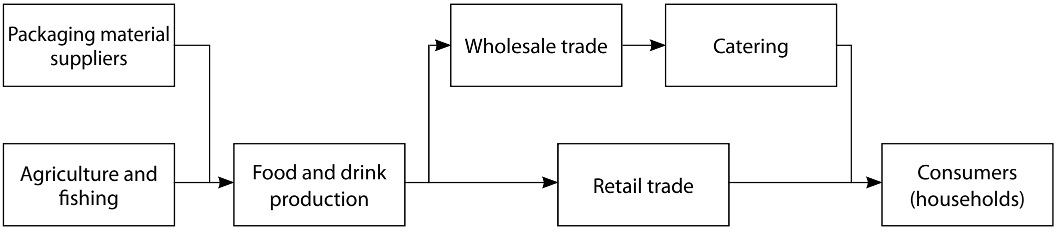
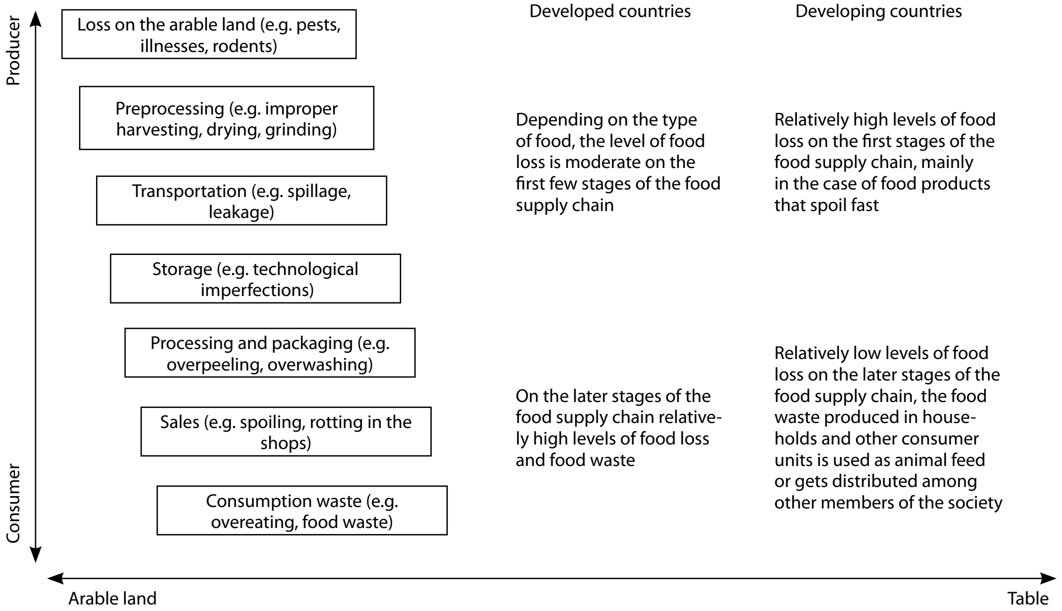


Figure II.2.1: Structure of the food supply chain *(Source: Mena et al., 2010)*

The Food and Agriculture Organization of the United Nations (FAO UN) differentiates between the terms food loss, food waste and food wastage. Food loss refers to a reduction in the amount of food available for human consumption within the food production provision chain. Food loss may occur at the production, post-harvest and processing stages of the food supply chain. The food loss at the end of the food chain (Figure II.2.1) (trade, food consumption) is considered to be food wastage (food that is wasted) and may be tracked back to the wasteful behaviour of traders and consumers. The terms 'food loss' and 'wastage' refer to human food and do not refer to food (by-products) that is used as animal feed or components of food that are unsuitable for consumption.

The amount of food wasted is approximately the same in developed and developing countries. In developing countries, food wastage takes place at the beginning of the food supply chain (when the produced food is stored and processed), while in developed countries it mainly occurs at the end of the food chain (during trading of food and during food consumption). Figure II.2.2 shows the various reasons for food loss, food wastage and food waste in both developing and developed countries.



Depending on the type of food, the level of food loss is moderate on the first few stages of the food supply chain

Relatively high levels of food loss on the first stages of the food supply chain, mainly in the case of food products that spoil fast

On the later stages of the food supply chain relatively high levels of food loss and food waste

Relatively low levels of food loss on the later stages of the food supply chain, the food waste produced in households and other consumer units is used as animal feed or gets distributed among other members of the society

Figure II.2.2: Reasons for food loss and waste production *(Source: Lundqvist, 2008)*

Food loss and food waste production start when the basic ingredients are produced (Figure II.2.2). After sowing, arable land plants are vulnerable to pests, infections and extreme weather conditions, which may lead to significant losses before harvest. Tools widely used for harvesting are another source of food waste, as machines that are used do not usually differentiate between ripe and unripe crops, or can only harvest some parts of the crop. External economic considerations or expectations (e.g. the expected size and colour of the specific crop) may make producers throw away some parts of the harvested crop or use it as feed if they cannot sell it.

The production of food waste continues after harvest (Figure II.2.2). If storage is inadequate, pests and germs may cause large amounts of losses, especially in countries with high temperatures and humidity or if there are no proper storage places available. In addition to direct losses (of quantity) during storage, quality losses may also be significant; this term refers to a decrease in nutritional value, calorific value, suitability for processing or marketability. These losses provide further opportunities for reducing food waste.

The food industry and product processing may also be significant waste producers. Globally, large amounts of food industrial by-products and wastes are created during fruit and vegetable processing (Figure II.2.3), vegetable oil production, fermentation (alcohol distillation, beer and wine production) and milk, meat and fish processing. In addition to solid by-products and wastes (e.g. fruit, vegetables, crop seeds, oily seeds, sugar cane, sugar beet, meat and fish parts), large quantities of liquid wastes may also be produced, such as molasses from sugar production, blood from meat processing, whey from milk processing and also the wastewaters of the food industry with high organic matter content (see Chapter II.3). Their treatment, agricultural, industrial and energetic reuse will be discussed in Chapters II.7, II.8, II.9 and II.10.

Figure II.2.3: Production waste from the canning industry *(Photo: László Simon)*

Table II.2.1 shows the so called specific waste indexes of food processing and various branches of the food industry. Each specific waste index is calculated by dividing the volume of the waste (by-product) produced during the food processing by the volume of the products that enter the market.

Table II.2.1: Specific waste indexes for various branches of the food industry

(Source: Russ and Schnappinger, 2007)

Food industry branch	Type of waste/by-product	Specific waste index
Potato processing industry	Potato skin	0.3-0.5
Milling, husking industry	Bran	0.11-0.18
	Broken seeds, husk, chaff, fine powder	<0.01
	Rice bran	0.11-0.18
	Rice flour	<0.01
Pasta industry	Pasta waste	0.0012-0.0014
	Eggshell	0.02-0.08
Sugar industry	Molasses	0.191
	Lye sugar beet slice	0.517
	Sugar industry beet potash	0.427
Brewing industry	Malt powder	<0.001
	Recrements (lye seeds)	0.192
	Yeast	0.024
	Siliceous earth sludge	0.006
Wine production	Recrements	0.136-0.145
	Dregs	0.015-0.050
	Yeast	0.03-0.045
Meat industry	Slaughterhouse waste (bone, sinew, skin, content, content of stomach-bowels tract, blood, offals)	0.1-0.87
Milk industry	Whey	4.0-11.3
	Waste of milk processing	0.04

The extent of the utilization of by-products and wastes of the food industry is quite low in most countries at the moment. A food industry is up-to-date if the technology consumes small amounts of energy, creates only minor raw material losses and the amount of by-product and waste produced in addition to the main product is small. To encourage the widespread use of environmental-friendly technologies in the food industry, the introduction of modern waste management methods is necessary.

Avoiding the production of some of the food waste produced during food processing (Figure II.2.3) can only be done with difficulty: products that do not meet food safety regulations must be removed from the market before they reach the shelves of supermarkets. Parts of these by-products/wastes could be used as animal feed; however, due to food safety regulations this is in many cases not possible, especially as far as by-products of animal origin and the products that are produced from them are concerned, as in the European Union they belong to a category of waste that requires special treatment (Chapter II.4).

Figure II.2.4: Vegetable and fruit waste of the food trade
(Source: http://blogs.independent.co.uk/2013/01/11/31502/)

During food processing most food is packaged to protect it from external effects during transportation, to keep it fresh and suitable for consumption until it reaches the final consumer. The packaging, which prevents the production of a large amount of food waste, may also prevent the expired food from being used directly, e.g., as animal feed. Packaging waste is an inseparable part of the food industry and is mainly produced by the consumer. Food consumption generates large amounts of household waste.

The food wholesale and retail trade also produces food, drink and packaging waste. As this waste means significant financial losses for traders, efforts are made to keep it to a minimum. In the European Union food losses are smaller at this stage than at other stages of the food supply chain (see data below). Still, higher-than-necessary levels of stock and excessive orders may occur in relation to the supply of, e.g. perishable, seasonal products. In supermarkets it is mostly fruit and vegetable waste (Figure II.2.4) and to a smaller extent fresh (unprocessed) meat, poultry and fish waste that is formed. Bakery, dry and dairy product waste may also be significant.

The food supply industry (that is, the catering industry, fast food restaurants, institutional, school, hospital and workplace canteens) all produce food waste when food is prepared and leftovers and unsold meals also lead to significant losses of food. According to European research findings, an av-

Figure II.2.5: Kitchen food waste and spoilt food *(Photo: László Simon)* erage restaurant meal produces up to 0.5 kg of waste per person. This quantity does not just include napkins and leftover food, but mainly the by-products used during preparation (e.g. used cooking oil, vegetable parts left after cleaning, meat trimmings, etc.) and also the amount of packaging materials. About 20 to 60 percent of restaurant waste is comprised of degradable organic waste. 65 percent of this amount is food left behind during preparation, 30 percent is leftovers and 5 percent is food that has spoilt.

Households produce waste in a similar way. During preparation, unsuitable or unnecessary parts of food (e.g. vegetable and fruit skins, seeds, eggshells) are left behind and need to be disposed of. Similarly, spoilt food must also be thrown away (Figure II.2.5). However, excessive shopping, overstocking and overeating, just like leftovers and their disposal, may be avoided.

The extent of food wastage and food waste produced in households depends on national characteristics, cultural customs, the nature and selection of the food consumed, the size of households and the budget available for food. In developed countries, household waste mostly consists of vegetables, fruit, dairy products, bakery goods, eggs, meat and fish.

In recent years the focus has been mostly on stemming food loss, wastage and the food waste production of the agriculture and food industry, such as losses due to food distribution, improper packaging, handling and distribution, transportation, storage and excessive ordering. However, food wastage in households has been a topic somewhat relegated to the background, just like the impact of food production and retail industry have on each other in this respect, an issue to which little attention has also been paid.

In the 27 member states of the European Union – according to an estimate from 2011 – the greatest amount of annual food waste is generated by households (42 percent; 38 million tons; 76 kg/person); this is followed by waste from food processing (39 percent; 35 million tons; 70 kg/person), then food supply, catering, public canteens (14 percent; 12,3 million tons, 25 kg/person) and, finally, the food wholesale and retail industry (5 percent; 4,4 million tons, 8 kg/person). In the EU27 member states this accounts for 180 kg of food waste per person (in terms of food waste and wastage).

For example in Hungary – according to estimates from 2006 – 1,858,000 tons of food waste were being produced yearly, which means about 180-190 kg per person; the European Union average. However, in Hungary, 62 percent of food waste was produced at the stage of food processing, while households were generating 21 percent, below the European average. In Hungary each household disposes of an average of 100 kg food yearly, worth 50,000 HUF (approx. 160 euros). Each Hungarian household wastes and disposes of 10 percent of the food they purchase, which means that every 10 families could provide food for one more family; if they shared the food they purchase but never eat.

The question arises: what should be done to reduce food wastage globally? One idea is to develop the infrastructure of storage and transportation in developing countries. By building up a cool chain, for example, the vulnerability of producers and the urgent need to sell not stored food could be reduced. This would reduce seasonal oversupply and the amount of food that perishes. More investment is needed in professional consultation and educational systems. Addressing food wastage in developed countries is more complex. The attitude of the population concerning food consumption and wastage (e.g. excessive shopping, overstocking and overeating) should be changed through education and professional consultation.

Representation, education and even legislation may help to reduce the amount of food waste in the food supply, catering and trade industries. The opportunities for using expired food and industrial kitchen waste should also be reconsidered. According to the current European Union regulations, all expired food must be disposed of. Every year hundreds of tons of food is dumped as waste directly from supermarket shelves just because it has not been sold before the date indicated on the packaging. Households have a similar system. Expiry dates are determined with safety in mind; that is, the sell-by date is earlier than necessary. In the case of food that perishes quickly, like fresh meat, fish and milk, an early expiry date is justified; however, food that perishes slowly, like pasta, chocolate some canned food (jam), rice or coffee could be consumed without any health risk even weeks after the date indicated on the packaging. If it were not banned by EU regulation, expired products that are still fit for consumption could be sold at a lower price. Earlier on in many countries, a trader could ask to do a quality inspection and get permission to sell 'expired' food products at a discount, of course clearly separated from the other products in the shop. In Germany it has been suggested that there should be two dates on packaging: one referring to best quality and the other to safe consumption without health risk.

European Union Directive 1999/31/EC requires that, by 2016, the proportion of biodegradable waste that goes to landfill should be reduced to 35 percent of the 1995 level. This objective can be reached by making the processing of recyclable by-products of the food industry more widespread and by increasing the proportion of biological waste treatment (e.g. aerobic composting, anaerobic digestion). The directives of the European Union require that the dumping of the biodegradable waste of vegetable and animal origin produced by agriculture and the food industry must be completely eliminated, and to achieve this goal composting, biogas production and utilizing and bioenergy utilization plants need to be established to treat waste that cannot be directly returned to the soil. At the same time, a complex system needs to be set up to process the by-products of animal origin. Pathogenic waste materials must be eliminated in incineration facilities.

II.3. The typical characteristics, categorization, identification and classification of food industry by-products and waste materials (László Simon)

In the following chapters the typical characteristics, categorization, identification and classification will be discussed.

II.3.1. Typical characteristics of food industry by-products and waste materials

The by-products and waste materials of the food industry can be easily differentiated from other types of by-products and wastes. Their main characteristics are the following:

- Waste with high organic matter content, which decomposes easily, and is biologically unstable. Their components are characterized by their fast auto-oxidation and high levels of enzyme activity. The decomposition of their fat content and proteins results in unpleasant odours. They either contain a large number of germs, or due to the fast multiplication of germs their components change rapidly.
- They cannot be stored or collected over a long time due to their fast decomposition. There is a risk of multiplication of pathogenic germs, toxin-producing moulds, flies, maggots and worms.
- High water content, which also hinders their utilization. The water content of meat, fruit and vegetable waste is 70 to 95 percent. This high water content makes their transportation and drying expensive. If they are pressed, the resulting wastewater with a high organic matter content must be treated.
- Significant volume, their economical utilization largely depends on transportation and collection costs.
- They contain a lot of components that may be reused as industrial raw materials (as secondary raw materials). Using the right technology, most of them are recyclable and reusable.

The by-products and waste materials of the food industry can be categorized based on their characteristics in different ways, based on their state: there are solid, liquid and mud-like materials. This categorization mainly helps with deciding which collection and transportation systems to use.

Based on their origin (place of production), the by-products and waste materials of the food industry may be:

- production wastes (by-products and waste from agriculture, the food industry and catering services),
- municipal (communal) wastes (waste produced in normal life, mostly household waste).

Based on their potential risk to the environment waste materials are categorized into the following groups:

- waste requiring special treatment ('hazardous') (see Chapter II.4), and
- non-hazardous waste.

Based on the two categorizations above, waste materials from the food industry mainly belong to the category of production waste (and partly to municipal, household wastes), and within these categories some of them are wastes that require special treatment.

Based on quality indicators, by-products and waste materials may be categorized in the following way:

- physical characteristics (coarseness, moisture content, dry matter content, etc.),
- chemical characteristics (pH, organic matter content, solubility, combustibility, etc.), and
- biological characteristics (degradability, pathogenicity).

II.3.2. Categorization of the by-products and waste materials of the food industry based on the branches of the food industry

The by-products and waste materials of the food industry are produced when food raw materials are processed and turned into food products which are suitable for consumption. Their production is unavoidable in food processing. When the nutritional component is extracted, it is essential to separate out those parts of the food raw materials that are of low nutritional value, indigestible and may even harm people's health.

In the following chapters the main by-products and waste materials of the food industry will be discussed based on the different branches of production (n.b. the list is not complete) of the food industry. The main quality indicators, components, characteristics, treatment and utilization opportunities will be presented.

II.3.2.1. By-products and waste materials of fruit and vegetable processing

The fruit and vegetable wastes (by-products) produced during the processing stages of the canned food, cooling and drying industry (Figure II.3.3) have a water content of 80 to 90 percent and high levels of fibre.

Fruit and vegetable wastes mostly consist of carbohydrates and have relatively low levels of proteins and fat. The organic fraction is about 75 percent sugar and hemicellulose, 9 percent cellulose and 5 percent lignin. Fruit and vegetable wastes decompose fast: 50 percent of the components change and start to decompose within 2 hours and 80 percent in 24 hours. Aerobic mesophilic germs, moulds and yeast fungi in particular start to multiply in the waste if their moisture content is over 12 percent. As they decompose fast, the opportunity to use them as animal feed is limited (i.e. only when their moisture content is less than 12 percent). Traditionally, fruit and vegetable waste is fed to ruminant animals because the digestion systems of these animals can digest food with high levels of cellulose and hemicellulose. Fruit and vegetable wastes with simple sugar components can also be fed to pigs. Certain grape recrement types and hop processing by-products are not suitable as animal feed because they contain large amounts of phenol compounds and pesticide residues.

The wastewater produced during the processing of fruit and vegetables contains a lot of water soluble organic matter and compounds, herbicides and cleaning material residues.

The by-products of fruit and vegetable processing are rich in several antioxidant compounds, pectins, fibres, carbohydrates, mineral salts, flavours, aroma and colour compounds. They are useful when used as additives in the nutrients of animal feed, can be industrially retrieved (Chapters II.8 and II.10.2) and can also be added to (so called 'functional') human food.

During the processing of fruit and vegetables a large amount of apple pomace, grape recrement and citrus marc is produced as by-product globally. The protein and vitamin content of apple pomace (Figure II.7.1) is low so its use as animal feed is limited. However, it is rich in pectin (<8%) (Figure II.6.2), which makes it an important basic material for industrial pectin production (Chapter II.10.1.1). Its water content is high and it mostly consists of insoluble carbohydrates (cellulose, hemicellulose, lignin). Its simple sugar content (glucose, fructose, sucrose) is also significant, which means that substrates can be produced from apple pomace that helps to multiply microbes which will produce important compounds biotechnologically. The most important by-product of grape processing is grape recrement (marc), which accounts for 13 percent of the processed grape. From grape recrement several valuable compounds can be extracted, such as ethyl alcohol (ethanol), tartaric acid, malic acid, citric acid, grapeseed oil, polyphenols (antioxidants) (Chapter II.8.4) and pectin. Citrus marc accounts for 50 percent of the processed fruit. When dried it is rich in cellulose, hemicellulose and pectin (Figure II.10.2), so can be used for feeding animals (Chapter II.7) and for pectin production (Chapter II.10.1.1). Using microbes, several compounds (ethyl alcohol, citric acid, essential oils, fatty acids), enzymes and biogas can be produced from citrus marc.

Potatoes contain about 18 percent starch, 1 percent cellulose, 81 percent water and soluble proteins and carbohydrates. Traditionally, the waste from potato processing gets ploughed into the soil, is composted and is fed to animals as long as transportation costs are not too high. The by-products of potato processing are four: 1) potato peel, 2) small, crushed potatoes, 3) materials produced during the cooking process, 4) materials from water recovery system. These materials can be used in fermentation processes to produce acetone, butanol and ethyl alcohol (biofuel). The by-product of potato starch production is mainly fibrous potato pulp. From this material it is possible to separate out pectin, starch, cellulase enyzme and protein, and the fibres can be utilized in paper production. The potato pulp can also be used as a substrate to multiply yeast and produce vitamin B_{12}. Potato pulp can also be used to make glue for, e.g., chipboard production. Other uses of potato processing by-products are discussed in Chapter II.8.2.

Among vegetables, the tomato is produced in significant volumes globally. During the production of tomato juice and other tomato products 3 to 7 percent of by-products are generated. Tomato marc is rich in proteins (Figure II.7.1) (20 to 23 percent of the dry-matter content). It also contains 12 to 30 percent raw fibres, and tomato seeds contain 12 to 18 percent oil. Tomato seed oil is rich in unsaturated fatty acids, mainly linoleic acid, which is further refined following extraction to be used as food and in cosmetics. After oil extraction, tomato seeds can be fed to animals as their protein content ranges from 40 to 55 percent. In the skin, the most important carotenoid is lycopene. Lycopene is an antioxidant that protects the cell and prevents cancer.

The onion is one of the most important garden vegetables globally. When onions are processed, the onion skin, two fleshy outer layers, the roots and small size, damaged or malformed onions are left behind as by-products or waste. 80 to 95 percent of the moisture content of the onion bulb is water. More than 65 percent of the dry matter content consists of so called non-structural carbohydrates (glucose, fructose, sucrose) and fructooligosaccharides. The brown onion skin contains large amounts of calcium and quercetin flavonoid, which is an important antioxidant as it protects human cells and blood vessels. The onion is also rich in magnesium, iron, zinc, manganese, dietary fibres, fructooligosaccharides (kestose, nistose, fructofuranosyl-nistose) and alk(en)yl cysteine sulfoxides. From onion waste it is possible to extract these compounds, which are beneficial to human health (see Chapter II.10.1.1). They can be used as food supplements and as ingredients in functional food products.

II.3.2.2. By-products and waste materials of the vegetable oil industry

The vegetable oil industry mainly deals with the production of vegetable oils and fats, the further processing of the produced raw fats and the widespread utilization of by-products (e.g. the production of feed grits and feed fats) generated during the production of the main products. Among the raw materials of the vegetable oil industry the fruit of the oil palm is significant (globally this plant provides the largest amount of fat). Other important sources are soya beans (30 percent of total fat production) and sunflower seeds (10 percent of total fat production). After the processing of oily seeds, the remaining solids (press cake) are mainly utilized as animal fodder depending on their protein and fibre content and protein quality. The extracted grits of the oil industry (Figure II.7.4) are also valuable fodder materials with a high protein content (Chapter II.7.3). From the oily seed grits, protein products can be made (protein meals, proteins concentrates, protein isolates) (Chapter II.10.1.2). From unrefined soya and sunflower oil the industry can produce lecithin (Figure II.8.2, Chapter II.8.2). The sunflower seed hulls can be utilized for energy production through incineration (Chapter II.9.3).

Among the by-products and wastes of the vegetable oil industry, the processing of olives and especially the wastewater that is generated is significant from an environmental point of view.

II.3.2.3. By-products and wastes of the fermentation industry

During the fermentation processes of the fermentation industries (distilling industry, brewing industry and wine industry), large amounts of solid and liquid by-products and waste materials are generated. A typical feature of the liquid wastes is their significant biological and chemical oxygen demand and the presence of some organic compounds (tannins, phenols and organic acids).

The raw materials of the distilling industry are usually materials with sugar content (sugar beet, sugarcane, sweet sorghum, molasses and isosugar (fructose syrup)) materials containing starch (corn, potato, grasses: e.g. rye, wheat) and other materials with lignocellulose (e.g. wood waste (forest pine, birch) and agricultural wastes (straw, corn cob, cottonseed hull)). The fermentation of the materials listed above is designed to produce ethyl alcohol, 67 percent of which is used nowadays as fuel (bioalcohol). In the last two decades, as bioalcohol production has become more popular, the amount of by-products and wastes that are created has also considerably increased.

During the processing of sugar beet and sugar cane, a thick, brown liquid, the so-called molasses is generated (Figure II.7.5) as a by-product of sucrose production. This material contains 11 to 13 percent of the total sugar content of sugar beet and sugar cane, which makes it ideal for ethyl alcohol fermentation with the help of yeast. After molasses-based ethyl alcohol production or distillation the remaining molasses substance has a dry-matter content of 8 to 11 percent. This material is thickened and vinasse is produced (Figure II.7.7). Vinasse has a high chemical oxygen demand and also a significant organic acid and polyphenol content. From the vinasse of sugar beet processing, a toxic material that slowly decomposes, betaine (trimethylglycine) may get into the wastewater. The proteins of the vinasse can be easily digested by ruminant animals. It is used at levels of under 10 percent to feed ruminants and under 2 percent to feed pigs. Vinasse also has significant nutritious element content, which makes it suitable for regenerating soil and for manuring (Chapter II.7.5).

The most important by-product of distillation plants is mash wash (stillage). The volume produced is about ten times as much as that of the ethyl alcohol that is produced. Mash wash generated during the fermentation of materials with starch contains a lot of nutrients. In addition to the remains of the raw material, it also contains vitamin B from the yeast and also proteins, amino acids and minerals. The mash wash of barley, corn, wheat, potato and millet has a dry matter content of 3.7 to 12 percent, 1.3 to 3.8 percent raw protein and 1.5 to 2.9 percent raw fibre. The high water content of these washes limits their use as fodder (it is not economical to use them) as transportation costs are too high. Costs can be reduced by thickening and drying the mash wash and by integrating distillation plants and animal farms. From the corn mash wash (stillage) biopolymers (alternan, pullunan), astaxanthin carotenoid, protease enzyme, chitosan and biodegradable plastics (e.g. poly-β-hydroxibutyrate) may be derived (see also Chapter II.10.3).

Distilling yeast, which is generated during spirit production, and the beer yeast of beer production (Figure II.7.9) can be used as fodder (Chapter II.7.5). Beer marc from beer production (Figure II.7.9 and II.8.7) can be fed to animals or may be burnt to produce energy or may even be used to produce steam for beer production (Chapter II.10.6.1).

Grape recrements and wine-lees (dregs) generated during wine production (Figure II.7.8) can also be utilized as fodder (Chapter II.7.5). From grape recrement raw alcohol, grape recrement “pálinka” (a brandy), calcium-tartarate, antioxidants and grape seed oil can be derived (Chapter II.8.4) and through recrement incineration, energy can be produced.

II.3.2.4. By-products and wastes of the milk industry

Whey is the most important by-product of the milk industry (Figure II.3.1). Globally, whey is produced in large amounts. During cheese and curd cottage cheese production a lot of whey is generated (1 kg cheese results in the production of 9 kg whey). During cheese production, 25 percent of milk proteins stay in the whey, which means that whey is relatively rich in proteins (water soluble protein content

0.6 to 0.8 percent). Its lactose (4.5 to 5 percent), mineral (8 to 10 percent in dried extracts) lipid (0.4 to 0.5 percent), milk acid (0.05 percent) and vitamin content is also significant. As in developed countries it is prohibited to dispose of this liquid into the public sewer system, several techniques have been developed to utilize it. Chapter II.7.6.2 discusses whey utilization as fodder, while Chapter II.8.6 discusses its industrial processing and utilization.

When butter is produced, during the churning process the fat particles of the cream cluster in clumps, and when the phase changes, it separates into butter lumps and plasm (buttermilk). Buttermilk contains 4.8 percent carbohydrates, 0.9 percent fat and 3.3 percent protein. It is thick (Figure II.3.2) and has a sour taste. Due to the low fat concentration, buttermilk contains relatively low levels of fat soluble vitamins; however, it is rich in lecithin. After drying, buttermilk powder is produced, which has 97 percent dry-matter content containing 34 percent protein, 50 percent lactose, 5 percent and 7 percent minerals (13 g/kg calcium, 9 g/kg phosphorus). Butter milk which is not used for consumption is ideal for use as animal fodder (Chapter II.7.6.2). Chapter II.8.6 discusses its industrial processing and other ways of using buttermilk.

Figure II.3.1: Whey *(Source: http://www.wisegeek.com/what-are-the-benefits-of-pure-whey-protein.htm#)*

Figure II.3.2: Fresh cow milk (left) and buttermilk (right) *(Source: http://en.wikipedia.org/wiki/File:Buttermilk-%28right%29-and-Milk-%28left%29.jpg)*

During milk processing and the production of dairy products, large amounts of milk industry wastewater is generated. Wastewater from the milk industry may contain solid materials from milk and dairy products, and also washing water, detergents, disinfecting materials and other substances. Wastewaters from the milk industry are characterized by their high amounts of suspended solid materials (0.024-4.5 g/L), varying chemical composition, high organic (fat, protein) and inorganic matter (ammonia, phosphate) concentration, high chemical (80-95 x 10^3 mg/L) and biological (40-48 x 10^3 mg/L) oxygen demand, and their pH is between 4.7 and 11. The materials they contain decompose fast, start to decay quickly and go sour. Chapter II.11.5 describes the wastewater treatment technology of a Hungarian milk plant.

II.3.2.5. By-products and waste materials of the meat and poultry industry and fish processing

Compared to other branches of the food industry, the technological processes of the meat, poultry and fish processing are responsible for the largest amount of by-products and waste on a global scale. The bodies of domestic animals are only partly suitable for food production directly for human consumption. For example, 52 percent of the body of cattle, 60 to 62 percent of sheep and goats, 68 to 72 percent of chickens and 78 percent of turkeys provide meat for consumption. When domestic animals are slaughtered and processed, large amounts of by-products and waste materials (e.g. blood, skins, pelts, fur, intestines, glands, offal, sinew, fat, bones, meat pieces (Figure II.3.3), trimmings, feathers, horn and hoof) are produced. According to Directive 1069/2009/EC by-products of animal origin refers to the whole body or body parts of animals, products of animal origin, other products extracted from animals, which are not meant for human consumption. The category of by-products of the meat industry also includes materials generated during the production of meat, fish products or other types of food of animal origin and also diminished and expired meat products.

Products made from the by-products of animal origin are products created through a one step or multi-step treatment process, modification or processing of by-products of animal origin (1069/2009/

EC directive). From the by-products and waste materials of the meat, poultry industry and fish processing it is possible to produce meat, blood, bone, feather meal, crackling meal, fodder fat and fish meal (Chapters II.7.6.1 and II.10.5), some of which – subject to limitations (see Chapter II.4) – may be utilized in domestic animal fodder or in pet food. From by-products of animal origin it is possible to derive e.g. glue or gelatin (Chapter II.8.5). Products made from the by-products of animal origin may be stored for a long time as their moisture content is low and most of the germs they contain are killed during heat treatment.

Processed animal protein refers to animal protein from animal waste from the 3rd category exclusively (see Chapter II.4), which has been treated to make it suitable for direct use as fodder raw material, organic manure, soil ameliorator or use in fodder for domestic animals or in pet food. Processed animal protein includes meat meal, bone meal, meat and bone meal, blood meal, dry cracklings, feather, hoof and horn meal and fish meal (see Chapter II.7.6.1) and other similar products, including their mixtures and products that contain these products.

Some by-product of animal origin is utilized by composting or anaerobic digestion (biogas production) (see Chapter II.9.1) and after processing is put into the soil as organic fertilizer or soil ameliorator (see Chapters II.7.7 and II.7.8).

Meat, poultry and fish processing technologies generate a large amount of wastewater, which is characterized by its high biological oxygen demand, high suspended solid matter content, high levels of nitrogen, phosphorus, fat and strong odour.

Wastewaters from the meat industry may have a high level of germs and present a risk of microbiological infection.

The processing of seawater and fresh water fish, crabs, mussels and molluscs also results in a lot of by-products and waste materials (Figure II.3.3). Fish processing generates by-products and waste such as skin, bone, fin, head, intestines, internal organs, pieces of fish, blood, etc. These materials are processed and fish meal (see Chapter II.7.6.1, Figure II.7.16) and fish oil is produced for utilization as fodder. Fish waste contains 58 percent raw protein, 22 percent ash, 19 percent raw fat (ether extract) and 1 percent raw fibre. From fishing waste it is possible to industrially produce enzyme and vitamin products, protein hydrolysate, collagen, gelatin and lipid extracts. The by-products of crabs are rich in protein, chitin and carotenoids. Chitin is primarily produced from these materials.

The wastewaters of fish processing plants are characterized by their high levels of suspended solid material content, high biological oxygen demand, high fat and oil content and high blood based nitrogen content.

Figure II.3.3: Wastes and by-productsof the meat and fish processing industry

(Source: http://codlapsa.pl/zywienie-barf-czesc-i/; http://www.worldfishing.net/news101/industry-news/harnessing-the-power-of-fish-by-products 9.jpg)

II.3.3. Identification and categorization of food waste

The producers and managers of waste materials have to keep exact records based on measures they take related to their waste materials, movements and treatment and the operation of the treatment facilities. Based on the records, statistical and official reports have to be made. The records and reported data form the basis of regular official checks and ensure the tracking of the waste materials. The waste reports also provide the basis for national data reporting to the European Union, for the planning of waste management and for the information provided to the public.

The identification and categorization of food waste is carried out based on the code numbers of the European Waste Catalogue, EWC. In the records waste materials have a 6-digit identification code number. The waste registration consists of main groups and subgroups and also waste types. The first two digits of the code identify the main group based on the origin of the waste. The second 2 digits refers to the subgroup within the main group. Main groups have a 2-digit code, subgroups a 4-digit code and waste material types a 6-digit identification code. Code numbers signed (*) refer to hazardous waste materials.

Food waste usually belongs to main group 02 (waste from agriculture, garden, aquaculture production, forestry, hunting, fishing, food production and processing). Some examples of the categorization codes are presented below:

02 01 waste from agriculture, horticulture, aquaculture production, forestry, hunting and fishing; 02 01 01 sludge from washing and cleaning; 02 01 02 animal tissue waste (body and body parts of dead animals that have died of non-contagious diseases); 02 01 03 vegetable tissue waste.

02 02 waste generated during the preparation and processing of meat, fish and other food of animal origin; 02 02 01 sludge from washing and cleaning, 02 02 02 animal tissue waste (bone, skin, hoof, nail, claws, bristles and fur; feathers with paraffin); 02 02 03 material not suitable for consumption or processing (e.g. meat, food with meat or of animal origin which are not for human consumption for commercial reasons, production or packaging errors or other problems that do not pose a public or animal health risk, hatching eggs and egg shells, blood, stomach and bowel content of slaughtered animals, animal fat), etc.

02 03 waste from the preparation and processing of fruit, vegetables, arable crops, cooking oil, cocoa, coffee, tea and tobacco; waste generated by the canning industry, the production of yeast and yeast extracts, waste produced during molasses processing and fermentation; 02 03 01 sludge from washing, cleaning, peeling, centrifugal separation and other methods of separation.

02 04 waste from sugar production; 02 04 01 earth from sugar beet cleaning and washing; 02 04 02 non-standard calcium carbonate.

02 05 waste from the milk industry; 02 05 01 material unsuitable for consumption or processing.

02 06 waste from the confectionery and bakery industry.

02 07 waste generated during the production of alcoholic or non-alcoholic drinks (except coffee, tea and cocoa); 02 07 02 waste from alcohol distillation.

Expired food waste belongs to sub-category 16 03 (unused products that do not fulfil requirements); 16 03 06 refers to organic waste different from 16 03 05 (organic waste containing hazardous materials).

Some biodegradable waste materials, fats or oils belong to the main group 20 (municipal waste (household waste and commercial, industrial and institutional waste similar to household waste, including the fraction which is collected separately); 20 01 08: biodegradable kitchen and canteen waste; 20 01 25: cooking oil and fat; 20 01 26*: oil and fat different from 20 01 25 (*hazardous waste).

II.4. By-products and wastes of the food industry requiring special treatment (László Simon)

The food industry and related activities generate large amounts of by-products and wastes (decayed and used vegetable oils, fatty acids, used fats, animal fats, meat pieces, stomach and intestinal content of slaughtered animals, feathers, bones, skin, hooves, claws, horn, bristle, fur etc.) which must be collected, treated and disposed of according to strict environmental regulations.

The term by-products of animal origin refers to the complete body or body parts of animals, products of animal origin, other products extracted from animals not for human consumption including eggs, embryos and even sperm. By-products of the meat industry require special collection, treatment and disposal due to their high levels of organic matter content and rapid decomposition. The treatment and utilization of by-products of animal origin are subject to both animal health and environmental regulations. The disposal of by-products of animal origin is important from animal health, environmental and public health perspectives.

By-products of animal origin are categorized based on:

- place of origin,
- level of hazard,
- physical and chemical features.

Based on place of origin by-products of animal origin may be:

- by-products of livestock farms (pig, cattle, poultry or other animals carcasses)
- by-products of slaughterhouses (slaughterhouse waste of poultry, pigs, cattle, rabbits or other animals)
- wastes from the food industry (canning factory, cooling, meat industries and trade)
- animal cadavers from households (domestic animals and pets).

II.4.1. Categorization of by-products of animal origin

By-products of animal origin and products made from by-products of animal origin are classified into categories 1, 2 and 3 based on their risk to public and animal health according to Regulation 1069/2009/EC. Below some of the most important criteria are listed.

Category 1 – high level of hazard (only for disposal)

Category 1 includes the following by-products of animal origin:

a). The whole body and all body parts of the following animals, including untreated leather and pelt:

- animals likely to have TSE infection and animals in which TSE infection has been officially confirmed (TSE – transmissible spongiform encephalopathy);
- animals slaughtered as part of a TSE elimination campaign;
- animals that are neither domestic nor wild, including especially pets, zoo animals and circus animals;
- animals used for experiments;
- wild animals, if they may be infected with contagious illnesses that may be transmitted to people and other animals;

b). the following materials:

- highly infectious materials;
- the complete cadaver or its parts, if they contain highly infectious materials at the time of disposal;

c). by-products of animals that have undergone illegal treatment;

d). by-products of animals that contain materials which are harmful environmentally, or residues of other materials, if these residues are over the limits prescribed in EU regulations or if there are no such regulations, the limits defined in national laws and regulations;

e). by-products of animal origin collected during wastewater treatment:

- from facilities and plants that process category 1 materials, or
- from other facilities or plants where materials that represent a high risk of infection are removed;

f). food waste from vehicles operating on international routes;

g) mixtures of category 1 materials with category 2 materials, or with category 3 materials, or possibly with both.

Animal by-products of category 1 have to be disposed of by incineration in incineration plants or – following pressure sterilization (heat treatment) in a treatment and processing plant monitored by animal health and food safety authorities - must be disposed of by incineration or combined incineration (see Chapter II.10.6.2.).

Figure II.4.1: Collection of animal cadavers of category 1
(Photo: László Simon)

Category 2 – significant danger (not suitable for animal fodder)

The following by-products of animal origin belong in Category 2:

a) manure, non-mineralized bird faeces and digestion system contents;

b) by-products of animal origin collected during wastewater treatment:

- from factories and plants processing materials of category 2; or
- from slaughterhouses that do not belong to the group of plants and facilities that process category 1 materials;

c) by-products of animal origin in which the level of permitted materials or polluting materials is over the defined limit;

d) products of animal origin that, due to their foreign body content, are considered unsuitable for human consumption;

e) animals or animal parts,

- which have been slaughtered not for the purpose of human consumption, including animals that have been slaughtered to stop diseases;
- embryos;
- eggcells, embryos and sperm that are not for breeding and poultry that perishes in the egg;

f) a mixture of category 2 materials with materials of category 3;

g) by-products of animal origin that do not belong to categories 1 or 3.

By-products of animal origin of category 2 must be treated in licenced treatment and processing plants. Prior to treatment and processing, the by-products of animal origin must be cut into pieces of under 50 mm, then must be heated to over 133°C (core temperature) and kept under these conditions for minimum of 20 minutes without a break under a pressure of 3 bars produced with saturated steam (see Chapter II.10..4). The produced material must be signed for long term using glycerine triheptanoin (GTH). The produced by-product with a protein content must be incinerated and can be used as organic manure or soil improver, or the produced by-product may also be utilized at biogas or composting plants. Manure and liquid manure must be treated according to separate relevant regulations. The rumen, stomach and intestinal content of any animal can be used as a raw material at composting or biogas plants.

Category 3 – slight danger (not for human consumption)

The following by-products of animal origin are defined as category 3 materials:

a) body parts, or in the case of wild animals, the bodies of the animals killed and also their parts, which according to EU regulations are suitable for human consumption, but for commercial reasons are not used for human consumption;

b) body parts and bodies and parts of animals slaughtered at slaughterhouses if an examination prior to slaughtering certifies that they are suitable for human consumption, bodies of wild animals and their parts that have been killed for human consumption in accordance with EU regulations:
  - body parts or animal bodies and their parts, which based on EU regulations are considered unsuitable for human consumption, but do not show any symptoms of illnesses that can be transmitted to humans or animals;
  - poultry heads;
  - raw leather and pelts of the animals listed below, including the by-products of slaughtering and also their split skins, horns and feet, including toe joints, the front and back tarsal and metatarsal bones: all animals, except for ruminant animals requiring TSE tests and ruminant animals with negative test results;
  - pork bristle, feathers;

c) by-products of poultry and rabbit types which have been cut up at animal farm plants and do not show any symptoms of diseases that can be transmitted to humans or animals;

d) animal blood with no clinical symptoms of disease that can be transmitted to humans or animals, of animals listed below and slaughtered at slaughterhouses if an examination prior to slaughtering has certified that they are suitable for human consumption:

- all animals except for ruminant animals that require TSE tests; and
- ruminant animals with negative test results;

e) by-products of animal origin generated during production for human consumption, including bones after the fat has been removed, crackling and centrifuge and separator sludge from milk processing;

f) products of animal origin or food products containing products of animal origin which are not used for human consumption for commercial reasons or due to production or packaging errors, or other problems that do not cause public or animal health risks;

g) pet food of animal origin and fodder of animal origin, or fodder of animal by-products or fodder containing products made from by-products of animal origin, which are not used as fodder for commercial reasons or due to production or packaging errors or other problems that do not cause a public or animal health risk;

h) blood, placenta, wool, feather, fur, horns, hoofs and raw milk from living animals that do not show symptoms of diseases that can be transmitted to humans or animals;

i) materials listed below from animals that do not show symptoms of diseases that can be transmitted through these products to humans or animals:
  - shells of testacean animals, with soft tissues or meat;
  - the following materials from land animals:
  - by-products of hatching,
  - eggs,
  - egg by-products, including egg shell;
  - baby chicks, etc. slaughtered for commercial reasons.

Category 3 by-products of animal origin can be disposed of or utilized by combined incineration; furthermore, they can also be utilized in treat-

Figure II.4.2: Category 3 by-products of animal origin before processing *(Photo: László Simon)* ment and processing plants, or plants producing animal food or technical products, and can also be modified in biogas or composting plants. Figure II.4.2 shows category 3 by-products of animal origin before processing.

II.4.2. Regulation concerning the utilization of by-products of animal origin

According to Regulation 1069/2009/EC, all by-products of animal origin must be collected and disposed of. Figure II.4.3 shows the collecting stations for by-products of animal origin of different categories.

By-product of categories 1 and 2 cannot be used to feed domestic farm animals, and waste of animal origin can only be buried in special cases. It must not be buried or placed into cadaver pits or cadaver collection places. As a result, local governments had to shut down cadaver pits and collection places by 31st December 2005.

In the licensed processing plants, while by-products of animal origin of categories 1 and 2 are processed, pressure sterilization (see Chapter II.10.4) must be used, even if the produced bone and meat meal is later utilized in incineration or combined incineration.

According to Regulation 1069/2009/EC, category 2 and 3 by-products are not classified as hazardous waste materials while category 1 wastes are considered wastes that should be treated as hazardous waste.

Figure II.4.3: The collection and transfer station of by-products of animal origin of different categories
(Photo: László Simon)

By-products of animal origin that cannot be utilized

Fish meal and products from milk and egg processing were not completely banned as fodder earlier either. Later the use of skin, fur and gelatin of non-ruminant animals was allowed for feeding non-ruminant animals. Nowadays, with some limitations red blood cell extracts and blood plasma can also be fed to non-ruminant animals. Bone meal can also be used if it is certified that it does not contain protein. No permission is given, however, for the utilization of meat pieces and offal produced in large amounts as animal fodder, although directives were made a little bit less strict on this point in 2011.

II.5. The collection and transportation of the by-products and waste materials of the food industry

(László Simon, Tamás Antal, Jenő Kiss)

The following chapters describe the collection and transportation of by-products and wastes of the food industry, food leftovers, and by-products of animal origin and also used cooking oil. Regulations differentiate between waste materials and by-products of the food industry. This is especially true for the collection and transportation of by-products of animal origin, for which special European and national regulations apply.

II.5.1. Basic concepts and regulations related to the collection, registration, storage, transportation and commerce of by-products and waste materials of the food industry

The term collection was introduced in Chapter II.1 Separate collection refers to collection when the waste flow is separated based on the type and features of waste, which makes their special treatment possible. Waste collected separately means waste collected based on its type and features, not including mixed waste. The collection container is a waste collection container with a standardised size, waste collection sack and tools and equipment for separate waste collection. The collection point refers to the place of collection, waste collection court, place for takeover and recollection and collection place at workplaces and plants. Transportation refers to transportation outside the plant.

Acts on waste materials include the principle of biodegradable waste utilization, which says that the separate collection and utilization of biodegradable waste must be encouraged so that after utilization the material that re-enters the natural circle of organic materials should be as clean as possible, and the biodegradable fraction of municipal waste that enters landfills should be reduced.

According to the regulations, the activity of waste transportation still requires a licence. An application for waste management for transportation, coordination and commerce must be handed in to the environmental authorities. It is possible to apply for a licence for all these activities together.

The Governmental Decrees regulates the obligation to register and provide data related to the waste (e.g. content requirements for waybills, obligatory data registration of waste producer, processing plant, utilization and disposal company, obligatory data provision for authorities, etc.). Only those traders and coordinating companies must be registered that do not own the waste. According to the regulation above the waste producer is obliged to keep weekly records about both the types and technology used for the waste produced on their premises. In addition to this, regular data must be provided about the waste types at each plant as long as the total amount of non-hazardous waste produced and owned in a specific year is over 2000 kg. According to the regulation, the waste transportation company is also obliged to keep registration documents, and in the case of non-hazardous waste keep transportation documents, which are part of non-hazardous waste documentation, about each waste transportation activity that has occurred for the last 5 years, in a chronological order, starting on the day the first act of transportation occurred. With respect to the handover of non-hazardous waste for commerce, the collector has a responsibility to provide data by 1st of March of the following year.

The waste code and classification category of waste is determined by the producer or owner of the waste.

Acts on waste management introduced the term by-product (Chapter II.1) by determining from which point and under which conditions the waste may be considered by-product.

The regulations for food and kitchen waste – as by-products of animal origin – are determined by 1069/2009/EC and 142/2011/EU Regulations on by-products of animal origin not for human consumption and on health rules for products produced from them. In 2002, in many countries the regulations prohibited the use of food waste as fodder to stop the spread of swine-fever. According to this regulation, public canteens, catering units, companies and commercial supermarket chains must make sure that food waste and leftovers are collected, transported and disposed of.

Expired food products are grouped based on the relevant regulations as waste – if they are of vegetable origin – or as by-product of animal origin – if they are of animal origin, in the following way:

1. Food products of vegetable origin (vegetables, fruit, and food products that only contain ingredients of vegetable origin);
2. Food products of animal origin or mixed of animal and vegetable origin – by-products of animal origin based on 1069/2009/EC and 142/2011/EU Regulations.

The regulation on animal health regulations for by-products of animal origin not for human consumption. The decree regulates national differences and procedural issues, a new data provision and registration obligation is introduced, and the commercial document was also introduced in a new form. The decree regulates the by-products of animal origin and their products, which based on European Union regulations, cannot be used for human consumption, and also the products which are, due to the irreversible decision of the operator, destined for use for other purposes than human consumption (products of animal origin which, based on EU laws can be used for human consumption or/and raw materials used to make products of animal origin). By-products of animal origin must be classified according to categories (1, 2 and 3) (Chapter II.4) in accordance with 1069/2009/EC Regulation. These categories show the public and animal health hazards of these by-products of animal origin. Based on the information mentioned above, by-products of animal origin do not have their own environmental waste codes (Chapter II.3).

Based on the regulation above, the owner of the by-product of animal origin is obliged to keep records about the by-products of animal origin that are produced and save them for a minimum of two years. The decree says that the owner of the by-product of animal origin must register the amount of by-product of animal origin handed over for processing or disposal for each plant of theirs, and, once a year – by the 1st of March the following year with the right content as determined by law – send the information to the relevant local animal health authorities. Based on the Decree, a report about the by-products of animal origin must be made only to the animal health authorities. To environmental authorities based on 2008/98/EC Directive a report must be sent concerning the relevant materials only; that is, materials of animal origin disposed of as waste and wastes of non-animal origin. According to the regulation, a by-product of animal origin that is transported must have a trading document (in triplicate) with the necessary content which has been filled in by the owner of the by-product or the company that hands it over. The trading document must be signed at the place of handover by both the transportation company and the person responsible for the handover.

Food waste and by-products of animal origin produced by food production, processing and trading companies are transported using special technology by enterprises that hold special licences determined by the regulations above, and the collected materials are handed over to companies that are correctly licensed to deal with their processing, disposal or utilization.

II.5.2. The collection, storage, transportation and processing of food waste and by-products of animal origin

The following general principles must be considered when biodegradable wastes/by-products are collected and stored:

- separate collection may be required, based on type of raw material (mixed collection and soft materials, e.g. blood, feather, bones),
- non-drip containers with covers (odour protection),
- storage in a cool or refrigerated place,
- quick transportation,
- mechanical movement of material (so as to minimize human contact),
- protection against flies, insects, birds, rodents and other animals,
- disinfecting needs (for surfaces, drainage water, faeces, clothes, protective gloves).

Figure II.5.1 shows the general procedures for the collection, transportation and processing of food waste (e.g. leftovers) and by-products. In EU collected food leftovers are mostly utilized for biogas production or are disposed of by incineration. Food waste and and its by-products can be utilized by composting.

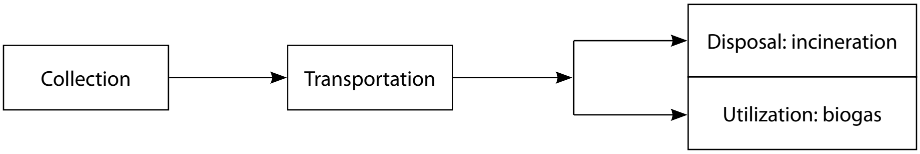


Figure II.5.1: The treatment process of food waste and by-products of animal origin

(Source: Biofilter Zrt., 2014)

After the contracts have been signed, the companies collecting and treating the food waste give their partners a 60-litre plastic container with a cover and a lock in order to collect food and leftover waste (waste code 20 01 08) or category 3 by-products of animal origin in accordance with Hungarian standard 7540-1998 (Figure II.5.2).

During the period of service they are replaced, and clean, sterilized containers are provided. Collection and transportation is carried out on days previously arranged with the partner. When the waste is taken over, the driver of the company provides a trading document and delivery note, both of which are stamped and signed by the customer. After transportation the waste arrives at the licenced company that will utilize and process the waste, and the waste materials are treated and utilized in accordance with legal regulations.

Figure II.5.2: Plastic collection containers for the collection of food waste and by-products

(Source: Biofilter Zrt., 2014)

Figure II.5.3 shows the collection and treatment of leftovers at a Hungarian enterprise.

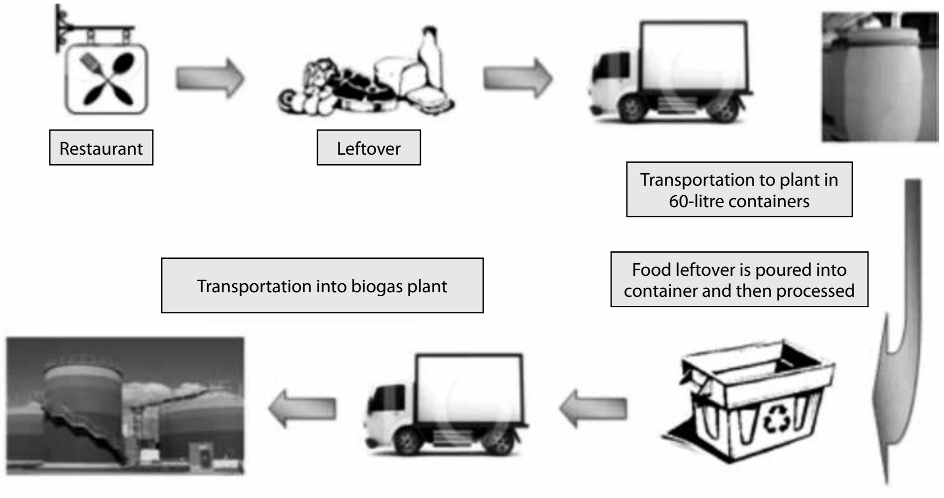


***Figure II.5.3: The process of leftover collection and treatment** (Source: Biofilter Zrt., 2014)*

The proper storage of quickly decomposing food wastes until the date of transportation is a problem in some cases. Modern fridge storage equipment is a good solution for the hygienic storage of small amounts of food waste and by-products and waste of animal origin for animal farms, waste collection courtyards, meat plants, food producers and distributers, local governments, hotels and restaurants. Fridge container equipment can use 1 or 2 240-litre containers. The inside temperature can be set at between 0 and 12 ^{0}C. Its use is ideal for managing waste, decreasing the frequency of transportation and also the risk of infection and odour impact (Figure II.5.4).

In most EU member states a complete selective kitchen waste and leftover collection system for households has not been built up yet. In more developed European countries there are good examples for this; e.g. kitchen waste is collected separately with a special kitchen waste collection car that either goes directly to houses or picks up waste using an island system. This system has high costs, but another innovative solution also exists: the construction of residential blocks with a separate food waste collection pipe system. A special vacuum system can be used to collect the food waste from one or more points where residents can dispose of their food waste.

Figure II.5.4: Fridge container for the storage of food waste and by-products of animal origin
(Source: www.ltvtrans.hu)

Animal cadavers are by-products of animal origin that pose infection hazards to the environment. Independent of the reason why the animal has died (illness or accident), the cadaver must be considered a potential source of infection. The organic materials in the cadaver mineralize in soil and water and in environments without oxygen, methane, ammonia and hydrogen are produced as a result of anaerobic decomposition. If there is oxygen in the environment, aerobic decomposition takes place, which also produces carbon-dioxide and water. In the decaying cadaver Clostridium bacteria may appear and multiply, which may cause tetanus and tympanitic abscesses. Animal cadavers may also spread anthrax (Bacillus anthracis) infection. This anaerobic bacterium remains potentially infectious for decades (see Chapter II.5). The general principle to follow is that early processing of animal cadaver and by-products of animal origin is preferred to their storage or preservation. Collection and storage may only mean a short-term and temporary solution.

The collection, transportation and treatment of animal cadavers and by-products of animal origin can only be done by professional companies with licences, in accordance with legal regulations. On storage and collection containers a sign indicating that they contain by-products of animal origin category 1, 2 or 3 is placed. Figure II.5.5 illustrates these types of signs and the sign which indicates infection hazard warning.

Category 1, for disposal only

Category 2, not for animal fodder

Category 3, not for human consumption

INFECTIOUS MATERIAL In case of damage or leakage the Public Health Authority must be immediately notified

Figure II.5.5: Signs with infection hazard warning

(Source: ATEVSZOLG Zrt. 2014 (left); www.back-tags.com (right))

A municipal collection point for by-products of animal origin may be established in the official area of the town or village – including the suburbs. This facility collects only by-products of animal origin and, apart from temporary storage and possible cooling, no other operations are carried out. The by-products of animal origin are later transported for further processing and treatment to other facilities with licences according to the Regulation (EC) No 1069/2009 of the European Parliament and of the Council. The municipal collection point must not be a hazard to the environment concerning public and animal health and environmental damage, and must not cause odour or smell impact. The collection point must be easily accessible via a road in all weather conditions. The collection point must be equipped with a fence that is a minimum of 150 cm high and a lockable gate.

At the municipal collection point a building must be constructed that is suitable for storing the container for by-products of animal origin (Figure II.5.6) as well as other tools necessary for cleaning and disinfecting, and also chemicals and – if there is no other solution – can also provide the staff with an opportunity to manage their personal hygiene. The great advantage of container based transportation (Figure II.5.6) is that loading and emptying does not require physical labour so, by simply changing containers, transportation is easier and faster. The walls and surfaces of the building that contains the storage container and the area in front must be easy to wash and disinfect. A water supply for cleaning, disinfecting and personal hygiene must be provided and wastewater treatment must also be organized. The collection point also needs a weighing scale which can be used to measure the weight of at least small or middle-size animals.

The plant-based collection point for by-products of animal origin is a building, or part of a building, for the collection, temporary storage and possible cooling of by-products of animal origin produced on the premises of the plant, such as an animal farm, slaughterhouse, food production plant, commercial unit, catering industrial plant or any other plant where by-products of animal origin are produced. The facility must adhere to all general epidemiological regulations. At slaughterhouses, by-products are stored in designated containers in well-separated areas. Into the containers for by-products of animal origin no other materials or waste (e.g., iron hooks, stones, plastic bags, etc.) must be added, as they may cause technical problems during processing.

When by-products of animal origin are transported within the country, a trading document is required (in 3 copies) and must be kept for 2 years. Based on the document, computerized records are kept, which makes it possible to monitor the amounts of specific by-products that are transported per business partner or time period. The trading document is completed by the owner of the by-product of animal origin and also by the company responsible for handover, but in the case of perished animals, the transporter of by-product of animal origin can also fill it in with the cooperation of the owner.

Large-sized animal plants, slaughterhouses, food producers, commercial and catering units are obliged to have a contracted transportation company and facility licenced to transport and process by-products of animal origin.

The owner of by-products of animal origin is obliged to report once a year about the amount of by-products of animal origin handed over for processing and disposal for each plant to the local animal health authority. No report is necessary for by-products of animal origin produced at small-size animal plants if the by-products have been handed over to municipal collection points, registered transportation companies or plants, and the documents are kept safe for a minimum of two years.

The transportation of by-products of animal origin is carried out – and is monitored regularly (quarterly) by authorities – with special modern trucks with closed boxes, no-drip and no-corner technology inside, that have easy-to-wash and disinfecting surfaces and a special back side with lifting technology. Such trucks must not be used for other purposes. Figure V.6 illustrates the vehicles for the collection and transportation of by-products of animal origin.

Figure II.5.6: Collection and transportation vehicles for by-products of animal origin
(Source: Biofilter Zrt.; ATEVSZOLG Zrt., 2014)

II.5.3. The collection, storage, transportation and processing of used cooking oil and fat

Used cooking oil and fat are the waste oil and fat materials derived from cooking activities in restaurants, catering units and kitchens – including central public kitchens and also household kitchens. Frying in fat and oil is one of the most popular kitchen preparation methods. When the oil is used several times, it undergoes changes that lead to a loss of value gastronomically; that is, the oil gets old and, as a result, sooner or later it is not suitable for food production any more. When oil of vegetable origin is overheated – especially to over 170-180°C – some of its components decompose and health-damaging carcinogenic materials (PAH) may accumulate. In Hungary tens of thousands of tons of cooking oil is used; however, it is estimated that 30 percent of it ends up in sewers (Chapter II.14.4.4). Used cooking oil and fat have a damaging impact on the environment.

Figure II.5.7 shows the process of used cooking fat treatment at a Hungarian company.

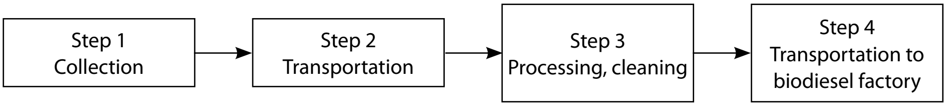


Figure II.5.7: The treatment process of used cooking fat *(Source: Biofilter Zrt., 2014)*

The greatest volume of collected used cooking oil comes from the gastronomy sector. According to regulations, catering units are obliged to hand over all used cooking oil to licenced companies. In public canteens, large hotels and restaurants this type of waste is collected separately and due to its processing environmental damage can be avoided.

However, the volume of residential used cooking oil that is collected is also increasing, which shows that society is getting more and more aware of environmental issues. Waste collection courtyards and some petrol stations have also started residential used cooking oil collection programmes. Certain community groups already selectively collect used cooking oil, and from time to time used cooking oil collection campaigns are organized (Figure II.5.8).

Figure II.5.8: The selective collection and transportation of used cooking oil
(Source: http://gondolkodjegeszsegesen.hu/olaj-a-tuzre/; http://transpack.hu/hirek/ismet-hasznalt-sutoolajgyujto-kampanyt-inditott-mol; http://www.sibio.hu/hasznalt-sutozsiradek-elszallitas)

A Hungarian company collects used cooking oil and fat mainly from the kitchens of catering units and public canteens. They become the owners of the waste with the obligation to treat and utilize it using modern technology.

The collection of used cooking oil and fat must be carried out in so-called unclean areas of catering units in containers that can be easily washed, disinfected and locked and which are placed in a separate and, if possible, cool (refrigerated) room. This way any unpleasant smells and public health risks (such as insects) may be avoided. Both inside and outside the catering unit the collection of waste must not contaminate food and dishes under preparation or that are ready for sale. Collection and storage containers must have proper covers with easy closing systems. Their design must ensure there are no gaps or holes in the containers and the material they are composed of must be easy to wash and disinfect. At restaurants, catering units and kitchens the collection of used cooking oil and fat is carried out using 60-litre plastic containers with covers and clamp closing systems (Figures II.5.2 and II.5.8).

The collected used cooking oil reaches the processing plant of the company, where the waste is processed using a closed technological system (Figure II.5.9). The unique technology developed by the company makes it possible to separate cooking oil after it has settled and been decanted in a container park, based on its future use. The 60-litre collection containers are cleaned in an automatic barrel washing machine.

After processing, the treated vegetable oil is mainly sold for the biodiesel sector, and a smaller amount is sold for the asphalt, gypsum, paint production and to carpentry industry. The collection and processing of used cooking oil and imported treated vegetable oils provide biodiesel plants with the materials they need, both in Hungary and in the neighbouring countries. From an environmental point of view, the use of biodiesel is much better than that of crude oil considering that crude oil takes millions of years to form, while the components of biodiesel are produced through relatively fast biological processes. The cleaning residues (breadcrumbs, leftovers) left behind during the processing of used cooking oil are utilized in biogas plants.

Figure II.5.9: The treatment of used cooking oil and fat at the plant *(Source: Biofilter Zrt., 2014)*

Figure II.5.10 illustrates the collection and treatment process of used cooking oil at the company presented in the example.

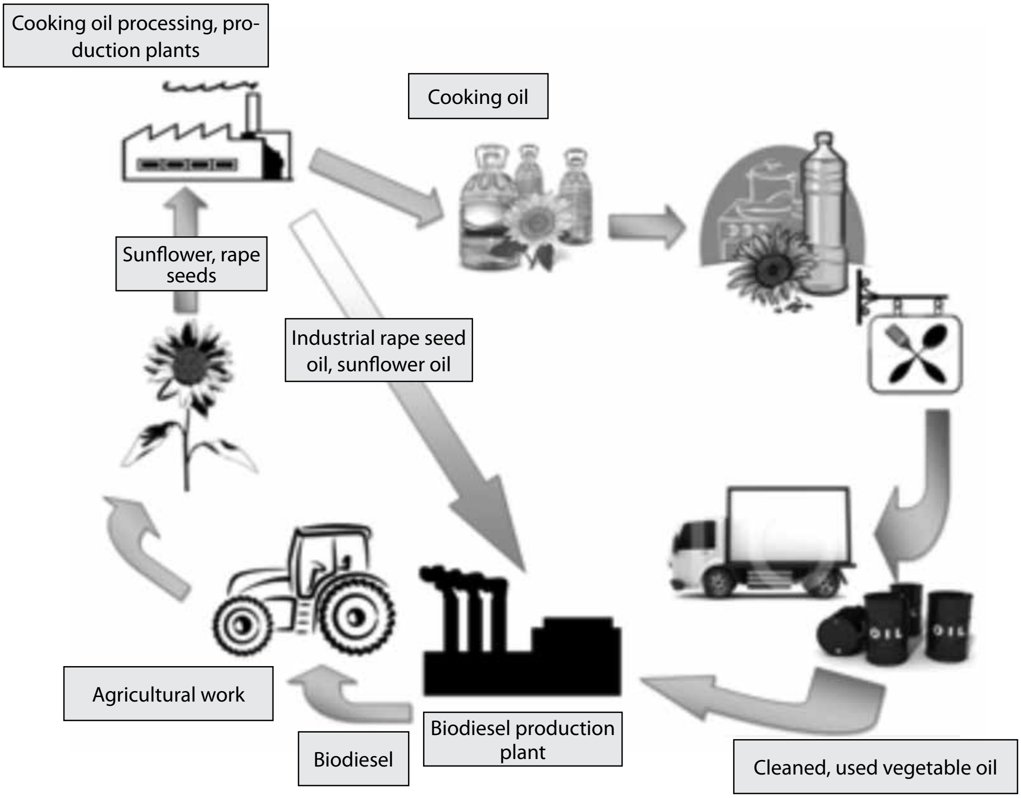


Figure II.5.10: The collection and treatment processes of used cooking oil

(Source: Biofilter Zrt., 2014)

II.6. The utilization of by-products and wastes of the food industry (László Simon)

Waste utilization (see definition in Chapter II.1) refers to the activity of modifying the by-products and waste materials produced during production and other activities to create directly or indirectly products that fulfil the needs of the customer. At the stage of utilization the by-products/wastes of the food industry either re-enter the production process as raw materials, or as energy sources or as semi-finished or finished products– or are directly reused.

If utilized, most of the material and energy the waste contains does not get lost, so from an economic point of view it is essential that the proportion of reprocessed and sold food by-products and waste should be as high as possible. A significant part of the by-products and wastes generated during food production contains valuable material content, which may be extracted through the use of different technologies. This is also important for the environment, as, due to the fact that the wastes are processed, the impact and pollution of the environment decreases.

II.6.1. Reusable components of the by-products and waste materials of the food industry

By-products and waste materials with a usually high organic content that are generated by the food industry are utilized using physical, chemical and biological processes. To select the proper technology it is essential to know the components and main groups of compounds of the material. These groups will be introduced in the following chapters.

II.6.1.1. Carbohydrates

Carbohydrates account for the greatest part of organic materials in the biosphere. Structurally, they are polyhydroxy aldehydes, polyhydroxy ketones and their derivatives. Their general formula is $(CH_2O)_n$ with $n \geq 3$. Carbohydrates can be classified into three groups:

- monosaccharides or simple carbohydrates,
- oligosaccharides (2-10 monosaccharides form a compound),
- polysaccharides, which are formed when large numbers of monosaccharides create linear or branched compounds.

Monosaccharides can be broken up into smaller units through acidic hydrolysis. In nature the most widespread monosaccharides are hexoses, which can also be found in their free form (e.g. glucose). The best-known monosaccharides are glucose or grape sugar (Figure II.6.1).

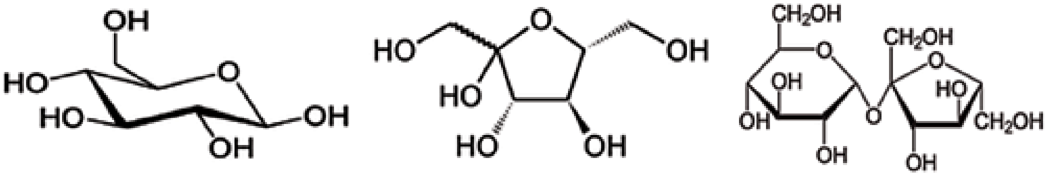


Figure II.6.1: Glucose, fructose and sucrose *(Source: http://hu.wikipedia.org/wiki/Glükóz;http://en.wikipedia.org/wiki/File:Skeletal_Structure_of_Cyclic_D-Fructose.svg; http://en.wikipedia.org/wiki/File:Saccharose2.svg)*

Glucose can be produced through the acidic or enzyme hydrolysis of starch (for example, corn or potato starch). The glucose produced through the acidic hydrolysis of potato starch is called potato sugar. Fructose (Figure II.6.1) or fruit sugar is the sweetest type of sugar. It is present in fruit and honey in natural forms. Link-up of glucose and fructose forms sucrose (cane sugar, beet sugar) disaccharide (Figure II.6.1), which is a very important sweetener and nutrient used by mankind. It is produced from sugar cane or sugar beet.

The most frequently occurring polysaccharides in nature are cellulose (Figure II.6.2) and starch (amylose, amylopectin, Figures II.6.2 and II.8.3) – both forms consist of glucose chains – the most frequent natural carbon compounds on Earth. Cellulose (e.g. carboxymethyl cellulose) is present in a large number of food products as an emulgator, expander or diet fibre. Starch is the most important component in a lot of basic types of food (crops, potatoes, legumes). It is used to thicken dishes, produce pasta or industrial grape sugar and also to stiffen textiles. Starch gum or flour-paste (produced from starch) is a cheap type of glue. When materials with starch content break down, grape sugar can be produced, which can be further processed to make ethyl alcohol. Pectins in fruit (Figure II.6.2) consist of different monosaccharides (they can be extracted from apple peel, gooseberries, grapes, pears, citrus fruit skin or sugar beet slices, see also Chapter II.10.1.1) and can be used as gel producer and gelling agent (E440).

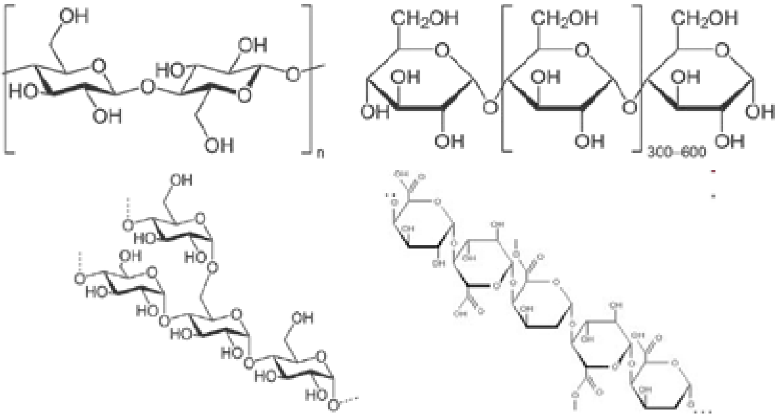


Figure II.6.2: Cellulose, amylose and amylopectin (starch), pectin (polygalacturonic acid)
(Source: http://en.wikipedia.org/wiki/File:Cellulose_Sessel.svg; http://en.wikipedia.org/wiki/File:Amylose2.svg; http://en.wikipedia.org/wiki/File:Amylopektin_Sessel.svg; http://sci-toys.com/ingredients/pectin)

II.6.1.2. Amino acids and proteins

Amino acids (Figure II.6.3) are carboxylic acid compounds which, in addition to the acidic carboxyl group, also contain the basic amino group (-NH_2). A large proportion of amino acids are involved in the building of proteins, the material of living organisms. L-amino acid is the primary compound that takes part in the formation of these proteins. It contains the amino group on the carbon atom next to the carboxyl group.

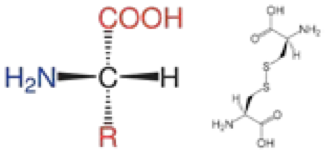


Figure II.6.3: L-amino acid and cystine *(Source: http://hu.wikipedia.org/wiki/Aminosavak#mediaviewer/F%C3%A1jl:L-amino_acid_general.svg; http://hu.wikipedia.org/wiki/Cisztin#mediaviewer/F%C3%A1jl:Cystine-skeletal.png)*

When amino acids are combined, peptides are formed. When polypeptide chains containing ten to hundred amino acids are combined, proteins are formed. Proteins are complex macromolecules that appear in both vegetable and animal cells. At least half of the dry matter content of living cells is protein.

Through hydrolysis, proteins can be broken down to polypeptides and then to amino acids. Poultry feathers rich in keratin can be used to produce e.g. fodder or amino acid products rich in cystine (leucine, serine) (Figure II.6.3).

II.6.1.3. Carboxylic acids, fats and oils

Carboxylic acids are carbon compounds found in both plants and animals in which the carboxyl group (-COOH) is present. The formula of monovalent aliphatic carbonic acids is R-COOH. The simplest carboxylic acid is formic acid (H-COOH) and by increasing the number of carbon atoms, acetic acid (CH_3-COOH), propionic acid (CH_3CH_2-COOH) and butyric acid ($CH_3CH_2CH_2$-COOH) are formed. The hydroxy propionic acid derived from propionic acid is called lactic acid, which is produced during lactic acid fermentation when milk sugar (lactose) (Figure II.8.7) breaks down. Among the by-products of the food industry, citric acid (E330) and tartaric acid (E334) can also be found (Figure II.6.4) (in the food industry these types of antioxidant materials are used as souring agents), which are carboxylic acids with more carboxyl groups.

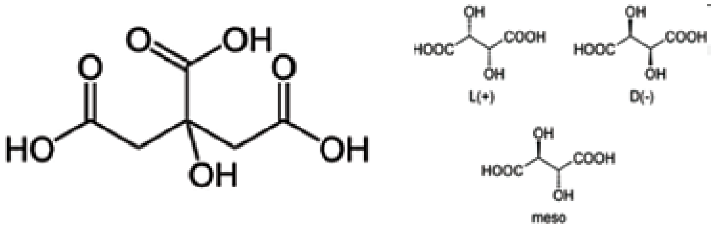


Figure II.6.4: Citric acid and tartaric acid

(Source: http://hu.wikipedia.org/wiki/Citromsav; http://hu.wikipedia.org/wiki/Tartaric_acid.png)

Citric acid is present in a lot of sour fruit in a free form or as a potassium or calcium salt. It can be produced from lemon juice or through fermentation of corn starch and waste from the food industry (e.g. apple pomace). Tartaric acid can be made from grape recrement (see Chapter II.8.4).

Some of the saturated, aliphatic carboxylic acids with high carbon atom numbers (fatty acids) are important components of fats of vegetable and animal origin. Fats and oils are glycerol esters of fatty acids. In fats, saturated fatty acids and in oils unsaturated fatty acids are dominant. Saturated acids (e.g. palmitic acid, stearic acid) contain a carboxyl group to which a longer or shorter monolinear, saturated hydrocarbon chain is connected. In food products, saturated fatty acids in free form are present only in low quantities. From the unstaurated fatty acids that are found in higher order organisms, oleic acids, linoleic acids, linolenic acids and arachidonic acids are found in greatest proportions. From e.g. deep sea fish, polyunsaturated essential fatty acids can be extracted (fish oil).

Biofuel (biodiesel) can be produced from vegetable oils and fats of animal origin for use in diesel engines through transesterification with short-chain monoalcohol (methanol or ethanol).

II.6.1.4. Alcohols

Alcohols are carbon compounds in which one or more hydrogen atoms of the saturated open chain, ring structured or unsaturated hydrocarbons are replaced by a hydroxyl (OH-) group. The best-known alcohols are monovalent aliphatic alcohols with an open carbon chain (general formula: R-OH). Their simplest compounds are methyl alcohol (CH_3-OH), which is poisonous even in small amounts, and ethyl alcohol (CH_3CH_2OH), which is the main component of alcoholic drinks. Ethyl alcohol can be fermented from several by-products of the food industry (e.g. molasses) or from grape recrement or wine-lees (dregs).

Bioalcohol (unrefined ethyl alcohol) can be used as fuel. Methyl alcohol is necessary for biodiesel production (see above).

II.6.2. The utilization processes of by-products and wastes of the food industry

The processes suitable for utilizing by-products and waste materials generated by food production depend on the composition and characteristics of these materials. During selection of the correct technological process, in addition to the composition and quantitative features of the by-products/ wastes the following features must also be examined:

- the amount of by-product/waste and the place of its production,
- if the production is regular or seasonal,
- what useful materials it contains,
- if the necessary technical conditions are present (buildings, area, machines, equipment etc.),
- if is it possible to economically carry out the collection, storage and transportation of by-products/waste between the place of production and place of processing.

After examining and assessing the conditions, the technology for the economical processing of the by-product/waste processing can be selected.

Table II.6.1 summarizes the technology used for some typical by-products and wastes of the food industry (this is not a complete list).

Table II.6.1: Technology used for treating by-products and waste of the food industry
(based on Kónya, 1999 with modifications by Simon, 2013)

Food industry branch	**Typical by-product/ waste**	**Applied utilization process**			
		Agricultural		**Industrial**	**Energetic**
		Soil power management	**Animal fodder**		
Conservation industry (canning, cooling, drying industries)	vegetable and fruit remains	+	++	++	-
Milling industry	bran, sprout, fodder flour, by-products of the husking industry[a]	-	+++	+	+[a]
Vegetable oil industry	extracted soya (sunflower) grits[b], sunflower husk[c]	-	+++[b]	+[c]	++[c]
Sugar industry	sugafactory beet potash[d] , lye sugar beet slice[e], molasses[f]	+[d]	++[ef]	++[f]	+[e]
Distilling industry	vinasse[g], mash wash[h], grape marc and fruit marc[i], sprituous yeast[j]	+[g]	++[ghij]	++[hi]	+
Brewing industry	beer marc[k], beer yeast[l]	-	+[kl]	-	+[k]
Poultry and meat industry	blood, bone, hoof, horn, feather, fur, meat, fat, offals, etc.	+	++*	+	+
Milk industry	buttermilk, whey	-	+	++	-

The by-products and wastes of the food industry can be utilized based on the ultimate purpose of their use in the following way:

1. Production of marketable products with a slight modification of the by-product.
2. Agricultural utilization (Chapter II.7), when the – often significant – protein, carbohydrate, vitamin and mineral content of the by-products of the food industry is extracted using different processes. For the purposes of agricultural utilization, 2 main groups are differentiated between:
   - feed – using the materials of the by-products for feeding to domestic animals,
   - compost or manure - when the materials of the by-products/wastes are used to enrich soil.

3. Industrial utilization as a raw material (Chapter II.8), when the valuable materials of the by-products/waste (e.g. antioxidants, diet fibres, pectin, aromas, organic acids etc.) are extracted and turned into products suitable for human consumption (Chapter II.10.1).
4. Energy utilization, in which the energy content of waste is extracted or the waste of the food industry is processed to produce materials to be used as fuel (e.g. bioalcohol, biodiesel) or for heating (e.g. biogas) (Chapter II.9). During these processes the energy content of the organic materials of the waste is utilized.

The following chapters provide details about the agricultural, industrial and energy utilization of by-products and wastes of the food industry and their technologies.

II.7. Agricultural utilization of by-products and wastes of the food industry (László Simon)

For agricultural purposes, the by-products and wastes of the food industry are mainly utilized as fodder, or as compost or manure to enrich the soil. The following chapter will discuss what opportunities are available for the agricultural utilization of the by-products and wastes of the food industry.

II.7.1. The agricultural utilization of the by-products and wastes of the canning, cooling (refrigeration) and drying industries

When vegetables and fruit are processed, the canning, cooling (refrigeration) and drying industries generate a lot of by-products and waste materials (e.g. stems, leaves, seeds, peel, vegetable and fruit remains, pomace or marc left behind after pressing), which can be directly or after slight modification (e.g. drying, grinding, fermentation) and effectively used as fodder. These by-products and wastes contain numerous useful nutrients (carbohydrates, proteins, fat and oil, see Chapter II.6.1). Due to their high water content, they decay fast as fodder. Some by-products are utilized as added ingredient through ensilage, or they can be ploughed into the soil after composting. The proportions of by-products generated during the processing of vegetables and fruit are the following: tomato 10 percent, apple 15 percent, apricot 25 percent, pear 18 percent, sour cherry, cherry 25 percent and raspberry 12 percent.

Tomato marc (Figure II.7.1) can be fed to ruminant animals after grinding as its raw fibre content is high. Apple pomace (Figure II.7.1) is also used as fodder for ruminant animals (cows, beef cattle, sheep). When corn is processed, husks and corn-cobs (cobs left behind after the corn kernels are removed) remain. Their carbohydrate content is high and they can be used in silos or as components of fodder.

Figure II.7.1: Dried tomato marc and apple pomace

(Source: http://premiumpetfood.wikidot.com/tomato-pomace; Photo on the left: László Simon)

II.7.2. The agricultural utilization of the by-products and wastes of the milling and hulling industries

Due to their high starch (and protein) content, most by-products and wastes of the milling and hulling industries are used as fodder. Some materials (e.g. corn cobs, rice hulls) are not suitable as fodder due to their high fibre content. Wheat bran (Figure II.7.2) is popular as fodder, is easy to digest and is delicious, rich in B-vitamins and fibre. They are mostly added to forage mixtures which are given to cows and brood sows and also pigs. They are carriers of micronutrients in pre-mixes.

Figure II.7.2: By-products of the milling and hulling industries used as fodder
(Photo: László Simon)

Wheat germ (Figure II.7.2) is valuable fodder, rich in oil, protein and vitamin E. Fodder flours are by-products produced when crops are milled. Their starch content is over 35 percent and their protein content is about 15 percent. Wheat fodder flour (Figure II.7.2) can be used as fodder similarly to wheat bran and barley, rye and corn fodder flours (Figure II.7.2). Pea fodder flour (Figure II.7.2) is produced after hulling when peas are polished. This fodder is also rich in protein. Rice fodder flour (rice bran Figure II.7.2) is produced when rice is polished. It has a high starch content.

II.7.3. The agricultural utilization of by-products and wastes of the vegetable oil industry

The vegetable oil industry produces large amounts of by-products from which fodder with high energy content can be produced. In industrial plants using so called hot technology (solvent extraction) vegetable oil is produced from the oily seeds of rapeseed, pumpkin, hemp, flax, sunflower, soya bean etc. while at small-sized plants tomato or tomato seeds (for example) are used to produce oil, usually through the application of cold (gentle) pressing technology. The remaining by-products and waste materials are seedhulls, presscakes, extracted grits and filtering residues.

Figure II.7.3: Sunflower press cake *(Photo: László Simon)*

Press cakes (Figure II.7.3) are wastes with an oil content of 4 to 8 percent. They are produced when raw materials with 50 percent oil content (e.g. sunflower) are pressed several times. Before the pressed oil cakes are mixed into the fodder, they need to be crushed into small pieces. The oil content of the cakes increases their nutritional value as fodder. They must be used within a short time, however, as the oil starts to grow rancid and acidic when exposed to air, which decreases their nutritional value in fodder.

The oil content of different seeds – after pressing – can be extracted using fat solvents (hexane, benzine). The oil content of extracted grits is usually under 1 percent, which means they can be stored for a longer time. Their protein content is high (35 to 50 percent). They keep their grit-like structure and it is not necessary to break them or cut them if they are used as fodder. The extracted grits must not have any fat solvent residues, even in very small amounts as they are poisonous to animals. The vegetable protein content of mixed fodder is usually defined at the right level with extracted oily seed grits. The grits must not be rancid, damp, mouldy or smell strange. The water content of extracted grits is most beneficial if it does not exceed 10 percent. Among the extracted grits used in fodder production the important ones are soya grits (Figure II.7.4), sunflower grits (Figure II.7.4), peanut grits, cottonseed grits, flaxseed grits, rapeseed grits (Figure II.7.4), lucerne grits and corn sprouts grits (Figure II.7.4).

Following solvent release and heat treatment (for soya trypsin inhibitor decomposition at a heat of over 100 ^{0}C for more than 30 minutes) the extracted grits become good quality, valuable materials to be used as fodder, even if they are not so delicious. Extracted soya grits (Figure II.7.4) are fed to young animals, pigs and milking cows. This fodder is the most significant fodder material for monogastric domestic animals. Its protein content is 44 to 49 percent and raw fat content 1 to 2 percent. The extracted sunflower grits (Figure II.7.4) are used to produce mixed fodder due to their beneficial dietetic effect. They have good dietary effects due to their high protein (40 percent), calcium and phosphorus content. This product is mainly used to feed ruminant animals but in small amounts it can also be used in the fodder of egg layers, broilers and pigs.

Figure II.7.4: Extracted grits of the oil industry used for animal fodders *(Photo: László Simon)*

II.7.4. The agricultural utilization of the by-products and wastes of the sugar and confectionery industry

In sugar production the leached sugar beet slices (beet-pulp) (Figure II.7.5) generated during the processing of sugar beet are used in largest amounts as fodder. This by-product is either directly fed to domestic animals (ruminant) or dried when pellets are formed and mixed with nutrient increasing additives.

Molasses (Figure II.7.5) is a by-product of the sugar industry that is produced in large amounts. It is a thick liquid left behind when sugar is crystallized. It is brown with a sweet, caramel-like taste. Its sugar content is 46 to 48 percent and it contains 7-8 percent mineral salts. Due to its high carbohydrate content – mixed with cattle fodder – it has a positive effect on fat and milk production. It can be enriched with urea and vitamins. Animals like its taste. When granulated fodder is produced, it is used to increase the energy content of fodders and also as binding agent. Molasses – due to its taste and sticky characteristics – can also be added to coarse fodder, usually for poultry.

Figure II.7.5: Dried sugar beet slices (beet-pulp) and sugar cane molasses
(Photo: László Simon (left), Source: http://hu.wikipedia.org/wiki/Melasz_(élelmiszer) (right))

Cocoa beans (Figure II.7.6) processed by the confectionery industry and their by-product, cocoa bean hulls and press cakes, are rich in nutrients; however, their use as fodder is limited due to their high theobromine content. In the husk of the cocoa tree fruit the theobromine content is low and it can be fed to cattle after drying and grinding. Cocoa bean shells (Figure II.7.6) can be used to cover the soil (as mulch) and can also be mixed into soil after composting.

Figure II.7.6: Cocoa bean shells
(Source: http://www.garberfarms.com/shell/)

II.7.5. The agricultural utilization of the by-products and wastes of alcohol, wine and beer production

The fodder value of fermented mash washes (distiller's wash, stillage) produced when fruit "pálinka" (brandy) is made and that of marcs is variable. Corn alcohol wash (stillage) has high protein content (30 percent of dry matter) and is used to fatten cattle and can be incorporated into fodder for milking animals. Vinasse (see also Chapter II.3.2.3) is concentrated molasses wash. It is produced by increasing the dry matter content of molasses wash to 70 percent. Its raw protein content is 21 percent and it is used as fodder for cattle. The vinasse produced from the fermentation residue of sugar beet molasses (Figure II.7.7) is also used to enrich the nutrients of the soil, and as soil conditioner.

Figure II.7.7: Vinasse spraying on the soil
(Source: www.mokkka.hu)

Distilling yeast is a by-product generated during alcohol production in small amounts. It contains a lot of biologically useful proteins and minerals. Alcoholic yeast is produced after mash distillation by separating out yeast cells. It is sold in liquid, pressed or dry forms and it is added to pig and poultry fodder. In the wash of the alcohol industry Torulopsis utilis or Candida yeasts can also multiply. The yeast that is produced can also be used, after drying, to feed domestic animals.

Grape recrement, which consists of grape skins, seeds and stems (Figure II.7.8) is used only in case of necessity as a fodder, since the energy content of its dry matter only exceeds that of fodder straws if it is finely ground and, in this way, the fat content of the hard grape seed hull can also be digested. Wine-lees (dregs) (Figure II.7.8) can also be used as fodder. Due to its high fibre content it can only be fed to ruminant animals. These two by-products of the wine industry can also be utilized as organic manure and can also be composted.

Figure II.7.8: Grape recrement and wine-lees (dregs)
(Source: http://www.dailymail.co.uk/sciencetech/article-2072166/Feeding-cows-wine-dregs-improves-milk-cuts-ahem-methane-emissions.html; http://en.wikipedia.org/wiki/File:W0470-Muscadet_5_Bourbes_15342.JPG)

Beer production generates large amounts of wastewater with significant organic matter content. As this has valuable protein and sugar content, the material produced when it is separated (filtered, cleared) can be used as fodder. When beer is matured, the yeast that multiplies in the mash settles only slowly. When this material is filtered, yeast milk is produced, which has a dry matter content of 8 to 10 percent. This material is then thickened and fresh (moist) beer yeast is created with a dry matter content of 20 to 25 percent. As it decomposes fast, it is dried until it reaches 90 percent dry matter content. This material is called dried beer yeast (Figure II.7.9). Beer yeast is good quality fodder; it contains nearly 50 percent raw protein. It is also rich in vitamin B and is used to feed pigs and poultry. Beer marc (brewer's grains) (Figure II.7.9) is left behind when sweet mash is filtered. Moist beer marc (Figure II.7.12) has a dry matter content of 20-22 percent and its raw protein content is 23 percent. It contains several valuable amino acids. It decomposes fast but it can be preserved through fermentation and drying. It is used to feed cattle.

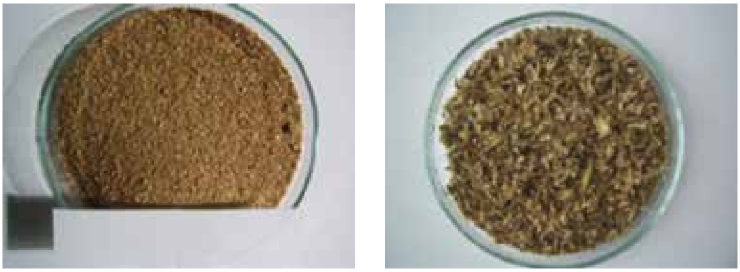


Figure II.7.9: Beer yeast and dried beer marc *(Photos: László Simon)*

The by-products of the fermentation industries such as wash, pomace (recrement, marc) and dregs can also be utilized as organic manure in agriculture.

II.7.6. The agricultural utilization of by-products of animal origin

The fodder materials of animal origin (by-products of the meat and milk industries) are easily digestible products. They have high protein content with appropriate biological indicators and amino acid composition mainly due to their significant lysine content. They are also rich in vitamin B. They facilitate the uptake of proteins of animal and vegetable origin. Their colour ranges from yellow brown to red brown. They have a typical smell. Their moisture content is maximum 10-11 percent, as at higher moisture levels several microbiological and enzyme-based diminishing processes get started.

It is mostly young animals that need nutrients of animal origin. Materials of animal origin usually diminish rapidly and their fat content easily turns rancid. If storage conditions are not satisfactory, proteins start to decompose. During the decomposition processes cadaver poisons may be released, which are very dangerous to animals. These products are a good medium for various germs so materials of animal origin – before use – must be strictly analysed (see Chapters XII and XIII). Fodder made from by-products of animal origin can be used in a limited way in accordance with the legal regulations (Chapter II.4).

The main components of mixed fodder of animal origin are:

- meat, blood, bones meal, feather meal, extracted cracklings (greaves) meal, fodder fat, fish meal, milk powder, whey and buttermilk.

II.7.6.1. By-products of the meat industry as fodder materials

Mixed animal protein meal

Figure II.7.10: Mixed animal protein meal (meat meal)
(Source: www.hu.all.biz)

Mixed animal protein meal (meat, meat bones, bone meat meal) (Figure II.7.10) is produced from category 3 by-products of animal origin by sterilization (see Chapter II.10.4), degreasing and drying. The product is homogeneous, finely-ground with a fatty touch and brownish in colour. It is a component of fodder. As far as its granularity is concerned, 90 percent will pass through a filter of 2 mm, and 10 percent through a 3-mm filter. It is treated with antioxidant (BHA, BHT). Its dry matter content is a minimum 90 percent, and it has a raw protein content 50, 54 or 62 percent. The specific essential amino acid content of the product is high. Its calcium and phosphorus content is well utilized. Its microelement and vitamin content helps the utilization of the active ingredients in mixed fodder. It is cadaver-free, produced exclusively from by-products of the poultry industry and pig slaughterhouses. It does not contain specific risk materials (SRM). It can be used to help set the protein level of fodder proteins to the amount required. At the moment it may not be fed to animals for food in the European Union; however it can be exported to foreign countries.

Blood meal

The organic matter content of blood consists almost exclusively of proteins that are rich in lysine and leucine amino acids. Blood meal (Figure II.7.11) is produced from the blood of category 3 non-ruminant domestic animals collected at slaughterhouses. It has a brown red colour. It is a sterilized, dried and chopped up product. Its raw protein content is 88±2 percent and dry matter content is 90 percent. The protein content added to fodders through blood cannot exceed 15 to 20 percent of the protein needs of the animal. Into the fodder of poultry no more than 3 percent, and into the fodder of pigs no more than 4 percent is mixed, as by destroying the amino acid balance it decreases appetite and, as a result, the fodder intake of the animal.

Figure II.7.11: Blood meal
(Source: www.carpmania.hu)

Bone meal

About 12 to 18 percent of the weight of animals is bone, which is a by-product of meat processing. Bone meal (Figure II.7.12) can be produced from raw bone or from boiled bone left behind after production of glue (Chapter II.8.5). Mixed animal bone grist is a product generated by the sterilization, degreasing, drying and grinding of raw animal bone. The product that is made from the glue-free, extracted (degreased) bone is called fodder bone meal. With some limitations bone meal can be used as a fodder additive or a manuring material, due to its calcium phosphate content. Its phosphate content is slowly released into the soil.

Figure II.7.12: Bone meal
(Source: www.co.all.biz/hu/ csontliszt-g16329)

Feather meal

Without any prior processing, the large amounts of feather collected at slaughterhouses do not have any value as fodder. However, by breaking down the keratin and cooking them at high pressure (chemical and enzyme treatment) and then by drying and grinding, feather meal (Figure II.7.13) can be produced, which is rich in cystine amino acid. Feather meal is utilized in quantities of up to 1-2 percent to feed poultry and ruminant animals as it serves as an amino acid source with sulphur content.

Figure II.7.13: Feather meal
(Source: www.ventus-aliance.cz)

Cracklings meal

Slaughterhouses produce cracklings as by-product when pig fat is melted. Products not intended for human consumption are pressed or extracted, and after grinding, the produced cracklings meal (Figure II.7.14) can be sold as fodder. The largest part of the protein content of cracklings comes from skin and connective tissue. Its biological value is much less than that of meat meal. However, its protein and fat content is easy to digest. The proportion added to poultry and pig fodder does not exceed 2-4 percent.

Figure II.7.14: Cracklings meal
(Source: www.ventus-aliance.cz)

Fodder fat

Fodder fat (Figure II.7.15) is produced from category 3 by-products of animal origin (at 133 ^{0}C temperature, under 3 bar absolute pressure with heat treatment for a minimum of 20 minutes). Its fat content is minimum 97 percent. Fodder fat can be produced from pig and poultry fat and may not contain SRM materials. It may be directly mixed into fodders in one step, or may be mixed with surface enlarged crops to feed as fat powder (Figure II.7.15). It is mainly used to provide extra energy; its quality is also influenced by its fatty acid composition. Into mixed fodder only fat from healthy animals can be mixed after having been stabilized with anti-rancidity agents (antioxidants). It is usually utilized mixed with poultry and pig fodder.

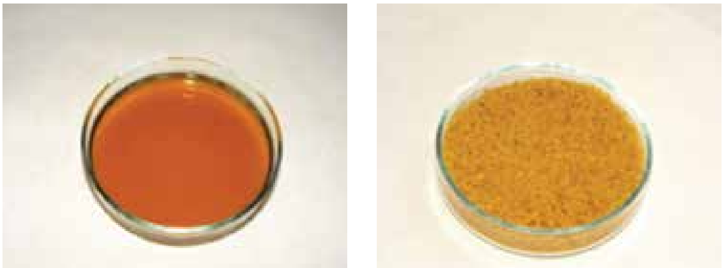


Figure II.7.15: Fodder fat and fat powder *(Source: www.atev.hu)*

Technical fat is produced from category 1 and 2 by-products of animal origin (heat treated at 133 °C temperature, 3 bar absolute pressure for min 20 minutes). It is utilized in the chemical and detergent industries and for biodiesel production. In animal protein processing plants it is used for energy production (incineration): its combustion releases 36 MJ/kg.

Fish meal

Fish meal (Figure II.7.16) is fodder material made from protein from fish and invertebrate water animals. Biologically, it is among the most valuable fodders of animal origin. It is rich in proteins (65-75 percent), lysine and also in calcium, phosphorus, microelements and vitamins. Fish meal is either produced from whole fish (e.g. cod, herring) or from waste generated during fish processing and from fish parts of lesser value.

If the fat content is over 10 percent it has a negative effect on the meal as in these cases the fish meal becomes rancid quickly. On the other hand, animals fed fish meal of higher fat content may have the typical taste and smell of the fish meal. The salt content of fish meal may not exceed 2 to 3 percent. Its colour ranges from yellow brown to red brown. Fish meal is mixed into pig and poultry forage mixtures in a proportion not exceeding 3 to 5 percent.

Figure II.7.16: Fish meal
(Source: www.horgasszunk.hu)

II.7.6.2. By-products of the milk industry as fodder materials

The technology of the milk industry (milk processing, butter, cheese and cottage cheese production) generates large amounts of waste (milk and cheese whey, buttermilk), which provides rich nutrients for use as fodder. In addition to low-fat milk, the products above are mostly used in calf, pig and poultry husbandry.

Whey (Figure II.3.1 and Chapter II.3.2.4) is a liquid with a low protein content (1 percent) which can be utilized to feed pigs and poultry. It contains a lot of B vitamins. It is a good lysine source and is also rich in cysteine amino acids. The milk sugar (Figure II.8.7) in whey can be assimiliated with yeasts (e.g. Torulopsis utilis, Torula casei, Saccharomyces fragilis) and in this way fodder yeast can be produced. Whey treated with yeast is mixed into fodder after drying. When whey is dried, whey powder (Figure II.7.17) is produced, which like the materials above can also be utilized as fodder.

Buttermilk (Figure II.3.2, Chapter II.3.2.4) can be used to feed pigs.

Milk powder (Figure II.7.17) is produced by the evaporation of the almost complete water content of low-fat milk. Its colour is white or yellow white. It is a powdery material; its moisture content does not exceed 10 percent. The biologically value of proteins is high; it is mixed into fodder for young poultry and piglets. It contains a lot of milk sugar, which in large amounts may cause intestinal problems, but helps with the bone formation process.

Figure II.7.17: Sweet whey and low-fat milk powder *(Photos: László Simon)*

II.7.7. Composting of by-products and wastes of the food industry

The by-products and wastes of the food industry that are not suitable for either making materials to be used later in the industry, nor fodder materials, but which have a high organic matter content but cannot be directly used as manure in agricultural areas are composted (the list includes sludges, fats from the wastewater cleaners of meat processing plants and slaughterhouses, materials generated when by-products of animal origin are processed, etc., see Figure II.7.18).

Figure II.7.18: Composting of municipal sewage sludge and sludge produced during the processing of by-products of animal origin *(Photos: László Simon)*

Composting is the process when separately collected biowaste (under controlled conditions, in the presence of oxygen) undergoes autothermic and thermophilic biological decomposition with the help of micro- and macroorganisms. Compost refers to the yield-increasing materials produced by the composting of biowaste. It is used to improve the nutrient supply of plants and the nutrient providing capacity of the soil. The final earth-like product of the process (usually taking 3-4 months to be created) has a moisture level of 40 to 50 percent. It contains stable vegetable mould producing materials and inorganic minerals, so in agriculture it is utilized as a soil improver.

Enterprises compost wastewater sludge of the milk, canning industries and slaughterhouses, fatty sludges, expired food products, by-products of animal origin, kitchen and canteen waste, expired animal food and production waste from the animal food industry and also manures, municipal sewage sludge and biodegradable waste (green garden waste). The goal of composting is to avoid the disposal of the by-products and waste materials listed above, which are not suitable for fodder material production and to ensure that, following the biological stabilization of their organic matter content, they are utilized in agriculture as manure mixed into the soil.

The common features of the wastes and by-products listed above (differentiating them from other wastes and by-products) are their high organic matter content, changeable solid matter content, high biological and chemical oxygen demand, high water content and poor physical structure. Due to the last two features it is important to mix them prior to composting with volume increasing, water absorbing straw or sawdust as loosening material or other organic materials. These loosening materials are also important for creating the optimal proportions of carbon to nitrogen (30:1).

II.7.8. Utilization of by-products and wastes of the food industry as manure

The utilization of materials with high organic matter content as manure to improve the nutrient level of the soil is also an old, traditional method for treating by-products and wastes from the food industry. Using suitable by-products and wastes (by mixing the compost from these materials into the soil), part of the organic and inorganic nutrient content of the soil is replaced, thus facilitating the growth of the plants cultivated in the area and providing them with nutrients.

Beet potash (defecation mud) (Figure II.7.19) from sugar manufacturing, a by-product of the sugar industry, can be used to improve saline and acidic soils.

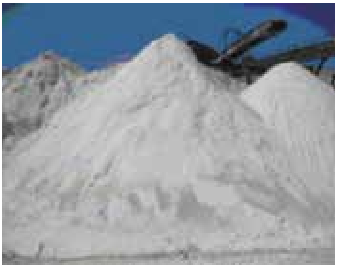


Figure II.7.19: Beet potash from sugar manufacturing *(Source: http://44101.kz.all.biz/en/agricultural-defecation-mud-g371274#!prettyPhoto/0/)*

The by-products and wastes of the food industry can be economically used in soil power management with little investment. The advantages of their utilization include the following:

– the organic matter content of the soil can be increased,
– soil structure improves,
– the need for artificial fertilizer is reduced,
– the energy demand for soil cultivation purposes decreases.

When by-products and wastes from the food industry are mixed into the soil, the so called nitrate decree must be adhered to. The decree limits the amount of nitrogen active ingredient that can be mixed into the soil annually, and determines the time of mixing.

Learning material titled 'Arable land utilization of by-products, waste materials and their products' provides detailed information about the utilization of by-products and wastes of the food industry as fertilizers.

II.8. Industrial processing and the utilization of by-products and wastes of the food industry

(László Simon)

The following chapters describe the industrial processing and utilization of by-products and waste materials.

II.8.1. Industrial utilization of by-products and wastes of the canning, cooling (refrigeration) and drying industries

In the canning industry (refrigeration and drying industries) valuable materials (e.g. pectin, colorants, flavouring materials, acids and seed oils) can be extracted from by-products and wastes (stem, leaves, seed, pressing and filtering by-products) that are generated during the vegetable and fruit processing.

Dried tomato marc (Figure II.7.1) contains 54 percent seeds and 45 percent skin. Dried seeds contain 23 to 25 percent cooking oil. The tomato skin contains 250 mg/kg carotene (ß-carotene and lycopene), which can be extracted with industrial processes. Among the compound group called carotenoids, lycopene – of which there is a very large amount in tomatoes – is one of the most efficient natural antioxidants with its cell protecting features. Lycopene can be extracted from tomato marc using industrial technology.

From apple pomace (Figure II.7.1) ethyl alcohol can be produced through fermentation, and using enzyme treatment, pectin, and through fermentation, citric acid can also be produced. From pepper seeds capsaicin can be extracted, while from the skin of colourful fruit colorants can be gained. When raspberries, sour cherries or apple pomace is distilled natural aromas can be produced and when the press remains of fruit are treated with acids or with alkaline materials, sugar can be obtained. Using chemical processes, amygdalin is produced from sour cherry pips. The hard cover of drupe fruit stones is processed to make artificial coal.

II.8.2. Industrial utilization of by-products and wastes of the milling, vegetable oil industries and of starch production

From corn cobs, sunflower seed hulls (rice and oat glume, cotton seed hull) furfural (furan-aldehyde) (Figure II.8.1) is extracted. Furfural is obtained from vegetable pentosan polysaccharides. During the process pentosans break into pentosan monosaccharides and dehydrate into furfural. Furfural is the initial material that produces the molecules that are important in the production of plastics and pharmaceuticals.

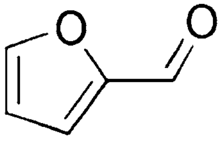


Figure II.8.1: Furfural *(Source: http://hu.wikipedia.org/wiki/Furfurol)*

From the fibres of corn cobs, xylitol sweetener (sugar alcohol) can be produced using malic acid or with the fermentation of various bacterium cultures.

Lecithin (Figure II.7.1) is produced industrially in large amounts and at high purity for the food and pharmaceutical industries. Its primary source is soya oil, but it can also be produced from unsaturated sunflower oil. In food products it is used as emulgator and stabilisator (E322) (margarine, meat products and confectionary industries, chocolate).

Figure II.8.2: Lecithin *(Source: http://www.naturalvitamin.hu)*

During potato starch production, by-products are also generated that can be made into valuable materials with the use of the appropriate technology. Yeast for baking is produced from the liquid left behind from potato liquid after the proteins have been separated out and precipitated with steam. From the fibres of potato pulp ethyl alcohol, pectin or starch can also be extracted. With some modifications (Figure II.8.3) more valuable materials can be extracted from starch, such as citric acid and lactic acid. Starch is used to thicken meals, create pasta and industrial dextrose and to stiffen textiles. From starch starch gum, glue, can also be made. From materials with starch content (e.g. corn) starch syrup (glucose syrup) and isosyrup (fructose syrup) can also be made.

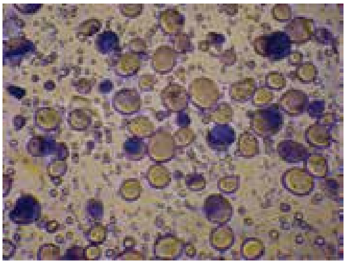


Figure II.8.3: Starch particles *(Source: http://hu.wikipedia.org/wiki/Keményítő)*

II.8.3. The industrial utilization of the sugar and sweet-making industries

The by-product with the highest volume in the sugar industry is molasses (Figure II.7.5), which is used to produce yeast and in the alcohol industry to ferment ethyl alcohol.

In the sweet industry, from the shell of cocoa beans (Figure II.7.6) theobromine (Figure II.8.4) is extracted, a raw material for the pharmaceutical industry. In cocoa this alkaloid is present at levels of up to 1.5 to 3 percent. Theobromine is a diuretic, vasodilator substance which also increases the activity of the heart muscles. It is used in different pharmaceutical industry products.

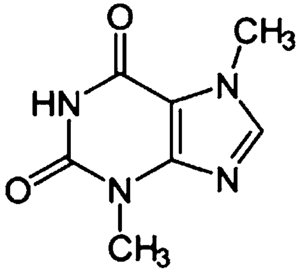


Figure II.8.4: Theobromine *(Source: http://hu.wikipedia.org/wiki/Teobromin)*

II.8.4. Industrial utilization of the by-products and wastes of the distilling and wine industry

The distilling industry is one of the main users of molasses as the by-product is utilized for fermentation and then fine spirits production. The thin distiller's wash (vinasse, see Figure II.7.7) produced during the distillation process is used to propagate (fodder) yeast.

Wine producing plants generate large amounts of grape recrement (Figure II.7.8) and wine-lees (dregs) (Figure II.7.8), which are processed to make ethyl alcohol and wine-stone. Grape recrement is also used to make grape recrement "pálinka" (brandy). Tartaric acid is produced from tartar (wine-stone) and is used in the industry as a strong but non-corrosive acid. Tartaric acid is also used in the food industry as acidifying and acidity modifying agent. Due to its complex forming features, tartaric acid helps the operation. As it does not bind the moisture from the air, it can be mixed in to drink powders and effervescent tablets.

In addition to tartaric acid, red anthocyanin colorants can also be extracted from grape recrement. From grape seeds cooking oils rich in essential fatty acids and tanning materials can also be produced.

II.8.5. Utilization of by-products of the meat industry as industrial raw materials

Using special technology, in addition to various types of fodders, from the by-products of slaughterhouses and meat processing plants materials for human consumption and other useful substances for industrial use can also be made.

From bone, glue (Figure II.8.5) is extracted to be used in the glue industry. From cattle bones bovine protein extracts are produced to be used as filling goods.

Blood from slaughterhouses is mixed with an anti-coagulant and then at low temperature is separated into plasma and thick blood. The plasma undergoes further treatment (ultrafiltering, drying, sterilization). Due to its protein content it is mainly used in the food industry (production of fillings, spreads and cottage cheese creams, cheese and bakery goods) and in cosmetics (nail and hair products). After homogenization thick blood is dried and sold. Thick blood powder is also used in the food industry; e.g., in biscuit production.

Figure II.8.5: Glue of animal origin *(Source: http://en.wikipedia.org/wiki/File:Animal_glue_liquid.jpg)*

Fur waste is used for making several products – mainly brushes for cleaning and painting. The material generated by the common processing of bone and soft tissues is used for soup powder production. Gelatin (Figure II.8.6) is produced from animal bones, pelts, skins, sinews and tendon sheathes. The protein (collagen) produced from these materials undergoes partial hydrolysis and a gel or non-gel natural soluble protein is made. This is made from pig skin, pig and cattle bone and fish. It is widely used in the food and pharmaceutical industries, photography and cosmetics. In food products it is used as jellifying agent (E441).

Figure II.8.6: Gelatin *(Source: www.cnunitedasia.en.made-in-china.com*

II.8.6. Industrial utilization of by-products of the milk industry

Among the by-products of the milk processing technology, whey is of the greatest volume (see Figure II.3.1, Chapter II.3.2.4). Pulverized and dried whey powder (Figure II.7.17) is present in amounts of 25 to 40 percent in baby food products, 60 to 70 percent in soup powders, and 3 to 10 percent in bakery goods and desserts. It may also get into bread, pasta, ice-cream and processed cheese. Whey powder improves the taste, colour and consistency of the materials listed above. Whey powder is also utilized as fodder (Chapter II.7.6.2).

As the protein content of whey is significant (0.7-1.1%), processes have been developed to concentrate whey proteins. As a result, from milk and whey rennet or acidic casein, caseinate, co-precipitate containing casein and whey protein altogether, heat coagulated and ultrafiltered whey protein can be produced. Caseinates and precipitates are used to make yoghurt, kefir, processed cheese, low-fat milk spreads, sweet pasta with milk, milky coffee, bread, bakery goods, meat products, desserts, cakes, soups, sauces, pudding, ice-cream and diet food items. Heat precipitated whey protein can be easily turned into water soluble whey protein concentrates with proteases (e.g. trypsin). This product has a high nutritional value as the proteins are easy to digest and its amino acid composition is close to optimal. It can be used to produce cheese (quark), milk products made with cultures, meat products, baked food items, pasta dishes and ice-cream.

There are various technologies for extracting proteins and lactose (milk sugar) (Figure II.8.7) from whey. Proteins are separated through ultrafiltering, electrodialysis or ion exchange while lactose is processed with hydrolysis. Proteins separated from whey are used to thicken milk products (yoghurt, ice-cream) or to produce salad dressings and cheese products (see above). Hydrolysed lactose is used as sweetener in products made by the confectionery industry, and in dietary food products. It is also widely used in other food products (aromas, spices, fruit drinks, baby food, mayonnaise, canned vegetables, etc.).

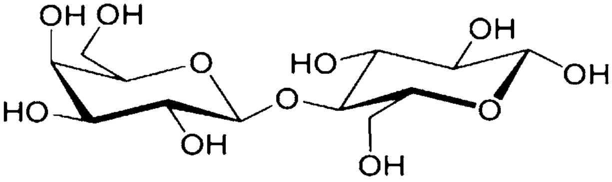


Figure II.8.7: Lactose (milk sugar) *(Source: http://hu.wikipedia.org/wiki/Fájl:Beta-D-Lactose.svg)*

Casein (Figure II.8.8) is the most important protein that can be derived from milk and cheese (phosphoprotein). It is rich in calcium and phosphorus. Its name – caseus – comes from the Latin word for cheese. Casein is an important industrial material (used in paints, glues, first plastic buttons and clips, textile materials, paper production, leather production, additives made by the food industry). It is also used in food supplements that have protein content.

Figure II.8.8: Casein and food supplements with casein
(Source: http://hu.wikipedia.org/wiki/Fájl:Beta-D-Lactose.svg)

Buttermilk (see Figure II.3.2, Chapter II.3.2.4) is a refreshing drink. It is also used in cheese production due to its significant protein content. Mixed with milk it is also suitable as fodder (Chapter II.7.6.2), while mixed with low-fat milk it is dried and pulverized. Dried buttermilk can also be utilized in bakery products.

II.9. The energetic utilization of the by-products and wastes of the food industry

(László Simon, Péter Simándi)

During the processes of energetic utilization, the energy content of wastes is extracted; this includes energy production from biodegradable waste as well as processing of wastes to make materials that can be used as fuel or heating material.

Wastes of the food industry with high organic matter content are suitable for energetic utilization if they have the necessary combustion characteristics. In the case of the energetic utilization of waste materials, the processes belong to two groups:

1. reactions in the absence of oxygen,
2. reactions in the presence of oxygen (air).

Processes that take place in the presence of oxygen provide heat energy through the direct incineration of the waste, while through processing under anaerobic conditions fuels are produced (e.g. biogas, methanol, pyrolysis oil, pyrolysis gas), which in the second step are turned into energy through oxidation.

If over 60 percent of the heat energy produced through incineration is utilized (or in the case of newer equipment, 65 percent), the process is called thermic utilization of the by-products and wastes of the food industry (Chapters II.10.7.1 and II.10.7.2). If less than 60-65% of the energy is used, the process is referred to as thermic disposal (Chapter II.10.6.2).

The following chapters describe the energetic utilization of by-products and wastes of the food industry under anaerobic (biogas production, pyrolysis) and aerobic (incineration) conditions.

II.9.1. Biogas production from the by-products and wastes of the food industry

Biogas is a mixture of methane, carbon dioxide and other gases in small proportions, which is produced mainly by the managed anaerobic decomposition of biowastes (23/2003. (XII. 29.) Decree of the Ministry of Environment and Rural Development). Biogas is a fuel in gas form produced through the anaerobic decomposition of natural organic matter. It can be produced from any natural organic matter which contains proteins, carbohydrates, fat and oil. Biogas can be generated only from materials that do not contain poisonous, toxic compounds. The majority of by-products and wastes of the food industry are good materials for biogas production. Biogas can be made – after proper preparation – from both liquid and solid by-products and wastes of the food industry. The following materials – after being correctly prepared – are all suitable for utilization in biogas plants and energy production: milk whey, production waste from the milk industry, meat pulp and waste from slaughterhouses, sludge from fat traps, processing wastes of the canning, refrigerator, vegetable and fruit industries, potato skins, remains of potato processing, used cooking oil or by-products of the cooking oil production, rapeseed and sunflower cake, leached sugar beet slices (for details see Chapter II.10.5), corn, beer and fruit marc, distilling industry wash, expired food products, wastes from restaurants of kitchens, by-products of animal origin of categories 2 and 3 (and middle stage products generated during their processing), rumen, stomach and intestinal content of any animals, dry bread, glycerine, etc.

By-products and wastes of the food industry containing easily degradable organic matter (sugar, starch, plants with organic acids) can be quickly turned into biogas with a high gas yield. Tables II.9.1, II.9.2 and II.9.3 show the amount of biogas that can be extracted from different by-products and wastes of the food industry and from wastewaters of the food industry.

The process of biogas production heavily depends on temperature. In addition to temperature, the composition of the by-product/waste material, its acidity and moisture content also influence the efficiency of biogas production and energy content of the produced biogas. In the first stage of decomposition (acidic or hydrogen phase) carbohydrates, proteins and fats undergo a biochemical fermentation process and decomposition materials (hydrogen, alcohols, amino acids, etc.) are produced. During the second stage (alkaline or methane phase) the decomposition products further decompose with methanogen bacteria while methane and carbon dioxide are produced.

As a result of methane bacteria activity during anaerobic decomposition the hygienization of organic wastes also takes place. The number of coli bacteria may be reduced and during the fermentation process most germs, insects and their eggs, and weeds seeds are killed.

After 25 to 30 days of fermentation the composition of the produced gases is on average 60-65 percent methane and 35 to 40 percent carbon dioxide. The biogas may also contain small amounts of hydrogen, carbon monoxide, sulphur hydrogen, ammonia and other gases. In the case of processing of by-products of animal origin, the biogas contains sulphur hydrogen in relatively high proportions, which may be harmful to the human body.

Table II.9.1: Amount of biogas and methane that can be extracted from municipal waste and by-products of the food industry *(Source: http://www.pointernet.pds.hu/ujsagok/agraragazat/2012/08/20120905230630525000000685.html)*

Ingredient substratum	Dry matter content (%)	Biogas volume (m^3/t)	Methane content (%)
By-products of the food industry			
Molasses	80-90	290-340	70-75
Grape marc	40-50	250-270	65-70
Fruit marc	25-45	250-280	65-70
Beer marc	20-25	100-130	59-60
Crop distillation mash wash	6-8	30-50	58-65
Municipal waste			
Kitchen food waste	9-35	50-480	45-61

Table II.9.2: Amount of biogas that can be extracted from the by-products and wastes of the food industry *(Source: Kónya, 1999)*

By-product/ waste name	Organic matter content (% dry matter)	Methane volume produced (m^3/kg dry matter)
Sugar beet slice	17	0.40-0.42
Potato pulp	10	0.27-0.29
Potato crush	15	0.29-0.47
Beer marc	20	0.37-0.39
Fruit marc	15	0.29-0.47
First stomach content	12	0.16-0.30

Table II.9.3: Amount of biogas that can be extracted from wastewaters of the food industry
(Source: Kónya, 1999)

Type of wastewater	kg COD/t	Methane volume produced (m^3/kg KOI)
Sugar industry	7	0.26
Molasses processing	215	0.24
Starch industry		
- potato starch	35	0.28
- wheat starch	110	0.31
- corn starch	14	0.30
Distillation		
- from potato	60	0.24
- from crops	190	0.24
Canned food industry (pickles production)	16	0.32
Fruit juice production	12	0.22
Milk industry	6	0.26
Meat industry	20	0.23

The energy content of biogas is on average 21-25 MJ/m^3. The produced biogas can be burnt in any type of equipment that normally burns natural gas and also in internal combustion engines. As a low pressure gas it is suitable for use in gas cookers, heaters, gas lamps, fridge aggregators and gas engines. Gas engines connected to generators produce 'green electric energy', which can be fed back into the electric grid. The hot water from the cooling system of the process is also utilized – partly to maintain the technology, partly to heat office buildings and social facilities at plants, and to supply the hot water. After fermentation the remaining digested mass (so called bio manure) and the biogas plant fermentation liquid are used as a supply of nutrients for nearby arable land.

Detailed information about biogas production technologies can be found in learning material 'Biological waste treatment'.

II.9.2. The pyrolytic thermal cracking of by-products and wastes of the food industry

Pyrolysis (thermolysis) is a thermal waste treatment process which takes place in a low-oxygen or oxygen free reductive environment. It is an endothermic process also called thermal cracking. It occurs at various temperatures.

The main point of thermal cracking is that the organic matter content of by-products/wastes goes through chemical decomposition as a result of heat in a low-oxygen or oxygen free environment. During thermal cracking (pyrolysis) gases (pyrolysis gas) liquids (pyrolysis oil) and solid materials (pyrolysis coke) are produced (Figures II.9.1 and II.9.2). Their amounts and proportions depend on the composition of the processed by-products/wastes (organic matter content), the applied thermal cracking process and physical-chemical parameters (temperature, reaction period, warm up time, coarseness, granule size, heat transmission, etc.).

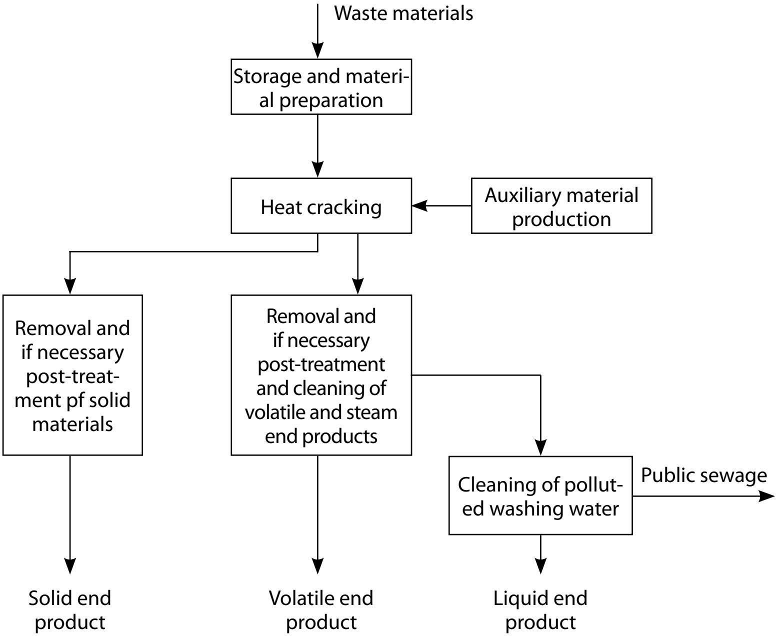


Figure II.9.1: The general technological process of thermal cracking
(Source: Kónya, 1999)

Figure II.9.2: Products created through pyrolysis (in the background: plant parts that have undergone pyrolysis, in the left: pyrolysis oil, in the medium: pyrolysis sludge, in the right: pyrolysis coke)
(Source: http://www.naturzona.hu/szakteruletek/pirolizis)

Pyrolysis is a series of physical and chemical process stages. The temperature range typically used for thermal cracking is 450-950 °C. In low temperature reactors (450-600 °C) the larger part of the produced end-product is solid material with high carbon content and pyro oil while gas production is very low. In reactors with a medium reaction time (600-800 °C) the largest part of the end-product is gas while the amount of solid remains, oil and tar is much lower. In reactors with high temperature (800-1100 °C) gases are mainly produced and the carbon content of the occasional solid part is significantly reduced.

Four reactor types are used for the thermal cracking of wastes, which depending on their operation may be vertical or shaft based, horizontally fixed, with rotating drums and fluidization reactors.

Depending on the technology used for thermal cracking, the produced end-product is volatile (methane, other carbon hydrogens, carbon monoxide, etc.), liquid (oil with methanol, phenol, toluene, etc. content, decomposition water with organic acids) and/or solid (charcoal, pyrolysis coke). The composition and proportions of the created product mainly depend on the temperature of the process.

Pyrolysis products can be utilized in three ways:

- the created product (pyrolysis oil, pyrolysis gas, pyrolysis coke) as fuel is burnt in a following step using oxidation to produce energy;
- a process is carried out to create synthesis gas, which is used as a secondary raw material of the chemical industry. During thermal cracking, from the produced synthesis gas ($CO+H_2$) hydrogen, methanol, alcohols and fuels are produced with heterogeneous catalytic processes. The high aroma carbon hydrogen content of synthesis gas is broken down to carbon monoxide and hydrogen in so called 'cracking units';
- the created products are used for other purposes (e.g. soil ameliorant with solid remains rich in carbon; so called biochar), wood preservation using water-based remains; (the granulated slag melt is used as an additive in the construction industry, etc.).

The organic matter content of by-products/wastes of the food industry and agriculture is high, which means that they can be turned into pyrolysis gas quite efficiently. The gases produced with thermal cracking in closed spaces on high temperatures can mostly be utilized energetically by burning them on the spot. From the vegetable wastes of the food industry and agriculture it is mostly those with high cellulose and organic matter content are treated by thermal cracking (e.g. rice hulls, walnut shells, peanut shells, refuse grains, corn cobs, coconut fibres, wood waste, straw, etc.). Wastes can be turned into pyrolysis gas with an efficiency level of 85 percent with a calorific value of 5-7.5 MJ/m^3 (14-20 percent of the calorific value of natural gas). The calorific value of the solid material (biochar) produced through pyrolysis is similar to that of lignite, and that of the liquids produced to methanol or ethanol.

Nowadays, the importance of agricultural utilization (Figure II.9.3) of biochar produced exclusively from the by-products/wastes of the food industry is increasing. Biochar is a material with stable carbon content made from biomass of vegetable or animal origin, whose utilization is controlled by official regulations.

Plant Based Biochar – PBC is a material with stable carbon content with high amounts of plant-based micro and mesopores and a relatively high water and nutrient retention capacity and carbon binding, but has no effect on the nutrient supply of the soil. It is produced at 450–550 °C in a reductive environment with near zero emission. It is used as soil ameliorant. It is typically used in proportions of 5000 kg/ha but in some cases the amount may be as much as 20000 kg/ha.

Animal Bone Biochar – ABC is a macroporous material with apatite mineral of high calcium phos-

Figure II.9.3: Biochar and '3R' zero emission equipment for the production of ABC biochar
(Source: http://refertil.info/public/public_upload/files//REFERTIL_newsletter_biochar_edition_March2014_HU.pdf and Edward Someus)

phate content (30% P_2O_5) and low carbon content, which creates a phosphate fertilizer with slow activation in the soil. It ensures the optimal conditions for the microbiological life of the soil and for binding macromolecular organic nutrients. It is produced from category 3 bones under reductive conditions at 500–650 °C with carbonization (Figure II.9.3) with close to zero emissions. ABC mainly contains the inorganic components, carbon and hydroxyapatite of natural bones. It is used in small doses (200-600 kg/hectare), but if necessary the dose may be as much as 1000 kg/ha.

Category 2 and 3 by-products of animal origin must be treated in Brookes gas units according to Regulation 142/2011/EU.

II.9.3. Incineration of wastes of the food industry

Solid or sludge-like wastes from the food industry with high organic matter content – if there are no other ways to dispose of them – can be utilized or disposed of by incineration (complete oxidation). Incineration is a good way to utilize or dispose of wastes of several types and composition. For high efficiency incineration the right conditions (temperature, air demand, smoke-gas time spent in the unit) must be ensured in the incineration units.

For waste incineration the primary concern is the calorific value (e.g. combustion value, water content, ash content, combustible matter content). There is a close relationship between these calorific features which have an impact on incineration.

The condition for the independent combustibility of solid wastes is that their calorific value should be minimum 8 MJ/kg and their combustible material content 30 to 50 percent. The calorific value, combustible material and ash content of liquid and sludge-like wastes vary considerably; however, there are minimum values for the material to be combustible.

The preparation of wastes (Figure II.9.4) makes their incineration energetically more efficient. The preparation steps are usually physical and mechanical. They may be the following:

– grinding, shredding,
– reduction of moisture content by drying,
– pressing,
– mixing with materials with higher calorific values.

However, these processes have high energy demands. The processes listed above turn combustible wastes into fuels (Figure II.9.4).

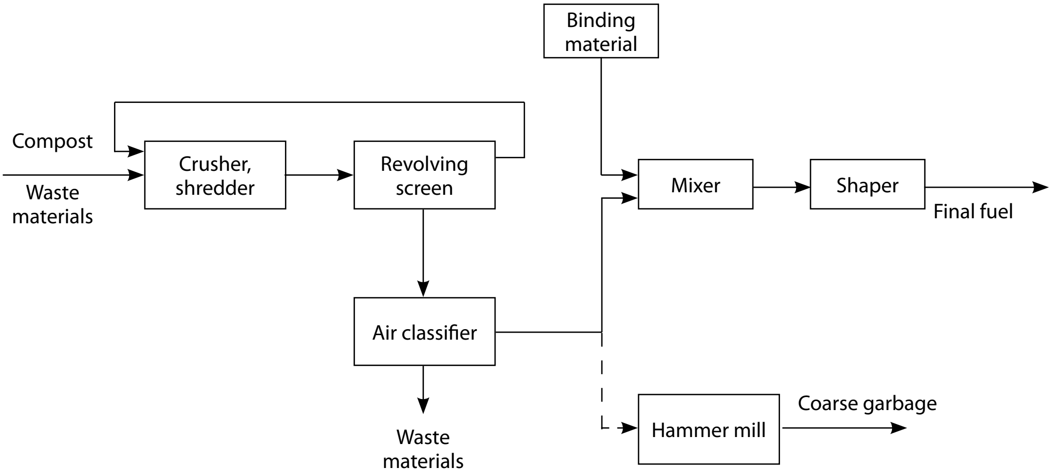


Figure II.9.4: The process of fuel production from wastes
(Source: Árvai, 1993 and Kónya, 1999)

Fuels can be in the form of fuel cakes (e.g. fuel cake from furfural bran, the by-product of furfural production) and pellets. The fuel (cakes, pellets) are solid and can be burnt in traditional heaters.

Figure II.9.5 shows the general technological procedure of waste incineration. The incineration of wastes from the food industry is not significantly different from that of other waste materials. When some part of the waste from the food industry is incinerated (high water content, low calorific value) incineration units using fuels (oil, gas supplementary fuel) are necessary for ensuring the proper conditions for the incineration process.

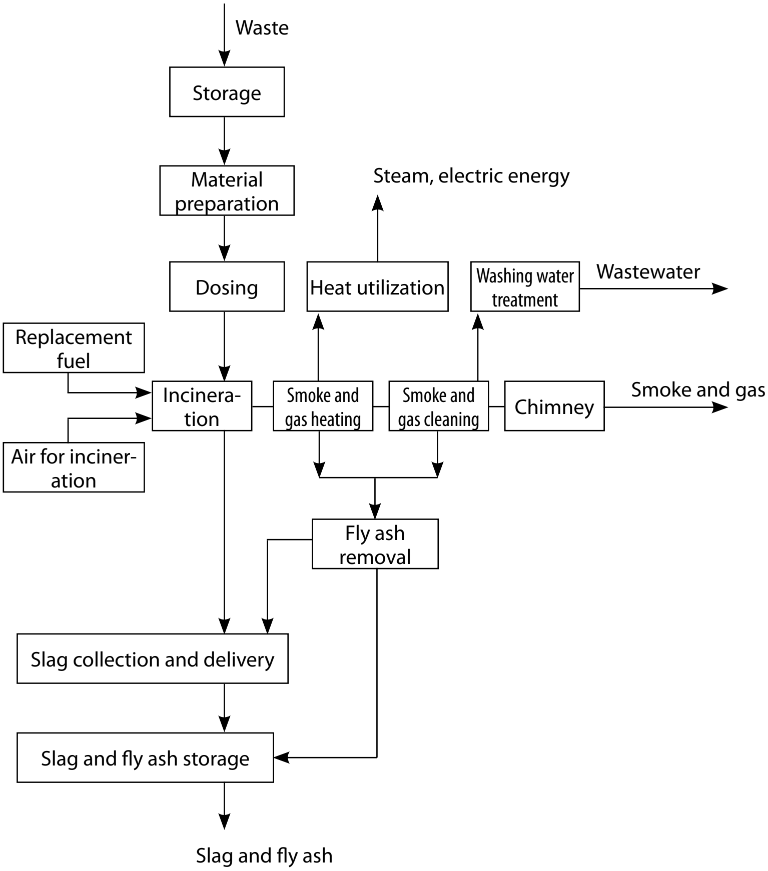


Figure II.9.5: Technological process of waste incineration
(Source: Árvai, 1993)

Most equipment that burns solid fuel is suitable for the incineration of wastes from the food industry. However, it is still beneficial to use equipment specifically built for incinerating waste (Chapter II.10.6.2, Figure II.10.28) as the efficiency of incineration can be significantly improved by correctly setting the parameters for the incineration process. There is a wide range of equipment for waste incineration and the right choice depends on the features of the waste. There are two types of units suitable for waste incineration: units with grates and units without grates. Units with grates are used for solid, and in some special cases sludge-like, waste while units without grates are used for liquid and sludge-like waste. In addition to the right choice of system it is also very important to construct a smoke gas cleaning system. During the burning process large amounts of combustion products are generated, part of which enter the air and pollute it. In order to reduce air pollution to a minimum, high performance smoke gas cleaning equipment must be used. In addition to smoke gas cleaning, the flue-ash, ash and slag that is produced must also be collected (Figure II.9.5) and stored – which, if it does not come from hazardous waste – can be dumped in landfills for municipal waste.

Energy can be generated from part of the waste of the food industry by oxidation; that is, by incinerating the material. The most popular method is using the thermic energy for heating and hot water. Sunflower seed hulls produced in vegetable oil or biodiesel plants can be incinerated on the spot (Figure II.9.6) to produce energy or fuel pellets.

Figure II.9.6: Incineration of sunflower seed hulls at a biodiesel plant

(Photo: László Simon)

Chapter II.10.6.1 describes the technology for beer marc incineration in a brewery. Energy is produced by burning rice hull and corn cobs, as well as operating, e.g. crops dryers and biomass plants. When rice hulls are incinerated, rice ash is produced, which can be used for various industrial goals due to its high silicon content (e.g. for cement production, heat insulation, oil absorbing products and chemicals and also as a soil improver). Through the incineration of the fruit stones produced in alcohol plants during the mashing process, energy can be made for distillation.

The thermic treatment of wastes (that is, incineration and pyrolysis) is regulated in detail the technical requirements for waste incineration and the operating conditions and emission limits of waste incineration technology. These regulations do not apply to facilities that treat unpolluted vegetable waste from the food industry if the heat generated during the incineration process is utilized.

By-products of animal origin require special treatment. By-products of animal origin rated to 3 categories are disposed of or utilized (Chapter II.4) depending on their hazard level by incineration or incineration or combined incineration following heat treatment. Decree 1069/2009/EC regulates that by-products of animal origin or products made from them can be incinerated and utilized as fuel, but this process is not regarded as waste disposal. Chapter II.10.6.2 describes the thermic utilization and disposal technologies for wastes of animal origin (meat meal and animal cadaver incineration).

II.10. Utilization and disposal technologies of by-products and wastes of the food industry (István Szőllősi, László Simon, Péter Simándi, Attila Kovács József, Nagyné Judit Szendefy, Zsuzsanna Uri)

The following chapters describe the utilization and disposal technologies for the vegetable and animal by-products and wastes of the food industry. The chapters will give detailed information about the industrial utilization of vegetable by-products to extract carotenoids, colorants, dietary fibres, pectin and proteins, the industrial utilization of bread waste through fermentation, the industrial utilization of by-products and wastes of the food industry to produce biodegradable packaging materials, the industrial utilization of by-products of the meat processing industry to make meat, bone, feather and blood meal, the energetic utilization of sugar beet slices through biogas production, the energetic utilization of beer marc through incineration, and the thermal disposal of by-products of animal origin and cadavers through incineration.

II.10.1. The utilization of by-products of vegetable origin to extract carotenoids, colorants, dietary fibres, pectin and proteins

The by-products of vegetable origin produced during industrial food processing are rich in dietary fibres and some of them contain significant amounts of colorants, antioxidants and other compounds that are beneficial to human health. The grits produced when oily seeds are pressed and extracted also contain a lot of proteins.

Globally, the largest amount of reusable by-products of vegetable origin are created when potatoes, grapes, citrus fruit, tomatoes, cooking bananas, carrots and apples are processed and a smaller amount when pears, apricots and kiwis are processed. Pressing cakes and extracted grits produced when oily seeds (mainly soya) are processed are especially notable (see also Chapters II.3.2.1 and II.3.2.2).

Dietary fibres are oligosaccharides, polysaccharides and hydrophilic derivatives which the human body cannot digest. Dietary fibres contain various compounds: cellulose, hemicellulose, pectin, rubber materials, and lignin. Dietary fibres are categorized as water soluble (pectin, rubbery materials) and water insoluble (cellulose, most hemicellulose and lignin). The consumption of dietary fibres reduces the risk of arteriosclerosis. Water soluble dietary fibres reduce the cholesterol level of the blood. Dietary fibres, when added to food products, change their texture (consistency) as they modify the structure and have a stabilizing effect. It is primarily water soluble dietary fibres that stabilize the structure of food as they create a jelly or thicken the liquid phase. Water insoluble dietary fibres increase the solidity and fat binding capacity of the food.

Among organic micronutrients that can be extracted from by-products of the food industry carotenoids and polyphenols are of particular significance. Carotenoids are mostly used as natural food colorants. Some of them (e.g. β-carotenoids, β-apocarotenal) contain vitamin A and have an antioxidant effect. Polyphenols are cell-protecting antioxidants as they bind or neutralize the free radicals that cause the oxidation of lipids, proteins and DNA and this way prevent numerous illnesses. Antioxidants are known to have anti-microbial, anti-thrombosis, anti-mutagenic and anti-carcinogenic effects.

It is well-known that the human body needs large amounts of protein and that it is more beneficial to get this protein from plants (crops, leguminous and oily plants) than from the meat of animals. Nowadays, numerous protein products derived from products of vegetable origin (flours, concentrates, isolates) can be found in the shops. These products have a beneficial effect on nutrient values, organoleptic and functioning properties. Protein products are used to thicken meat products and are also used in health nutrient drinks. Soya protein products are used in large amounts to make imitation cheese, whipped cream, soya milk and bakery goods.

Nowadays there are more and more so called health conscious customers, so demand is rising for food products that are enriched with physiologically important nutrients (functional food items).The natural components of by-products of the food industry, which have a specific, dietary, functional effect on the human body and health, are playing an increasingly important role in the production of such food.

II.10.1.1. Extraction of carotenoids, colorants, antioxidants, dietary fibres and pectin

Figure II.10.1 shows the general production process of compounds with a functional effect that can be extracted from different fruit and fruit skin or by-products of vegetables and can be added to human food products.

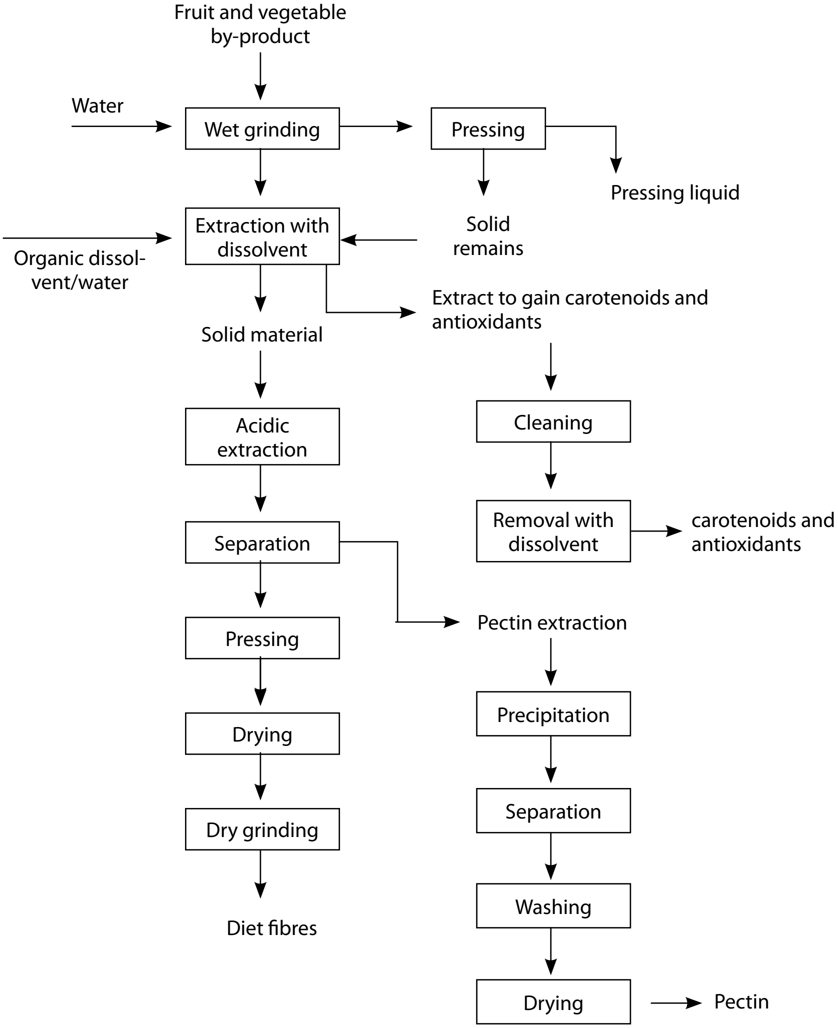


Figure II.10.1: Chart showing the processing of fruit and vegetable based by-products to extract carotenoids, antioxidants and pectin *(Source: Oreopoulou and Tzia, 2007)*

Carotenoids are usually produced from carrot marc, orange skin and tomato marc. Among organic solvents, the most efficient are acetone, ethyl alcohol, petroleum ether and hexane. The extracted carotenoids undergo dissolvent removal and cleaning in several steps.

Colorants can be extracted from carrot mash using pulverized drying or frozen drying processes. Anthocyanins are produced from grape recrement and banana hypsophyll.

Antioxidants (tocopherols, flavonoids, coumarins, cinnamon acid derivatives, chalcons, phenolic diterpenes, phenolic acids) are present in grape skins and seeds, in citrus skin and mash, apple pomace, potato skins, bean pods and the by-products of onion processing. The press remains of oily seeds, olive press cakes and by-products of the processing of certain cereals may also be rich in antioxidants. Tocopherols and some polyphenolic terpenes can be extracted with apolaric solvents (hexane, petroleum ether). Ethyl ether and ethyl acetate are efficient at extracting flavonoid aglycones, small molecule phenols and phenolic acids. With higher polarity ethyl alcohol or a mixture of ethyl alcohol and water it is possible to extract flavonoid glycosides, and phenols high large molecule weight.

Dietary fibres rich in biologically active materials (carotenoids, antioxidants) can be extracted from citrus skin or grape recrement following grinding, washing with warm water, dewatering with pressing, mild drying and breaking down the powdery material to the necessary particle size (see Figure II.10.1).

Pectin (Figure II.10.2) is a water soluble dietary fibre and makes excellent jelly. Large amounts are used in the food industry for jam production.

Figure II.10.2: Citrus pectin *(Photo: László Simon)*

This is mostly extracted from citrus skin and apple pomace but it is also possible to obtain it from peach marc or by-products of other fruit. Pectin is usually extracted using thin and hot hydrochloric or nitric acid. The extracted material is separated from the solid component by filtering, the liquid is concentrated in vacuum and the pectin is precipitated with ethyl alcohol or propyl alcohol. After separation the precipitated pectin is cleaned by washing in acidic, alkaline and then neutral pH alcohol. The product is dried at a low temperature (50 °C) in a vacuum or atmospheric driers or pulverizing driers (Figure II.10.1).

II.10.1.2. Protein extraction

Figure II.10.3 shows the complete utilization of oily seeds. In addition to vegetable oil extraction several protein products can also be produced during the process. There are two basic techniques for extracting proteins. Either the non-protein components are removed and this way the protein is cleaned, or the proteins are separated by extraction followed by cleaning and precipitation.

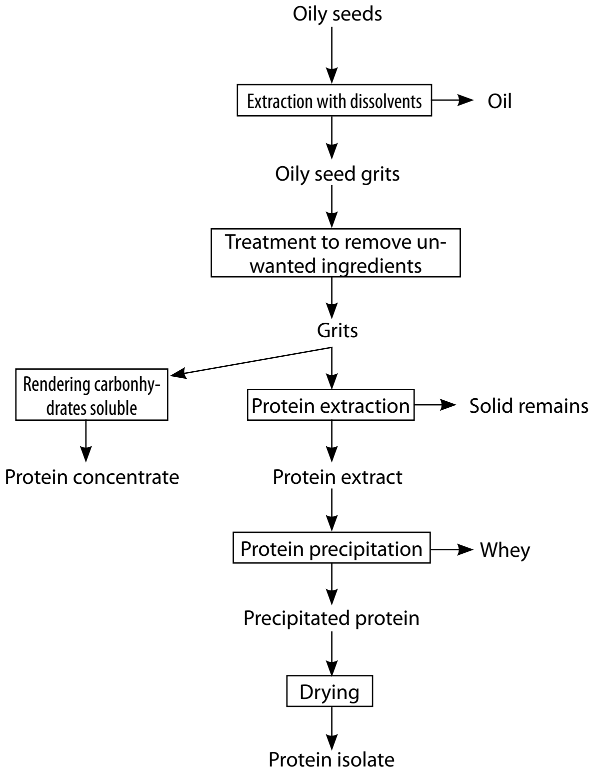


Figure II.10.3: The process of oil seed processing for protein extraction
(Source: Oreopoulou and Tzia, 2007)

Protein products are categorized based on their protein content: protein meals (grits) contain about 50 percent, protein concentrates about 70 percent and protein isolates over 95 percent protein.

On a global basis, these products are mostly made from soya, however, other oily plants (sunflower, cotton, and flax seed), extracted oil grits (Figure II.7.4) and by-products of tomato and fruit processing can also be used for this purpose.

Protein meals and extracted oily seed grits are produced during the oil extraction process. The oil is extracted from the cleaned and prepared seeds by pressing and solvents (e.g. hexane). The solvent residue is removed with steam and then the flakes are heated to over 93 °C (toasting) to block enzyme inhibitors (e.g. the trypsin inhibitor in soya). Protein denaturation is prevented using vacuum technology. The toasted darker flakes are utilized as animal fodder while the lighter flakes that are produced with a milder technological process (a vacuum) are used as food for human consumption. The dried grits are ground with hammer mills until they reach the required particle size. If solvent extraction does not take place, it is possible to produce full fat grits or to return part of the fat or lecithin into the grits. For degreased soya grits the protein level is 53 percent, and the raw fat content is under 1 percent, while full fat soya grits have 41.5 percent protein and 18-25 percent fat content.

When protein concentrates are produced, carbohydrates, salts and other small molecule volume components are removed from the grits, which enriches the insoluble proteins. The degreased grits are ground and the materials above are extracted with a mixture of water and ethyl alcohol (methyl alcohol, ethyl alcohol and isopropyl alcohol), a dilute acidic solution, the toasting of the flakes or hot water. The protein concentrates produced with these technologies improve their organoleptic features and their protein content is typically 70 to 72 percent. Usually, 750 kg of protein concentrates can be made from 1000 kg of flakes.

During the production of protein isolates proteins are extracted from seed grits using cleaning techniques after extraction. Unlike in the case of protein concentrate production, proteins are dissolved from the seed grits while the unnecessary materials stay in the solid phase. Protein isolates are usually produced from degreased seed grit, although they can be made from full fat cakes. During their production the typical steps are the following: extraction of the proteins, precipitation of the proteins and then drying of the precipitated protein (Figure II.10.3). Extraction usually takes place with warm water, the pH of which is increased with alkaline compounds (NaOH, $Ca(OH)_2$, NH_3) to pH 8-10. Most soya proteins can be extracted with such a solution. The protein content of protein isolates is over 90 percent. Their taste, smell and colour are suitable for the purpose and do not contain toxic or antinutritive materials. One third of the original volume can be used to make protein isolates: from 1000 kg of oily seed grits, 300-350 kg can be produced.

II.10.2. Bread waste utilization with fermentation

Cereals account for more than half of all food and fodder consumption. Yearly, over 2 billion tons of cereals are produced, one third of which is wheat. Wheat is ground to make flour, to which water, additives and yeasts are added to make dough, which is then baked and bread is produced. Globally, bakery goods – mostly bread products – produce the highest amount of wastes.

Due to its fast production process bread starts losing its organoleptic features in 1-3 days; that is, it starts to dry out and microbial decomposition starts (Figure II.2.5). Bread dries and gets old partly due to moisture loss and partly to the transformation (the so called retrogradation) of starch. The carbohydrates in bread (mostly starch), water and protein are easy to digest not only for people but also for microbes. It is mainly Penicillum, Aspergillus, Cladosporium, Mucorales and Neurospora genera molds that are responsible for the decay of bread (Figure II.2.5). Microbial decay can be prevented and slowed down if preservatives are added (e.g. propionic acid, sorbic acid) but consumers generally try to avoid these. Bread gets mouldy faster if it is stored in a plastic bag as the moisture in the bread cannot leave. 1-5 percent of bakery goods are wasted as a result of microbial decay. Due to these processes a lot of bread and bakery goods enter household waste, even though they do not yet contain materials harmful to health.

Annually, about 100 million tons of bakery products are made globally. Bread and bakery waste (Figure II.10.4) is produced at bakeries, trading units, catering units and households.

Figure II.10.4: Bread and bakery goods waste

(Source: http://www.usda.gov/oce/img/rotator/food%20waste/bread.jpg)

According to estimates, the proportion of bread that is wasted may be as high as 10 to 40 percent in developed countries. Every day the amount of wasted bread may be as high as 10 or even 100 thousand tons globally.

Dumped bread and bakery waste may produce significant amounts of greenhouse gases (methane, carbon dioxide), which means that the reuse and utilization of bread waste is also of key importance as far as climate change is concerned.

Bread waste which is not mouldy was traditionally used to feed domestic animals (e.g. pigs, sheep, poultry and horses). As this type of use is reduced, new solutions must be found to deal with bakery waste in the developed world. The easiest way to utilize bread and other bakery waste is fermentation, as bread contains the right proportion of carbon (glucose), nitrogen and other important macro- and microcomponents for microbes. Using the commercially available enzyme products (e.g. starch decomposing amylase, glucoamylase, protein decomposing protease) bread waste can be turned into hydrolysate, which microbes can easily use to make useful molecules. Another process is so called solid phase fermentation, when bread waste is hydrolysed and decomposed by several fungi and enzymes (Figure II.10.5).

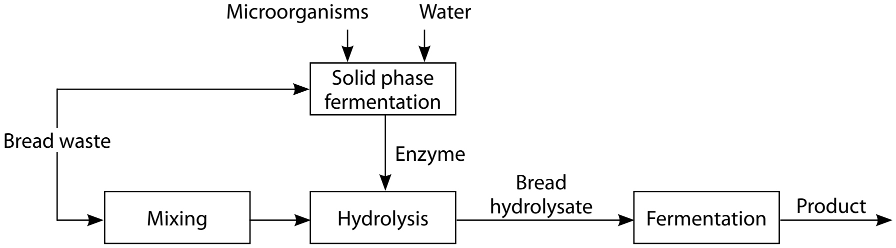


Figure II.10.5: Bread waste utilization process with solid phase fermentation
(Source: Melikoglu and Webb, 2013)

In the last few decades, bread and other bakery waste have been mainly used to produce ethyl alcohol and animal fodder, ethyl alcohol and enzyme-rich syrup, lactic acid, acetic acid, succinic acid and industrial starch (material that replaces starch), aromatic substances, methane, and biohydrogen through fermentation techniques. The processes are carried out with various microbes (e.g. Saccharomyces cereviseae yeasts, Lactobacilus amylovorus lactic bacteria), and starch and protein decomposing enzymes. For solid phase fermentation Aspergillus awamori, Aspergillus oryzae and Aspergillus succinogenes filamentous molds are used.

The substances produced from bread waste are used to multiply microbes, produce other molecules, biodegradable polymers (bioplastics see Chapter II.10.3), glucoamylase and protease products and biofuels (biohydrogen). The production of bioalcohol from bread waste is cheaper than from lignocellulose remains (from 1 ton of bread waste 255 litres of ethyl alcohol can be made). The fermentation-based utilization of bread waste is not only environmentally friendly but also economical.

II.10.3. Biodegradable packaging material production from by-products and wastes of the food industry

Packaging refers to products made from any kind of material that are used to store, protect, hand over, receive, transport and display goods, including all products from raw materials to processed products, and also one-way products used for the same goal.

Packaging materials and covers of food products for human and fodder for animal consumption belong to a special category with separate legal regulation. Food packaging refers to materials for covering, protecting, handling, transporting and displaying food products at any stage of the food production process, from raw materials to the final product, from food companies to the consumer.

The most accurate categorization of packaging materials is provided in Packaging Material Catalogue, which lists specific products based on their material and types in separate categories. The catalogue contains special codes for biopolymers, plastics made from renewable raw materials.

II.10.3.1. Biopolymers

Biopolymers and bioplastics have a unique feature: they are biodegradable. They are of great significance to the packaging industry as their widespread use may change waste management considerably.

Biopolymers can be categorised in two ways: on one hand, based on their origin, on the other, based on their degradation.

Categorization of biopolymers based on their origin

Biopolymers are of two types. One type includes biopolymers derived from natural materials – among them polymers from renewable energy sources (Table II.10.1).

Table II.10.1: Biopolymers are materials made from living organisms by living organisms

(Source: http://www.scientificamerican.com/article/how-green-are-green-plast/)

Biopolymer	Natural source
cellulose glucose	wood, cotton, corn, wheat
soya protein	soya bean
starch	corn, potato, wheat, tapioca, etc.
polyester	bacteria

The other group includes biopolymers polymerized from renewable materials (Table II.10.2). The complete decomposition of these bio plastics into water, carbon dioxide and humus takes place due to their structural makeup.

Table II.10.2: Polymerized molecules from renewable natural sources

(Source: http://www.scientificamerican.com/article/how-green-are-green-plast/)

Biopolymer	Natural source
lactic acid (produced with fermentation, its raw material is sugar)	corn, potatoes, beetroot
triglycerides (the largest amount is stored in plant and animal cells)	vegetable oil

In addition to these methods, biodegradable polymers (biopolymers) can be also made from fossil based materials. In these cases additives are added to the known polymers and in this way degradation takes place. Biodegradation is very fast: it may only take one year under composting conditions, which means that these materials can be composted, unlike traditional plastics.

Grouping of biopolymers based on biodegradation

Biodegradable plastics belong to four basic groups (Figure II.10.6):

– biomass products,
– products made from microorganisms,
– products made with biotechnological solutions,
– petrochemical products.

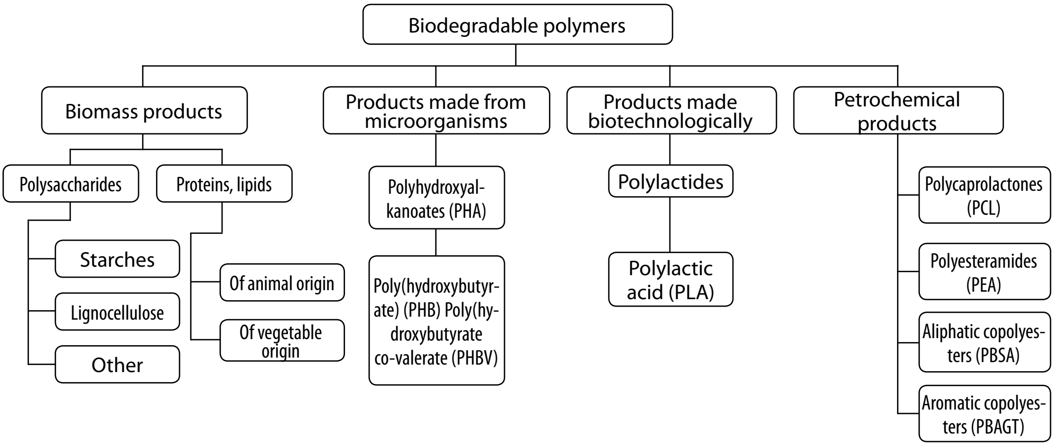


Figure II.10.6: Classification of biodegradable polymers

(Source: Averous and Boquillon, 2004)

Biomass products are natural polymers that provide the components for living organisms in nature. These biomass products can be divided into two groups: materials consisting of polysaccharides, and materials consisting of proteins (lipids). Among polysaccharides, starch and cellulose (see Chapter II.6.1.1 and Figure II.6.2) are the most important.

Poly(hydroxybutyrate) (PHB) and poly(hydroxybutyrate-co-valerate) (PHBV) are products derived from microorganisms. PHB is produced by some algae, fungi and bacteria and is stored in their cells. Both PHB and PHBV can be produced using bacterial fermentation then extraction from biomass with glucose content (see Chapter II.10.2).

Products made with biotechnological processes can be produced from polylactic acid (PLA) through starch fermentation. In the food industry polylactic acid can also be made from agricultural fodder plants (corn, wheat, sugar beets, potatoes).

Petrochemical products are of fossil-based origin, they are produced during crude oil processing and they do not decompose completely.

Biopolymers can be made from several sources. All wastes from the agriculture and the food industry which contain these chemical substances are suitable for their production. It is also important to note that polluted, infected materials that are unsuitable for human or animal consumption are suitable for this purpose. Some products can be made from, e.g. palm leaf waste or potato skins, the waste remaining after potato crisp production. Corn mash wash (stillage) can also be used to make biodegradable plastics (poly-β-hydroxybutyrate) (see Chapter II.3.2.3). Molecules made with bread waste fermentation can also be used to make biodegradable polymers (Chapter II.10.2). Crab shells left behind after the flesh is consumed are rich in chitin. Chitin can be turned into chitosan polysaccharide, which also makes biodegradable plastic.

Whichever source is used to make biopolymers, the following conditions are necessary to ensure their economic competitiveness:

- the final products made from biopolymers must be of similar quality and physical-chemical characteristics to those of traditional plastics,
- their processing (foil coating, die-casting etc.) must be possible with traditional plastic processing equipment,
- they must have a competitive price compared to traditional plastics,
- producers must get discounts from licence fees for packaging materials, and their development must be supported with this money,
- their range of use must be expanded continuously.

Biodegradable plastics are mostly used as packaging materials as their air and water steam permeability is better than that of crude oil based substances, which makes it possible to keep vegetables and fruit fresh 2-3 days longer. In addition to this, fast food chains often use plates and cutlery made from bioplastics (Figure II.10.7) to improve the reputations of their businesses. The disadvantage of bioplastics, among them PLA, is that due to their decomposition rate they are less suitable for use as packaging materials for foods with a long expiry date.

Figure II.10.7: Die-cast and foil products and cutlery from biopolymers
(Photo: Attila Kovács)

II.10.3.2. International and domestic tendencies in biopolymer production

In Western Europe the proportion of biopolymers in the packaging industry is over 5 percent. Their cost is now only 10-20 percent more than that of traditional polyethylene. As the raw material, it is mostly plant-based materials (e.g. potato starch) that are used.

In EU there have been several good initiatives for producing bioplastics. Since the environmental tender system was introduced, many companies have gone through quality tests with shopping bag products; however, most of the bags they use are polyethylene foils produced with decomposition facilitating additives, and only very few of them are bags from corn based bioproducts. However, more and more companies are deciding to use bio packaging materials even though the price difference is still significant compared to traditional plastic bags. In addition to matters of economy, the production capacity for these products is another problem in EU member states.

The opportunity for composting must also be discussed. There are products on the market (e.g. shopping bags) that carry the sign 'biodegradable' or even 'can be composted' although they do not decompose organically.

In EU, a product is environmentally friendly if it fulfils the legal requirements and passes tests. The main point is that if one-use packaging cannot be replaced, the most environmentally friendly alternative is to use packaging materials from natural sources and renewable raw materials that can be composted. The quality requirement for biodegradable environmental friendly plastic packaging is that they must be packaging materials made from natural sources and/or renewable materials that can be composted. This means that, for example, starch or polylactic acid based packaging materials are considered to be environmentally friendly.

All in all, from both an ecological and an economic perspective it is time for biodegradable plastics and packaging materials to become more widely used.

II.10.4. Utilization of by-products of animal origin to produce meat, feather and blood meal

The processes of meat, bone, feather and blood meal (from now on referred to as 'meal') and fat production from by-products of animal origin are similar all over the world. Following heat treatment for the sterilization of the raw materials, the fat and water content of the cooked material is partly removed then the product is ground and sold after a check is performed on microbiological content. Figure II.10.8 shows the technological processes available for meal production. The yellow and red colours show the technology that is used in many EU countries.

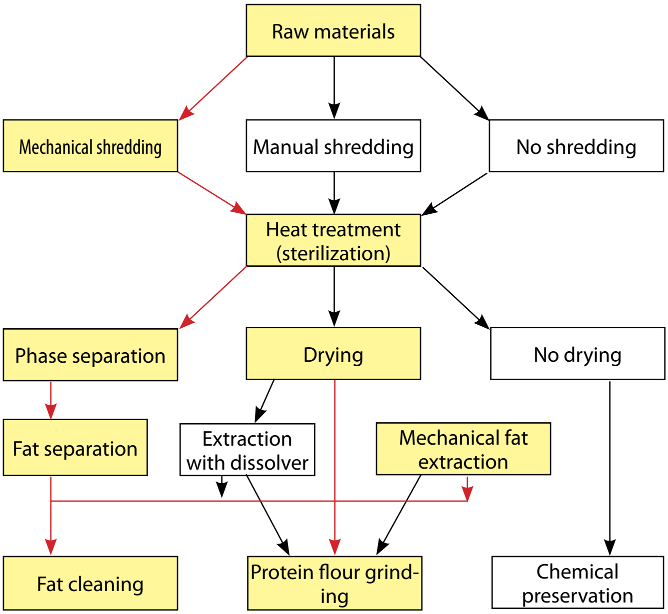


Figure II.10.8: Technological processes for meal production
(Source: www.szatev.hu/dokumentumok/szatev_bat_technologoiak.pdf)

Based on the above, the basic technological steps of meal production are the following:

- receiving the raw material,
- treating the raw material (chopping),
- sterilization (heat treatment),
- drying,
- fat separation,
- grinding,
- cleaning wastewater and air.

The specific production processes can be grouped in different ways (Table II.10.3). The yellow filling colour in the table indicates the processing techniques for by-products of animal origin used at many plants. However, it is difficult to group processes based on the same principle as the different techniques often use mixed processes.

Extraction processes based on solvents are not used anymore, so these techniques are not discussed here.

During the production process mostly wet and dry methods are used. The main point of the wet method is that the fat is removed from the raw material before drying. Cooking and drying take place in two different units. The main point of the dry method is that the cooked material is first dried and the fat is removed later with mechanical presses. The cooking and drying processes are carried out in one unit, the disinfector without any added steam. The raw material cooks in its own liquid and then dries. The liquid is removed when the drying process finishes. The heat necessary for cooking and drying is provided by indirect steam heating.

Table II.10.3: Classification of production processes for by-products of animal origin

(Source: www.szatev.hu/dokumentumok/szatev_bat_technologoiak.pdf)

Based on fat extraction	Wet processes	Fat removal in wet medium	
	Dry processes	Fat removal from dry matter	
	Mechanical fat extraction	Pressing processes	
		centrifuge processes	centrifugal process with material without drying
			entrifugal process of dried material
		extraction processes with dissolvent	from dried material (benzine, hexane)
			from dried material (benzine, hexane)
Based on technology processes	Processes in stages		
	Continuous processes		

Production processes are also divided into the categories of periodic and continuous. The advantage of continuous processes is that they have higher performance and lower specific energy demands and they can be operated by fewer people.

Continuous operation is suitable for using:

– in an integrated way for all the technological steps (sterilization, fat extraction, drying), or

– for a specific step within the technological process (e.g. continuous drying, after cyclic sterilization).

The steps of continuous drying and fat removal are simpler than continuous sterilization, therefore, these machines became popular first. Continuous sterilization is made technically more difficult by the fact that animal health regulations require that the material should be kept at a temperature of 133 °C at a pressure of 3 bar (3 x 10^5 Pa) (absolute pressure) for 20 minutes. The continuous sterilization units may be dangerous as far as animal hygiene is concerned so their operation requires strict microbiological control (the survival of sporulated bacteria must be checked for). One of the most major drivers behind the development of continuous sterilization technologies is the need to reduce odour emissions. In the case of cyclic sterilizing units the release of pressure creates a sudden impact on the condensers which decreases air cleaning performance (odours leak out). With continuous sterilization vapour is produced continuously, which means it can be used in heat exchangers to transmit heat (e.g. for hot water provision, or heating of vacuum driers). Continuous systems are practically closed; the material does not come into contact with the airspace or staff. However, they have a much higher investment cost than traditional processes and cannot be used properly if the incoming material is variable in nature.

II.10.4.1. Mixed animal protein meal production technology

In the described plant, by-products of category 3 are processed. Category 1 and 2 materials are only collected (Figures II.9-II.11). The incoming material is always accompanied by vet certificates which categorize the specific shipments. By-product which is suitable for meat meal production must be fresh and of good quality (e.g. slaughterhouse waste comprising pork, poultry and other animals, SRM free slaughterhouse waste of ruminant animals, processing waste from wild animals, etc.). The meat meal produced from the processed slaughterhouse waste is sold as raw material for pet food. The fat extracted during the process can be utilized in different areas of the industry and fodder provision. Parts of category 3 slaughterhouse by-products that are not suitable for pet food production are utilized in composting plants. The collection of by-products of animal origin must be carried out in consideration of the need to meet hygiene standards by using closed, anti-drip and anti-leak transportation vehicles exclusively for this purpose (see Chapter II.5, Figure II.5.6).

The technological process is based on wet fat removal; that is, fat is extracted following sterilization and before drying in a wet condition. The main technological processes are described in Figure II.10.9.

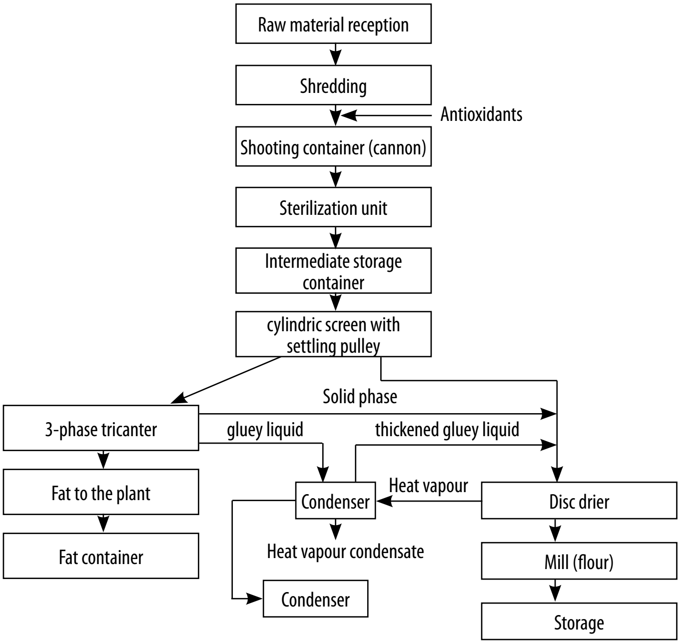


Figure II.10.9: Wet technology for meat meal production in a Hungarian processing plant for processing by-products of animal origin *(Source: SZATEV plant at Szikszó, 2014)*

The vehicles that are delivering the selectively collected raw materials empty their loads into a 100 m^3 raw material receiving container with a carpet pulley (Figure II.10.10). At the bottom of the trough, transporting pulleys (carpet pulleys) carry the material away. The speed (revolutions per minute) of the pulleys can be modified and they are powered by frequency based engines. The 4 transporting pulleys in the trough can also be started separately.

Figure II.10.10: Raw material receptacle
(Source: http://atevszolg.hu/uploads/files/allati_hulladekok_kezelese.ppt#294,34,34. slide)

Distinct feathers or bones must be emptied and spread out in the trough. The carpet pulleys carry the material to a double twin pulley, which, based on the speed of supply, carries them to the raw material chopper (Figure II.10.11), which shreds the material into 50 mm particles as regulated. Dry feathers must be moistened to make processing easier and to prevent the filling pulley from becoming blocked.

Figure II.10.11: Raw material chopping equipment
(Photos: László Simon (left); www atevszolgalat.hu (right))

Shredding is carried out by specially sharpened and hardened clawed discs (Figure II.10.11). The claws are pushed in an angle and, as a result, meet other sharpened standing claws at different moments. The shredding unit is usually powered by a driving mechanism connected to an asynchronous engine with alternating current which provides the power required for the shredding. In the case of overloading due to overfilling or materials getting stuck, the equipment prevents possible damage to the machine by temporarily rotating in reverse.

Following shredding one transportation pulley transfers the shredded by-products to a 8000-litre raw material shooting container (so called "Kanon") (Figure II.10.12).

Figure II.10.12: Raw material shooting containers (Kanon) *(Photo: László Simon)*

The feed volume of the shooting container can be modified. Until the cooking stage the prepared raw material is stored in the shooting container. The shooting container stands on measure cells and when a pre-set volume has been reached, it stops the carpet pulleys, twin pulley, shredder and spreading pulley and closes the knife bolt on the Kanon filler. After the shooting starts, it opens the steam valves (loosening and pillow steam) and when a pre-set steam pressure has been reached and the knife bolts have opened, the raw material is directed into the selected cooker. In the case of a 60-80 percent feather and/or bone mixture, 1200 to 1500 litres of liquid must be added to the shooting container. The filling process of the shooting container is operated by computer. The process is automatic once it has been started. The shooting pressure must be set at 4 bars. In the operational room a separate screen is available to follow the process and a picture is recorded using 3 cameras.

The next step is sterilization. The cooker has a volume of 10.5 m^3. It is a pressure-tight, horizontal cylindrical, double cover pot with heated mixer and mixing propellers (Figure II.10.13).

Figure II.10.13: Sterilization unit *(Photo: László Simon)*

Heat treatment in this plant takes place at a minimum of 3 bars (absolute) pressure at a minimum 133 C^{o} temperature for a minimum 20 minutes. If within the pre-set 20 minutes of the heat treatment the temperature or pressure decreases to under the pre-set values, the process operation system automatically restarts the heat treatment period from the beginning (forced heat treatment).

Minimum cooking parameters for different raw materials are the following:

– distinct bone: 40 minutes, 4 bar absolute pressure, min. 143 ^{o}C temperature,

– distinct feather: 40 minutes, 4 bar absolute pressure, min. 143 ^{o}C temperature,

– if in the cooked liquid the proportion of feather or bone or the two together is as high as 35-40 percent, 40 minutes, 4 bar absolute pressure, min. 143 ^{o}C temperature.

When the cooking period is over, the mixture gets shot into the middle container. The disinfected cooked material is stored in the middle container and is continuously mixed until the next step of the process. In the middle container the material becomes more homogeneous.

On the line that processes category 3 materials, the fat is separated by a tricanter, a horizontal pulley based, self-emptying centrifuge that separates the material into three phases (Figure II.10.14).

Figure II.10.14: Tricanter *(Photo: László Simon)*

The tricanter drum revolves at 3500 revolutions per minute (RPM), the pulley revolution difference is 1.5-29.6 RPM. The performance of the tricanter with the cooked liquid is 7.5 t/hour. To be degreased, the cooked liquid is first directed from the middle container through a drum screen that is perforated with holes with a diameter of 10 mm (Figure II.10.15), which separates the bigger bone pieces and other foreign materials, which are directly taken to the disc drier (Figure II.10.18). From the separated liquid phase the pulley settling container under the drum screen separates the remaining smaller bone parts and other foreign materials. The pulley transports the now-settled thick materials onto the transporting pulley that carries the solid phase separated by the drum screen.

Figure II.10.15: Drum screen (cylinder screen) with settling pulley
(Photo: László Simon)

The remaining – free of solid parts – liquid phase is directed to the degreasing tricanter. The tricanter separates the material into fat and degreased gluey liquid and solid meat sludge (Figure II.10.16).

Figure II.10.16: Solid meat sludge (front), fat (left, at the back) and gluey liquid (right, at the back)
(Photo: László Simon)

The fat is cleaned with a vibro screen and separator (Figure II.10.17) and then stored in fat containers until it is sold. The separated solid meat sludge gets directly transferred to the disc drier through the pulley. The degreased gluey liquid is collected prior to condensing in a gluey liquid collecting puffer container with a volume of 5 m^3.

Figure II.10.17: Degreasing with separator
(Photo: László Simon)

The conditions for efficient degreasing are the following: good quality, fresh raw materials free of foreign materials (e.g. sacks, ropes, etc.) that may block the separator plates if they enter into the fat phase. Phase separation should be done directly after disinfecting at about 95 ^{o}C, as at under 90 ^{o}C the efficiency of degreasing quickly decreases. The tricanter separates most efficiently at a performance of 4-6 t/hour, while if the period spent in the drum decreases so will the settling time while the fat content of the liquid and meat paste will increase. Fresh raw material makes a yellow-greenish suspension, which becomes an almost white gluey liquid after degreasing. If allowed to continuously operate, the efficiency of degreasing must be checked every two hours. The permitted fat content is about 0.5 percent. The quality of the fat must be continuously monitored: about 90 percent fat, 2-3 percent contaminant content, 7-8 percent water and emulsion levels are optimal.

The main machine of the drying process is the cylindrical disc drier with a heating surface of 250 m^2, which has rotor heating and inside propellers (forward, reverse mixer). To the machine is added a condensation operation step, ensuring the condensation of the drying steam. In the disc drier the maximum overpressure is 6 bars and the maximum temperature allowed is 165 ^{o}C. The capacity of the drier is 6 t/hour of raw material.

Figure II.10.18: Disc drier *(Photo: László Simon, István Szőllősi)*

The aim of condensation is to increase the concentration of the gluey liquid through vaporization. The thickening of the gluey liquid is carried out by the thickening unit with the help of the vapour generated by the disc drier. As far as thickening the gluey liquid is concerned, the thickeners are arrayed in a line. As far as the heating vapour is concerned, the thickeners are positioned in parallel. The condensation unit works as a condensator for the drier and also uses the vapour of the drier, thereby decreasing the heat energy demand of the drying by almost 50 percent. About 30 minutes after the condensation system is started, the vacuum settles at about 0.7 bar and at the same time the temperature of the circulating gluey liquid settles at about 65 °C. The water evaporated by both the drier and condenser must be continuously monitored. One kilo of water vapour evaporated by the drier can evaporate 1 kilo of water in the condenser. The drying system functions well if both the drier and condenser evaporate 2000-2500 litres of water per hour.

Depending on the quality of the raw material, the quality of the meat meal must be checked at about 105-110 °C about 2.5-3 hours later. If the quality of the meat meal is found to be suitable, then removal from storage must commence. The quality of meat meal must be continuously monitored.

The next steps involve the categorization, shredding and packaging of the final products. The material removed from the drier is still only a semi-final product as it may contain particles of a larger size, which are not permitted according to the standard. In a milling system the final product of the required particle size gets placed into a bag after going through a sorting drum screen and the right size screen line. The collected meat meal (Figure II.7.10) of a larger size is finely ground using a hammer grinder (Appendix 7) when it is of the right particle size and has gone through a sorting system. The finished product is stored in huge bags (so called 'big-bags') (Figure II.10.19).

Figure II.10.19: Storage of meat meal in huge bags (so called 'big-bags')
(Photo: László Simon)

The final product is stored on pallets in warehouses. The product may only be transported out of the plant when it is of the right content and has been checked for microbiological activity. The room

where the fodder is stored must be regularly cleaned, disinfected and aired. Animal protein fodder must not be stored in the same room together with material not intended for feeding animals.
The odorous vapour produced in the plant is extracted and eliminated using a biofilter (Figure II.10.20).

Figure II.10.20: Odour extractor and biofilter
(Photo: László Simon)

Depending on the level of decay of the raw material the technology used in the above processes may change.

The critical control points of the technological process (CCP, see Chapter II.14):

- Ensuring a particle size of 50 mm: at the beginning of each shift it must be ensured that the jags and knives of the raw material shredder are in good condition. If not, processing can only start after repairs have been carried out.
- The specified heat treatment procedures must be followed: equipment must be calibrated once a year for pressure and temperature readings. If the equipment is faulty it must be replaced without delay.
- Parameter table: at the beginning of each shift, the pre-set parameters must be checked.
- Porter scales: at the beginning of each shift, the correct working status of the scales (using the zero point, and a known weight) must be checked. If there is a fault, service must be called in without delay.
- Phosphorus acid dosage: at the beginning of each shift the dosage pump must be checked to ensure its correct operation.
- Biofilter: at the beginning of each shift the status and condition of the water cleaner must be checked. If the air resistance of the biofilter goes over 10 mbar (local pressure measure) the insides must be turned around or replaced.
- Heater steam pressure control.
- Pressure control of operational air.

II.10.4.2. Animal protein feather meal processing technology

Figure II.10.21 shows the equipment used for category 3 poultry feather processing. The numbers in brackets in the text correspond to the numbers in circles in the Figure.

Wet feathers (1) are delivered to the processing plant and are emptied into a specially designed receiving trough (2). The trough has a cubic capacity of about 100 m^3 and is made of stainless steel with 4 built-in carpet pulleys at its bottom. The material is poured in at the end of the trough so processing takes place in the order of arrival. The trough can be emptied by the operation of the carpet pulleys through their adjustable rotation. A dosage pulley (3) that forms a right angle to the trough transports feathers towards the shooting container (Kanon) (4). The loading process is supported by the moistening blast pipe system fixed to the open top of the transportation pulley. The loading process is operated by a process management computer, which stops the loading when the pre-set loading weight (5000 kg) has been reached. The feather shooting container (Kanon) (4) has a cubic capacity of 15 m^3. It is a cylindrical pressure tight pot with a cone shaped bottom part that is loose at the bottom and equipped with a pillow steamer at the top. From the shooting container the feathers enter the disinfecting sterilization feather cooker (5) under steam pressure. Heat treatment is carried out a 15-m^3 horizontal cylindrical pressure-tight piece of equipment with mixer heating and double coating. To deal with the protein structure of the feathers, heat treatment takes place at a minimum of 3.5 bar absolute pressure at a temperature of a minimum 148 °C for a minimum of 35 minutes. This process ensures that the final product is germ free and is 75 percent digestible.

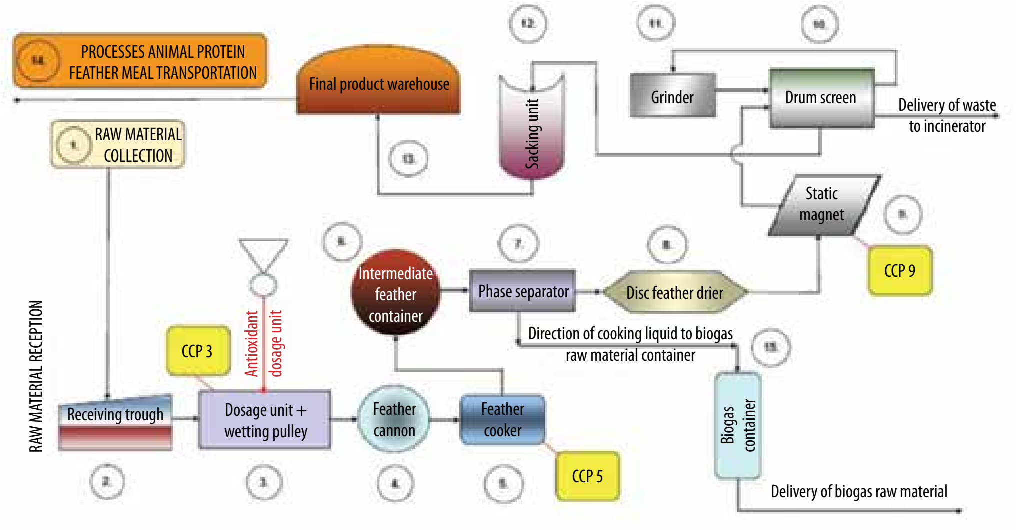


Figure II.10.21: Poultry feather processing technology
(Source: ATEV Hódmezővásárhely Plant, 2014)

This heat treatment ensures that no significant cleaving occurs on the heating surface of the drier during the drying process. Heat treatment is carried out using 15-m^3 horizontal cylindrical pressure tight equipment with mixer heating and double coating. The entire heat treatment process is operated by computer. The period of heating starts when the absolute pressure is 3.5 bars and the temperature 148 °C. If the temperature should drop during sterilization, the computer restarts the 35-minute treatment process. The computer registers all parameters of the heat treatment and keeps records for two years.

Following heat treatment and sterilization, shooting starts when the pressure goes down to 1.8 bars, then the bottom bolt opens and the load enters into the middle container (6). From the middle container the material enters the decanter centrifuge (7). The decanter is loaded by a continuously-revolving loading pipe pulley. The material is loaded on a knife bolt fixed to the bottom of the middle container. The revolving loading pipe pulley is a transportation pulley equipped with perforated housing so some of the water leaves the process and this way decreases energy demand. The decanter (7) separates the material into two phases. The feathers go into the drier (8) and the separated cooked liquid goes into a biogas raw material collection container (15). During the drying process the temperature must be above 100 °C in the drier. The length of the drying process is about 3 hours. The goal of the drying is to produce 3-5 percent moisture content meal as a final product from the 60 to 65 percent water content feather hydrolysate. The vapour produced in the drier is precipitated in the squirt condensator while the vapour from the pressure release and shooting is precipitated in the pipe condensator. The condensate that is produced enters the wastewater treatment plant through the sewage system.

The meal from the drier is transported by a bucket elevator through a magnetic metal separator (9) to a drum screen (10) on the level of the middle container. Here, the feather meal is divided into two phases. The part with less than 3 mm particle size enters a sacking device with standardized measuring equipment. The operator sets the automatic stop level at between 500-1000 kg based on the customer's request. The fraction of over 3 mm particle size goes first into the drier (11), then to the drum screen. Parts of up to 3 mm go through the screen while larger ones go back into the grinder. Parts of over 3 mm parts (poultry scalding rubber and other materials) that are left behind on the drum screen are collected once every shift and they are put into a specially designed sacking device (12).

II.10.4.3. Production technology of haemoglobin products

Figure II.10.22 shows the technological process for category 3 pig and poultry blood processing. The numbers in brackets in the text correspond to the numbers in circles in the Figure.

The incoming blood first goes to the number 1 receiving container (1). From here, through the macerator, it goes into the number 2 and 3 receiving containers. The two containers (2) have a cubic capacity of 30 m^3. If the material stays here for a longer time before processing it is stored at under 8 °C in the number 3 cooled container. The macerator (3) is a knife shredder with a screen which shreds the larger size foreign materials (chickens, heads, feet, feathers) into particles of under 3 mm. This material then goes to the processing line. Larger than 3mm parts go into a collection trough. From the container, the blood goes through a pre-heater (4) to the coagulator (5). The pre-heater is warmed up to 40 °C through a heat exchanger with the heat of the liquid phase separated by the decanter. Coagulation is the rapid heating up of blood elements and proteins with direct and sharp steam, which results in flake formation. The coagulator is a heated standing container with heat insulation, in which the blood moves upwards and is mixed with a pulley mixer oriented on a vertical axis. The coagulation temperature must be set to 89 °C on the post-coagulation thermometer and this temperature must be kept constant throughout the process.

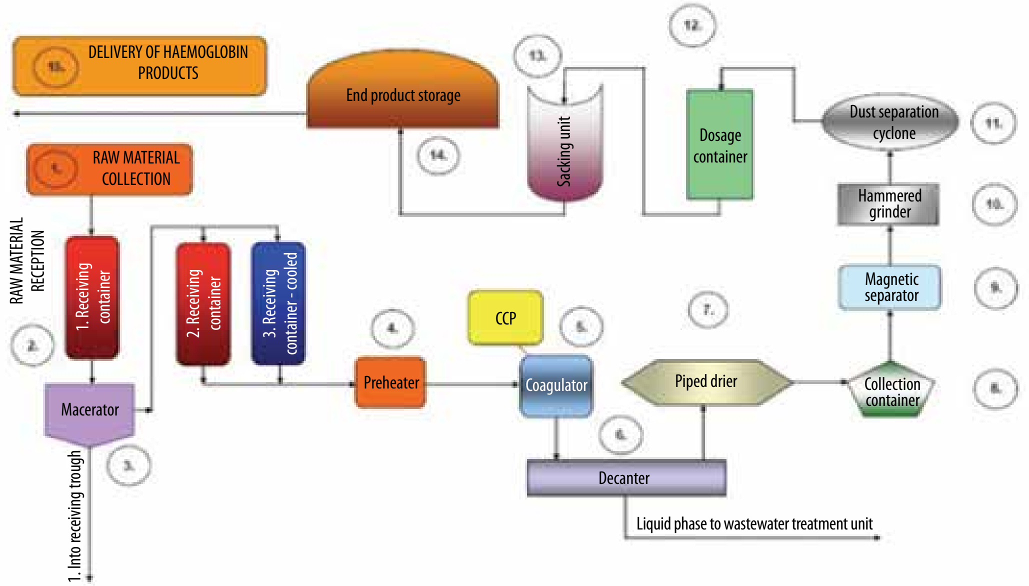


Figure II.10.22: The technological process of blood processing
(Source: ATEV Hódmezővásárhely Plant, 2014)

The amount of coagulation steam and pressure are increased gradually until the right pressure has been reached. The time period for coagulation is 2 hours. If the temperature is too low (at 75-85°C); coagulation will not be complete and the blood plasma will become dark red. If the temperature is too high, the blood may be overcooked. Coagulation is considered to be adequate if the blood plasma is white with only little foam, and after the decanting phase, coagulate consists of small ball particles with a diameter of about 1-3 mm. During the process the quality of both the blood serum and coagulated decanted blood must be monitored. In the next step the decanter centrifuge (6) separates the coagulated blood into two phases. The liquid phase goes to the wastewater treatment unit, the solid one to the drier (7). During the drying process the water content of the coagulated blood decreases from about 57-58 percent to about 5-6 percent. The drying process takes 1.5 hours and the temperature is 110 °C. In the pipe drier (7) the drying process can only be modified by changing the time period it spends in the drier.

From the drier the semi-final blood meal goes into the buffer container (8) through two transportation pulleys and bucket elevator. The buffer container can receive about 6000 kg of material and is equipped with a spreading pulley. The buffer container makes the temporary operation of the milling system possible; that is, it is enough to empty the storage silo cell at the end of each shift. Blood meal shredding is automatic. When the shredder starts, the dust filter, called a cyclone (11) is also activated, just like the system filling ventilator with the grinder (10) and the emptying pulley spreading on the grinder (8) whose performance can be modified with a frequency modifier.

From the collection container the blood meal is drawn in into the grinder through the magnetic iron separator and stone separator (9) (air lock) and is then ground into fine meal with a 3-mm screen inlay. The meal is then forwarded by the throw scoops through the cyclone head into the dosage container (12) above the scales. When the container becomes full, the upper level sensor stops the pulley loading on the grinder. When the level decreases, the bottom level sensor restarts the loading of the dried blood meal onto the grinder. Based on the customer's demand, the finely ground meal is packaged either into 50-kg polypropylene bags from the loading container with a valve, or into 1000-kg polypropylene big-bags (13) using finely calibrated scales.

II.10.5. Biogas production from leached sugar beet slices in a Hungarian sugar factory

Processing sugar beet requires significant amounts of heat and electricity. The Hungarian sugar factory used to provide the necessary energy using natural gas for the sugar production process. The dramatic price increase in fossil based energy sources, especially natural gas, meant a competitive disadvantage for the factory compared to sugar factories that use cheaper energy sources (coal) to provide the necessary energy. In addition to this problem, the use of natural gas as fossil based energy source was rather limited by a carbon dioxide quota. The capacity increase goals of the factory could only have been reached if extra carbon dioxide quotas had been purchased, or if they could have produced the necessary extra energy from raw materials (e.g. biomass) that were not affected by the energy source quota regulations.

Biogas equipment produces bioenergy from renewable plant based energy sources, the fibres of the sugar beet plant. The production and use of this bioenergy does not damage the environment as the plant, during its physiological processes, binds carbon dioxide from the air and uses it to build carbohydrates, fibres and cellulose for its tissues. Biogas is produced in several steps during the anaerobic fermentation of these carbohydrates. This process is part of a cycle which does not damage the environment with extra carbon dioxide emissions, unlike when fossil based energy sources are used.

Sugar production generates large amounts of by-products with high levels of organic matter content, which are the right raw material for biogas production. Among them, leached (extracted) and pressed sugar beet slices are available in the largest quantities at the factory that processes yearly

900000 tons of sugar beet. A daily 1800-2000 tons (204 000 t/year) are produced during the operating period. In addition to this, in smaller amounts – 200 tons daily – by-products are produced during the sugar beet cleaning process: sugar beet pieces, fragments, other organic vegetable remains and weeds can also be used in the fermentation process. As by-product of the sugar production, molasses with very high energy content is also generated. As this material is often used for alcohol production, it is currently not used as a raw material for biogas production.

Before making an investment, the sugar factory established an experimental plant as the market did not have well-developed technology with reference to the specific task (production of biogas in the right quantity and quality using monosubstrate fermentation, using only the available by-products from the sugar factory, variable operating times; that is, production of a large amount of biogas during the period of sugar beet processing and a temporary shutdown at other times of the year). The experiments carried out in the two 5 m^3 (simultaneously operating) fermentation units of the established experimental plant concluded that a one-step process; that is, when the fermentation process did hydrolysis and produced acid and methane in one container, was most efficient.

In semi-operational experiments it was determined that it takes 24 days for the anaerobic decomposition of the pressed slices. In addition to this, the operators also determined the suitable macro- and microelement requirements, the right dosage and foam reducing techniques and the volume of gas that could be produced under optimal conditions, which in the case of pressed slices with dry matter content of 22 percent is 110 m^3/t biogas with 50-52 percent methane content.

Based on the results of the semi-operational experiments the industrial equipment was set up, meaning the construction of two 13,500 m^3 fermenting units and the connecting feeding and gas system and machinery. At the first stage of the investment, two fermenting units were built. During the campaign period they are able to receive 1000 tons of pressed slices. Feeding is done by adding recirculated sludge from the fermenting unit. During the campaign period intensive gas production ensures the right mixing, in addition to which 4 diving mixers per fermenting unit were also installed. The removal of the sand, pebbles and other materials that settles inside the fermenting unit is done by a dredging machine.

Based on the experimental data, the amount of biogas that was to be produced was as much as 110,000 m^3 daily. Thanks to optimization over the years, this amount has increased to 150,000 m^3. In the heaters of the sugar factory (Figure II.10.23) burners were replaced by ones able to use biogas and natural gas 0-100 percent so the biogas that was produced was burnt directly on the premises during the campaign period. Biogas leaving the fermenting units at a pressure of 25 mbars is forwarded by blowers at a pressure of 950 mbars to heaters through a gas pipe stretching hundreds of metres. Before reaching the heater, the polluting materials are removed from the gas and cooled to 40°C in the gas receiving.

Figure II.10.23: Sugar factory heater operated with biogas and natural gas

(Source: Magyar Cukor Zrt, Biogáz Fejlesztő Kft., 2014)

After the fermenting units had been made operational, the experiments that continued in the semi-operational equipment proved that further biogas could be extracted from the fermentation liquid leaving the fermentation units. The sugar factory decided to build a so called post fermenting unit. The goal of the expansion was not only to produce more gas but also to increase the efficiency of the wastewater treatment of the plant, which also processes fermentation red sludge (a biogas production fermentation liquid) and to reduce odour impact. In the post-fermentation unit the remaining part of the raw material supplied for fermentation decomposition also decomposes, so the putrid (rotted) sludge leaving the system is not an extra burden for wastewater treatment processes. As with the post-fermentation unit, there is no nutrient supply: the bacteria in the fermentation liquid consume the remaining nutrients, which means that during the process the organic matter content that causes the odours from the fermentation sludge significantly decrease. The post-fermenting unit of 3000 m^3 that was constructed increased the daily biogas production of the plant by 7000 m^3 and the storage period for the fermentation excess sludge may be as long as 2-3 days (Figure II.10.24).

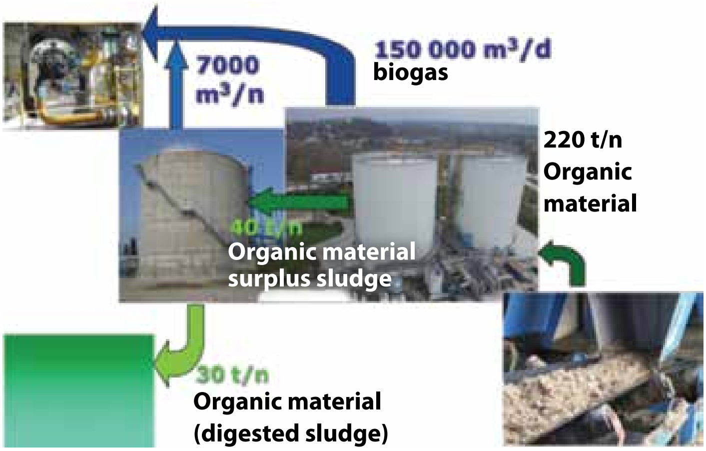


Figure II.10.24: Sugar factory biogas plant with post fermentation unit

(Source: Magyar Cukor Zrt, Biogáz Fejlesztő Kft., 2014)

The microorganisms used in the fermentation units are mesophilic bacteria. They are kept at a pH of 7.2 and a temperature of 37-38 °C. As the sugar beet slices that leave the factory have a temperature of 55 °C, they must be cooled, which is done with a reversed current heat exchanger and water from a river. This requires a daily 9-10,000 m^3 of water. The water that is used is later directed back to the river. If heating is necessary, the steam produced from the biogas is used to reach the required temperature. The pressed slices mainly provides the carbon source for the microbes responsible for fermentation. In addition, the proper nutrient supply is ensured by adding phosphorus, nitrogen and further trace elements. As beside the produced CO_2 and $CH_{4,}$ hydrogen sulphide is also present, to bind it $FeCl_3$ is added to the fermentation, a solution which will be replaced by the water wash of the biogas. As only some part of the sugar beet slices left behind after the processing process enter the fermenting units earlier established by the plant, a third fermenting unit was built to produce biogas from the so far unprocessed raw materials. This fermentation unit processes the earlier unused sugar beet slices to produce biogas during the sugar beet processing campaign period and during other parts of the year it produces biogas from other materials. Together with the extra 16,500 m^3 capacity of the 3rd fermentation unit, in the campaign period the biogas plant at the sugar factory produces

250,000 m^3 daily. This way 75-80 percent of the sugar production energy demand can be covered with biogas. Biogas and natural gas is burnt in 5 steam heaters. The steam produced provides the energy and heat required by the sugar production with the help of two steam turbines with reverse current (counterflow).

The aim of the sugar factory is to use the by-products of agriculture and food processing to make the sugar production process energetically independent of outside energy sources in the medium term (in 3-6 years). By doing this it should be possible to avoid the negative impact that changing natural gas prices have on production and prices. On the other hand, sugar production can be based completely on Hungarian resources with practically zero carbon dioxide emissions.

II.10.6. Thermal utilization and disposal of by-products and wastes of the food industry

In the following chapters the technology of thermal utilization and disposal (elimination) of by-products and wastes of plant and animal origin (and animal cadavers) of the food industry will be discussed.

II.10.6.1. Thermal utilization of by-products of plant origin of the food industry (incineration of beer marc)

The leached cereal seeds (e.g. barley, corn, rice, millet) used for alcohol production are the by-products of the fermentation, distillation processes (e.g. beer and whiskey production). The solid material formed during beer production (called brewer's grains), left behind after screening, contains the hulls of crops (mainly beer barley), debris of the seeds and the remains of the cooked malt. About 200 kg of marc is produced per cubic metre of beer.

Wet beer marc (Figure II.10.25) is rich in non-decomposing proteins and water soluble vitamins.

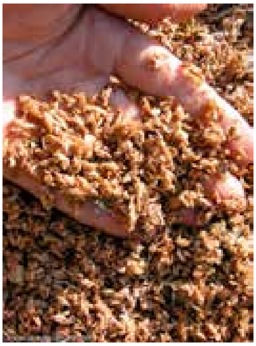


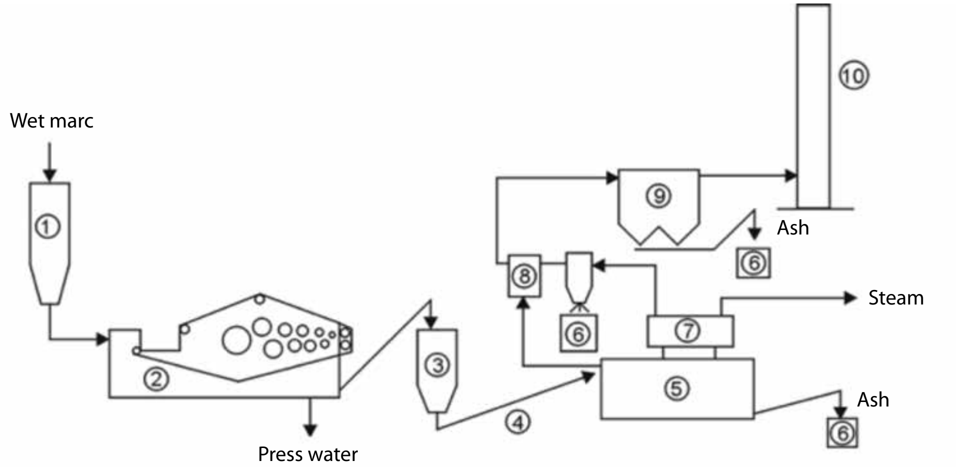
Figure II.10.25: Wet beer marc (brewer's grains)
(Source: http://www.ukagriculture.com)

When fresh, beer marc is a sterile, germ free and delicious fodder, while in a wet state it is fed to ruminant animals (cows and sheep). The marc left behind after the beer has been screened has a moisture content of 75-80 percent; that is, its dry matter content is 20-25 percent. Due to the high moisture content it is biologically unstable and starts to decay after 2-3 days. It can only be stored longer and used later if it is stored in silos or it is dried. Dried beer marc (Figure II.7.9) can also be fed to monogastric animals (e.g. pigs or horses). Drying, however, requires a lot of energy and further costs are generated when the marc is transported to animal farms. The number of cattle has dramatically decreased in most European countries in the last few decades so alternative ways have had to be found to use beer marc. Due to its over 5 percent organic carbon content, beer marc cannot be stored in landfills.

The idea has come up that marc could be used to produce light bricks or pressed cardboard elements for the building industry, or could be utilized as food or a fodder additive. Beer marc is also suitable as fungi growth medium, or if composted as a soil ameliorant, for supplying nutrients. It can be incinerated in heat power plants, although it has a low calorific content due to its high water content and very high NO_x emissions so this may not be feasible. As beer producing factories must pay large fines if they do not make sure that beer marc is utilized, the idea has come up that the high energy costs of the factories could be decreased by incinerating the marc on the spot.

The incineration of beer marc is carried out using a completely automatized system (Figure II.10.26). The wet marc is taken by a pump from the storage silo to the extrusion press. Here, the water content of the marc is reduced from 80 percent under 58 percent. In the specially designed and continuously operating extrusion press the upper and bottom lines move between pulleys of decreasing diameters, which creates steadily increasing shearing and pressing power. The extrusion press can produce 7 tons of marc with a dry matter content of 42 percent every hour.

About half of the processed marc leaving the extrusion press leaves the system as press water. After mechanical dewatering from 20 percent dry matter to 40 percent, 1 ton of wet marc creates 520 litres of press water. Press water can be utilized during the production of anaerobic biogas. 1 ton of press water gives 6-8 N m^3 biogas. In a plant that makes 100000 m^3 of beer annually, 20000 tons of wet marc is generated, and out of the press water 80000 m^3 of biogas can be produced. The press water can also be added to the water used for mashing up to 10 percent without reducing the quality of the beer that is produced. From the press water nutrients enter the beer and help yeast fungi multiply during the fermentation process.



1. Wet marc storage; 2. Line press; 3. Buffer container for dewatered marc; 4. Transportation pulley; 5. Mobile bars oven; 6. Ash storage container; 7. Steam container; 8. Air preheater; 9. Dust filter; 10. Chimney

Figure II.10.26: The technological steps of beer marc (brewer's grains) incineration
(Source: Zanker et al., 2007)

The dewatered, pressed marc enters a buffer container, where if needed (e.g. at the weekend when no energy is required for beer production) it can be stored for 2-3 days.

As the next step, the dewatered marc is fed by a transportation pulley into a furnace with a moving screen. The fire-proof inside of the furnace makes it possible for the irradiated heat to preheat and dry the marc. Preheating balances the changeable moisture content of the marc. Incineration is most effective if the moisture content of the marc is lower than 60 percent. Dewatering before incineration is indispensable, otherwise the material cannot burn and produce heat. When 1 ton of wet marc is incinerated, about 1000 kWh heat energy can be produced. The calorific value of marc is about 21 MJ/kg, a value close to that of lignite. The hot gases produced during the incineration can be used to make saturated steam and hot water. The heat energy that is generated can cover 80-100 percent of the heat energy demand of the beer factory.

The smoke and gas that are produced are cleaned with cyclone and electrical filters. This way the NO_x, sulphur dioxide, carbon hydrogen, carbon monoxide and dust concentration in the outgoing gas does not exceed 50 percent of the relevant limits.

The chemical composition of the ash produced during the incineration of beer marc is different from that of wood ash, as more than 60 percent of the material is phosphorus (P_2O_5). Beer marc ash contains significantly lower levels of potassium and calcium than wood ash. Its magnesium content, however, is similar.

In a brewery that produces an annual 20000 tons of marc, 180 tons of ash must be disposed of. As marc ash is rich in P_2O_5, this quantity is enough to make 920 tons of NPK artificial fertilizer. If marc ash is sold, the cost of beer production can be reduced.

II.10.6.2. The thermal utilization and elimination of by-products of animal origin

The elimination of by-products of animal origin through incineration became more important in the 1990s when (BSE) Bovine Spongiform Encephalopathy appeared. The illness was caused by infected meat meal, which had been used to feed milking cows since the early 1980s. Earlier on, meat meal was heat treated at 110 °C, but this temperature was not high enough to kill pathogen prions (Chapter II.12.4). To prevent the danger from meat meal, it cannot be currently used as fodder. There are several opportunities for its disposal (storage in landfill, agricultural utilization) but each one has some level of environmental risk. As a result, incineration is the only real solution. Incineration at over 850 °C completely destroys the protein structure of the infectious prions.

The incineration of the products only makes sense if the energy balance stays positive. The incineration of unprocessed animal bodies is energetically not economical due to their chemical composition and high water content. Heat utilization is minimal. The calorific value of animal bodies is 8.5-9.5 MJ/kg, much less than that of meat meal (16 MJ/kg, animal fat ~40 MJ/kg), which is relatively similar to that of brown coal (~15 MJ/kg), or coal (~30 MJ/kg), which means this method of utilization creates the same amount of energy. On the other hand, incinerating meat meal is preferable as it must occur to reduce the risk of epidemics in any case. The processing of animal bodies into meat meal results in a hygienic substance that can be stored for longer without further special protective measures.

There are two possible techniques for incineration:

- combined incineration in cement factories, coal based power plants, induction furnaces and communal waste incineration equipment,
- incineration in special waste incineration equipment.

Combined incineration of by-products of animal origin

The calorific value of meat meal is relatively high (see Table II.10.4), which must be taken into consideration when it is mixed with the main fuel. The permitted proportion of meat meal is 5-20 percent. It is also important that the incineration temperature cannot be very high due to the calorific value of the substance, so the heat pressure of the furnace must be reduced. A temperature of about 1000 °C ensures the safe destruction of pathogen prions present in the material at the beginning of the process. The combined incineration of meat meals usually leads to a reduction in harmful material emissions, so the legal standards can be met. The high calorific value of the meat meal ensures that incineration is efficient, which reduces CO_2 emissions. However, the high nitrogen content of the meat meal leads to higher primary NO_x concentrations in the outgoing smoke and gas. If they increase, more smoke and gas filtering equipment is necessary, which in the case of selective non-catalytic reduction requires the use of ammonia solution or urea. The chlorine that comes from the common salt contained in meat meals presents a risk of corrosion. During waste incineration the remains that are screened out need to be thermally treated again. Due to the amount of materials that fall through the screens of waste incineration equipment, the load on such screens may be unsuitable (e.g. they may be operating empty) and in certain cases the unburnt slag must be returned to the system. Phosphorus oxide and calcium oxide may get disposed at areas of high temperature and the same may happen with flying ash. The phosphorus oxide gases and compounds can have a negative impact on catalysers that are used.

Combined incineration of meat meal prepared for incineration in cement factories

By-products of animal origin and products made from them are allowed to be utilized as fuel through incineration, and this solution is not considered to be waste disposal (1069/2009/EC Regulation). By-products of animal origin not suitable as fodder containing category 1 SRM materials (specified risk material see Chapter II.4) are handed over to cement factories as meat and bone meal that has been prepared for incineration (direct utilization). In cement factories they are utilized or eliminated by combined incineration.

For example, a Hungarian company that processes by-products of animal origin collects 25,000 tons of category 1 raw by-products of animal origin on a yearly basis. During the collection process in some cases some category 2 and 3 materials also become mixed with category 1 by-products. In such cases the entire amount must be considered a category 1 material. According to Hungarian regulations, hazardous waste is turned into meat and bone meal and the material is then incinerated in the cement factories of Duna-Dráva Cement Ltd. Category 1 products are prepared for incineration based on meat meal line technology (see Chapter II.10.4).

The fat produced from by-products of animal origin category 1 and 2 is utilized at the same plant to produce renewable energy and steam (direct utilization). Animal fats mostly contain saturated or unsaturated fatty acids with linear carbon chains and even-numbered 2-26 carbon atoms. Animal fats consist of a few types of compounds with high boiling temperatures. Changing fuels means that the Hungarian company had to change existing furnaces and their burning equipment (revolving cup burner) and also their fuel supply system. Fat burning as renewable energy production has a lower impact on the environment than heat energy production based on fossil energy sources and also has the advantage that it reduces the CO_2 emission coming from burning fossil-based energy sources. Annually, about 5-6,000 tons of fat is incinerated. Fat burning has an effect on the level of emissions: the concentration of NO_x increases. This can be controlled by recirculating smoke and gas. Recirculation is efficient and economical and its level is 5-20 percent. At 20-percent smoke and gas recirculation the thermic NO_x concentration goes down by exactly 50 percent. To keep the efficiency level of the incineration process and emission levels under the permitted limits it is important to keep the quality of the fat that is created during the production and storage processes at approximately the same level. It is also important to keep the nominal performance of the furnace at 80-85 percent. The furnace house waste (yearly 4-5 tons) is not hazardous and can be treated together with municipal solid waste.

Table II.10.4 shows the content values of bone and meat meal prepared for incineration. The table shows that meat meal has very good calorific values, about the same as brown coal.

Table II.10.4: Content values of bone and meat meal prepared for incineration *(Source: Süveges, 2010)*

Parameters	**Minimum**	**Average**	**Maximum**
Moisture content [%]	2.0	3.8	9.0
Fat content [%]	9.0	15-20	28.0
Nitrogen content [%]	7.0	8.6	9.9
Protein content [%]	44.0	53.9	62.0
Ash [%]	17.0	25.7	32.0
Incineration heat [MJ/kg]	17.0	18.0	22.0
Calorific value [MJ/kg]	16.0	**17.0**	20.0

During combined incineration at a cement plant, waste or waste gas is used as main or additional fuel.

Additives used for the combined incineration at cement plants:

- secondary (alternative) fuels,
- wastes as raw materials.
- industrial by-products (wastes), as cement additives.

During the treatment energy costs go down and waste management problems are solved and energy efficiency improves. The so called replacement proportion based on the amount of heat used during the technological process is 12 percent in Europe. The by-products of animal origin are utilized completely, both energetically and in terms of their material components, without leaving any slag left behind. The replacement of fossil-based fuels with waste-based fuels results in the reduction of specific fuel emissions.

The revolving furnace at the cement factory has several features ideal for the utilization of alternative fuels, like the ability to reach a high temperature (2000 °C gas and 1450 °C material-based temperature), a long period of stay and maximal utilization of the energy/material content.

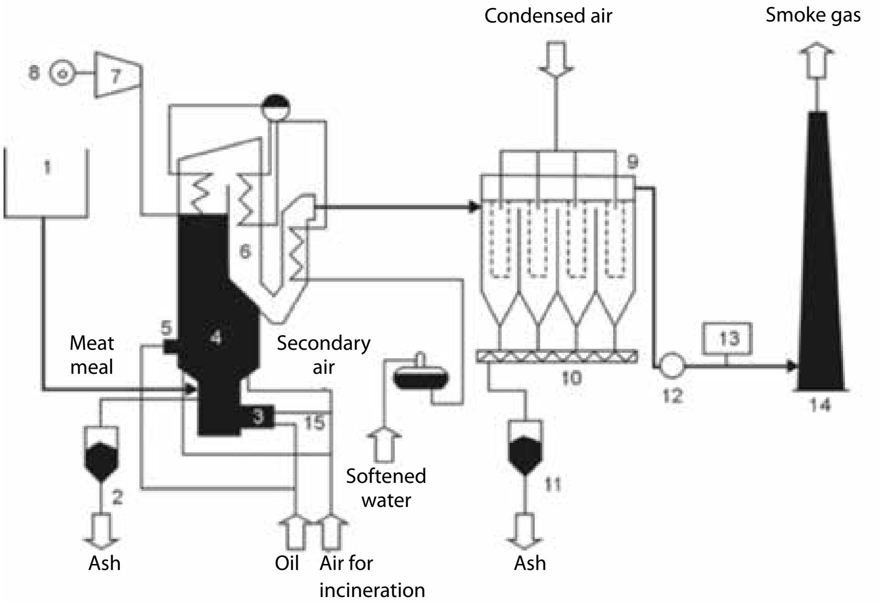
The amount of by-products of animal origin that can be incinerated a day in a cement plant is about 5 mass percent for each furnace. Figure II.10.27 shows the feeding techniques for by-products of animal origin at cement factories, namely, feeding in bulk and with big-bags.

Figure II.10.27: Feeding by-products of animal origin (bone and meat meal) for combined incineration at the cement plant in bulk and big-bags *(Source: Süveges, 2010)*

Incineration of by-products of animal origin in waste incineration equipment

Having separate incineration equipment is technologically better than using a combined incineration process. These machines are optimized as far as fuel management, thermal processes and smoke and gas cleaning are concerned. The more or less stable quality of fuel with high calorific value (meat meal and animal fat) ensures the optimal conditions for incineration. The optimization of the incineration process makes it possible to meet all the regulations about air pollution (including the elimination of smoke and gases from ash) without the application of any secondary rules. The incineration of meat meal can be carried out in a narrow temperature range (from 900 °C to 950 °C). The fuel burns well and safely. Fluid bed furnaces are usually used for this purpose.

A British company has established a mono fuel incineration facility (meat meal based power plant) for the thermal utilization of meat and bone meal. The meat and bone meal is heat treated in an immobile fluid bed system and then the waste heat is used to produce electricity. Smoke and gases are properly cleaned. Figure II.10.28 illustrates the simplified process.



1 – Meat meal storage, 2 – Ash unit 3 – Initial incineration chamber 4 – Fluid bed oven 5 – Complementary burner 6 – Waste heat recycling heater 7 – Turbine 8 – Generator 9 – Hose filter 10 – Ash transportation 11 – Ash unit 12 – Breathed air 13 – Air pollution measure 14 – Chimney 15 – Primary air

Figure II.10.28: Meat meal incineration in a fluid layer – simplified flow chart
(Source: http://www.omikk.bme.hu/collections/mgi_fulltext/trend/2002/05/0506.pdf)

Incineration of animal cadavers

The incineration of animal bodies (cadavers) is carried out in compact furnaces with a capacity of maximum 1-2 tons per occasion. The advantages of small size animal incinerators is that during their operation no animal cadavers are taken in or out of the plant, which significantly decreases the risk of infection, there is no delay in the collection system, no transportation is necessary and the waste can be immediately eliminated without creating any unwanted odours.

Small capacity cadaver incinerators consist of 2 connected chambers. The first is a main chamber, where the cadaver is placed and incinerated. The gases produced in this chamber go to a secondary chamber where all of the gases are burnt. Both chambers have their own incinerators with a ventilation system. The temperature of the post-incinerator must be a minimum of 850 °C and this temperature must be maintained. The fuel that is used is oil or natural gas.

In Hungary, incinerators of different sizes can be used for the thermal elimination of pig, poultry, sheep and pet cadavers. In pig farming the feed capacity of such incinerators may be 500, 1200 or even 2000 kg. In poultry farming an incinerator of 75 kg feed volume can cremate a few animals while an incinerator of 150 kg feed capacity can incinerate up to 30 chickens at the same time. Incinerators of feed capacity of 200, 400 and 500 kg can cremate 50, 100 or more chickens at the same time. In sheep farming an incinerator of 150 kg feed capacity can cremate a maximum of one medium size sheep; however, equipment of 200, 300 and 500 feed capacity are suitable for the cremation of a number of small size sheep or 2-3 larger size sheep at the same time. As concerns pets, incinerators of 75 and 150 kg feed capacity can cremate birds, rodents and medium size pets (dogs, cats). Equipment with a capacity of 300 or 500 kg is used for average sizes and types of pets.

Any equipment with a capacity to incinerate 50 kg material per hour is considered to be small capacity incineration equipment, which means it is easy to manage the permitting process (a permit from the local animal health unit is required). Figure II.10.29 shows incinerators of 75, 200 and 1600 kg volume.

Figure II.10.29: Cadaver incineration equipment with feed capacity of 75, 200 and 1600 kg

(Source: http://www.bentleyhungary.hu/allattenyesztes/waste-spectrum-allati-hullaegeto/allati-hullaegeto/V75/; http://www.bentleyhungary.hu/allattenyesztes/waste-spectrum-allati-hullaegeto/allati-hullaegeto/v200/; http://www.bentleyhungary.hu/allattenyesztes/waste-spectrum-allati-hullaegeto/allati-hullaegeto/V1600/)

II.11. Wastewater treatment in the food industry

(Zsuzsanna Uri)

The food industry is one of the industries with the highest amount of wastewater production. This chapter describes the main features of the wastewaters of the food industry and the cleaning technology they employ. The wastewater cleaning processes of the main water consumers in the food industry (canning, refrigeration, dairy, animal protein processing industries) are introduced.

II.11.1. Quantitative and qualitative characteristics of wastewaters from the food industry

Water pollution refers to all effects that modify the quality of surface and subsurface waters in such a way that their suitability for human consumption (drinking water supply, industrial, agricultural or other use) and for ensuring natural life processes decreases or stops altogether. Water pollution may be natural but it can usually be traced back to human activity. Statistical examination provides data regarding the yearly average household after-cleaning nitrogen and phosphorus load, the 5-day biochemical oxygen demand (BOD_5) and also dichromate oxygen consumption (chemical oxygen demand – COD). Emission data from agriculture and industry, however, are not complete. In the last few years water consumption has decreased by about 20-30 percent, which at the same time has led to the 'thickening' of wastewaters and the quality parameters of wastewaters have also deteriorated. The food industry is among the largest water consumers and wastewater producers. In Hungary the food industry is the fourth largest water consuming industry. The quantity and quality of the wastewater produced by the food industry largely depends on the size, type of the plant, the production technology that is used and local environmental conditions. Most of the branches of the industry require drinking water quality water. Large size food production plants consume hundreds of cubic metres of water daily. As far as the load on the water is concerned, the largest water consumers are the meat, poultry, dairy, canning, beer and soft drink processing facilities while the sweets, wine, baking, milling, vegetable oil and alcohol industries are more moderate users. The estimated yearly water consumption of the meat and poultry industries together is 22 million m^3. Industries that process by-products of animal origin and alcohol produce the largest volumes of wastewater. For the production of 1 ton of pork (with bone) 17-23 m^3 of wastewater is produced, while for 1 ton of living poultry this amount is 15-25 m^3 daily.

The wastewaters produced during the technological processes can be categorised into 4 groups:

- wastewater produced during the stages of preparation,
- wastewater derived as a result of the technological process,
- cooling and condensing waters,
- rinsing, washing and cleaning waters.

Wastewaters of the food industry have typically the following parameters: COD 1300-7600 mg/L and BOD_5 600-4800 mg/L, what is a narrow BOD to COD ratio. E. These polluting materials are easily biologically degradable in aerobic and anaerobic decomposition processes. In the case of slaughterhouses and the meat and dairy industries the polluting materials are mostly fatty substances (colloids) while in the canning and beer industries they are mainly present as dissolved organic matter. Table II.11.1 provides information about the quality characteristics and the proportion of wastewater of the food industry.

Regulations about treated wastewater quality: The majority of food industry plants direct their waste wasters into the public sewage system. Decrees concerning standards and the application of water polluting material emissions defines the standards required for pre-cleaning before waste mater may be transported into public sewage and the necessary cleaning required before the water may be allowed back to the environment. The decree contains two different emission standards in accordance with regulations about the technological capacity (technology standards) and for the protection of the environment (environmental standards). The emission standards are determined for the emission producer through the permitting process of the authority that uses the related opinions of the relevant professional bodies. The decree also contains regulations concerning specific food industry standards.

Table II.11.1: Typical data for some wastewater from the food industry *(Source: Lux, 2003)*

Industry	**COD (mg/l)**	**BOD mg/l**	**Total floating materials (mg/l)**	**Fat and oil content (mg/l)**	**pH**
Slaughterhouses and meat industry	2500-5000	1000-2400	1000-2000	200-600	6.5-8.5
Dairy industry	3500-6000	1500-3000	400-600	200-550	5-10
Canning industry	4000-9000	2000-5000	1500-3500	50-150	5.5-10
Beer industry	2500-4500	1200-2300	300-800	20-50	4.5-12

II.11.2. Wastewater treatment technology used to clean wastewaters from the food industry

The wastewater treatment process largely depends on the character and origin of the wastewater. There are various ways of treating wastewater from municipalities, industries and agriculture, etc. The treatment level of the wastewater depends on the condition of the place of disposal, the amount of wastewater that is treated, the amount of polluting materials that are allowed to enter the place of disposal together with the treated water, economic considerations and the treatment standards determined by the water protection regulations in the specific country.

The following are the most important stages in treating the wastewater from the food industry:

- extraction, removal of floating materials, fats and oils etc.,
- removal of floating materials,
- decomposition of the organic substances of wastewaters, decrease in COD and BOD according to standards,
- removal of micropollutants and materials that damage taste and fragrance,
- removal of materials that cause cloudiness and discolouration,
- extraction and removal of air polluting volatile materials,
- removal of nitrogen and phosphorus compounds in order to delay or prevent eutrophication,
- removal of toxic compounds,
- removal of biologically non-degradable or only partially degradable materials.

A new and more modern task involves reusing the polluted water and extracting and utilizing the valuable materials it contains.

When the treatment technology for the wastewater is selected, the type of pollution must be considered. The following categories of treatment are distinguished:

- mechanical wastewater treatment,
- physical-chemical wastewater treatment,
- biological wastewater treatment.

Mechanical treatment of wastewaters of the food industry

The first step in wastewater treatment is mechanical treatment. The main goal of this step is to remove any coarse or fine floating pollutants from the wastewater using mechanical-physical methods. Due to this, the next stages of the treatment can be simplified as wear and clogging of equipment (e.g. pumps) used in those stages will be reduced, just as will the amount of by-products and sludges produced during the treatment. The rough pollutant particles in the wastewater are filtered out using a wastewater screen. Sieve bends (arched screens) are widely used in wastewater treatment of the food industry in plants of all sizes. The phase separated by the arch screen is often used as fodder. The minerals in the wastewater can be separated by sand and sludge traps. The typical components of wastewaters from the food industry are fats and oils, which can be separated from the water using fat and oil traps. The most frequently used type of mechanical treatment is a settler. The food industry often uses hydrocyclones to separate out mineral pollutants.

The physical-chemical treatment of wastewaters of the food industry

The primary aim of the physical-chemical pre-treatment of wastewaters of the food industry is the removal of floating materials and the reduction of the organic matter content. Numerous companies sell flotation equipment of various designs and in large numbers for the food industry. The two main technological steps that flotation equipment employ are flocculation and flotation. Dissolved air flotation machines (DAF) support the separation of the solid and liquid phases with air dissolved in water. To increase the efficiency of the process, chemicals are usually also added, which results in coagulation and flocculation in the treated liquid. Due to coagulation the solid particles destabilize and precipitate. During flocculation, the destabilized particles gather in larger units, so called flocs or flakes. The flocculation equipment contains a pH measuring instrument which ensures that chemicals are automatically added to ensure neutralization. During the flotation process the water (to which air has been added under pressure) enters the liquid container of the flotation machine where, as the pressure goes down, microbubbles leaving the water with the air become stuck on the surface of the flakes. The microbubble flake aggregate floats to the surface due to differences in density. The pollutants that have risen to the surface of the water are removed by an automatic surface cleaning machine. These pollutants must be taken away from the container and treated as hazardous waste and disposed of at an authorized plant. Chemical based flotation is used to remove pollutants from slaughterhouses and meat and dairy processing plants which mainly contain colloid pollutants.

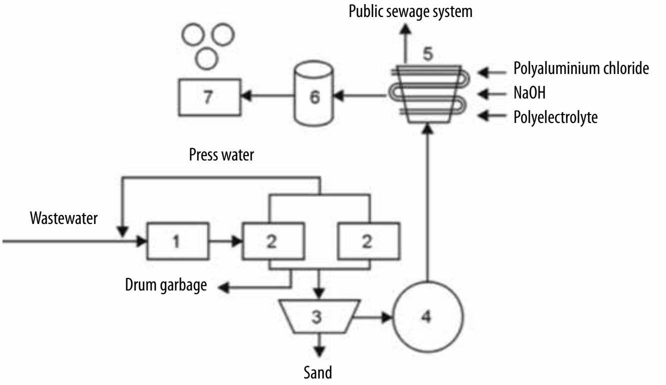
Cutting edge membrane technology is also used to treat wastewaters of the food industry. Membrane technology is based on a screening process. Depending on the size of the particles to be filtered, there exist micro (MF), ultra (UF) and nano filters (NF) and reverse osmosis (RO) systems. Prior to using these systems, advanced pre-cleaning is required as these processes have high energy demand. It is possible to recirculate wastewaters but the cost of doing this is several times higher than that of traditional wastewater treatment processing.

Biological wastewater treatment methods used in wastewater treatment of the food industry

During biological treatment the removal of the organic pollutants in wastewaters is carried out using microorganisms under aerobic (using fresh air, or with aeration or ventilation) or anaerobic (no air present) conditions. For some wastewaters of the food industry the efficiency of biological treatment is increased when nutrients are added (nitrogen and phosphorus compounds). To treat wastewaters with lower organic matter content (COD =1500-2800 g/m^3) and/or of relatively smaller quantities (200-600 m^3/d) aerobic wastewater processing is more suitable. During these processes, compared to anaerobic wastewater treatment, a larger amount of biological surplus sludge is produced. One of the practical ways of aerobically treating wastewater is modern, deep aerated, activated sludge technology, in which the phase separation of the activated sludge is returned in the treatment process using recirculation, and the treatment of the wastewater (also the separating of excess sludge) takes place after biological treatment in the biological post settler. The organic matter content of wastewaters of the food industry may reach several thousand COD, which makes multi-step biological treatment necessary, especially if the final place of disposal is to be a natural water body. The two steps can also be built up by combining the activated sludge and dripping unit systems. Dripping unit wastewater treatment technology is also based on an aerobic process in which bacteria become attached to solid carriers with high surface area. For wastewater with a high organic matter content anaerobic wastewater treatment is used. During this treatment biogas is generated as a by-product which can be used to produce energy. This treatment technology has a relatively high investment cost and a low operational cost, low sludge production and energy recovery. The system tolerates load fluctuations very well. The sludge that is produced is properly stabilized and free of pathogens. The disadvantage is that it is economical only in the case of the treatment of concentrated wastewaters (however, the latest systems can also operate at 100 mg COD/L). It must be noted that, following anaerobic treatment, drainage water must always be cleaned. The reason for this is that treated drain water has high levels of ammonia and also contains volatile acids and non-fermentable dissolved organic compounds. In many EU member states, the beer industry is already using this wastewater treatment process. This process can probably also be used for wastewaters from the canning industry with high organic matter content: however, the seasonal production of wastewater from the food industry at the moment is preventing this technology from becoming widely used.

Sludge that is produced when wastewaters from the food industry are treated

The amount of the sludge produced annually during the wastewater treatment of the food industry is 100 thousand tons. 66 percent of this amount is produced by the meat industry, 30 percent by the poultry industry and 2-3 percent in plants that process by-products of animal origin and 0.4 percent by the alcohol (distilling) industry. The treatment of the wastewater sludge produced during wastewater treatment is one of the most critical points of concern for the food industry. The use of sludge still requires development. There have been some patented innovations regarding the composting and agricultural utilization of these materials, but due to high cost and strict regulations such technology is not yet widely used.



1. Lifting unit 2. Drum screens 3. Sand trap 4. Biological FLEXIPAK reactor
5. Pipe flocculator and DAF flotation equipment
6. Sludge dewatering unit 7. Sludge containers

Figure II.11.1: Flow chart of the wastewater treatment of the canning industry
(Source: Zsuzsanna Uri, 2014)

II.11.3. Wastewater treatment of the canning industry – a case study

About 90 percent of the water used by the canning industry is of drinking water quality. 75 percent of the fresh water is used to replace cooling and furnace feed water. Large amounts of water are required for raw material transportation and washing, box cleaning and heat treatment. The most concentrated waters come from washing, peeling and precooking (blanching). The quantity and quality of the wastewater that is produced depends on the product. The operation of a pre-treatment system makes it possible to direct wastewaters from the food industry into the sewage system. Among the suitable treatment technologies, one of the country's most cutting edge pre-treatment systems, consisting of mechanical treatment, fix biofilm, biological treatment with contact elements and chemical conditioning, is presented as an example (Figure II.11.1).

Wastewaters produced in different places first enter a transloading object. The transloaded wastewater then enters a drum filter with a gap size of 0.75 mm, in which the pressing of the collected material is also ensured. The produced press water is directed back to the untreated wastewater while the filtered material can be used as fodder. After the drum filter the wastewater goes, due to gravity, to sand trap equipment, where the remaining sand particles are separated. The separated sand is placed into a transportation vehicle with a sloping steel pulley object. The mechanically treated wastewater goes gravitationally from the sand trap equipment to the biological Flexipak reactor (Figure II.11.2), where the biodegradable organic dissolved pollutants are aerobically removed. The Flexipak system is not a conventional activated sludge system. Biological degradation takes place on the biofilm layer that forms on the built in immobile Turbopak contact elements (Figure II.11.2). The old part of the biofilm continuously breaks off and floats away with the treated wastewater. The cleaning efficiency of this biological waste treatment unit (calculated for BOD_5) is 80-95 percent, and for COD 70-90 percent.

Figure II.11.2: The Flexipak® biological wastewater treatment unit of the canning plant and the ring reactor of the Flexipak® system *(Photo: Zsuzsanna Uri)*

After going through the biological cleaning section, the wastewater goes to a pipe flocculator (Figure II.11.3) where the pollutants that have emulsified in the wastewater or are present as colloids become solid phase floating substances. To increase flocculant production chemicals are added (BOPAC, NaOH and polyelectrolyte). Specific chemicals are added at different points in the pipes of the flocculator. Intensive mixing is ensured by the development of a turbulent flow. In the next step, the wastewater that contains the flocculated sludge is taken into DAF flotation equipment with overpressure (Figure II.11.3). Dissolved air flotation (DAF) is a modern phase separation process of high efficiency. Before it goes into the flotation equipment, recirculating water enriched with air is added to the wastewater. The fine air bubbles are mixed with the solid particles from the water and sludge flocculant is formed. The floating particles are quickly moved to the surface of the liquid by the air bubbles that get stuck on their surface. The sludge phase that floats up can easily be removed.

Figure II.11.3: Pipe flocculator and flotation equipment with dissolved air (DAF)
(Photo: Zsuzsanna Uri)

A sludge dewatering belt filter is connected to the flotation equipment. The sludge, with 3-5 percent dry matter content, is stored in sludge containers and then gets utilized as biogas plant raw material.

II.11.4. Wastewater treatment in the refrigeration industry – a case study

90 percent of the water used when quick-frozen products are made is of drinking water quality. About half of the amount consumed is used to replace cooling and furnace feed water. During the technological process, most of the water is used for cleaning raw materials.

The wastewater treatment processes of the cooling industry are introduced through the example of a cooling plant that produces frozen vegetable food products. The company separates the water used in the process from the communal wastewater. The rain water produced in the area of the raw material receiver and final product loading is treated together with the industrial wastewater. The technology-related water that has gone through mechanical and chemical treatment is directed to a 2.9-hectare poplar filtering field, which is also used by a vegetable and fruit juice making company in the neighbourhood.

Mechanical treatment is carried out using settling and filtering units over the area of the plant (a dissolving pool, a filter of 10 mm gap size, a sand and scum trap and a sieve bend (arched screen, Figure II.11.4).

Figure II.11.4: Sieve bend (on the left), and settling, filtering and slack lime feeding unit (on the right) in front of the poplar filtering field *(Photo: Zsuzsanna Uri)*

The combined water from the two nearby production plants is filtered of coarse particles by the settling unit and drum filter with a rod screen that is located directly next to the poplar disposal area and then the water is treated with slack lime which results in an increase in pH (to make it slightly alkaline).

To match the operational work programme, the water is sent to the poplar area at a limited, specified period of time: 6 months – from July and November.

The plantation system has double-lined draining (swallowing) ditches (Figure II.11.5). The concrete spreading ditches help the water to spread across the area (Figure II.11.5): its direction of movement is managed by blocking units placed in sections (Figure II.11.6). The water is directed into the swallowing ditches through plastic pipes placed in the gravel bed. Efforts are made to spread the wastewater homogeneously over the area. A distance of 150 cm must be maintained between the leakage level of the wastewater that is led into the watering ditch and the ground water level.

Figure II.11.5: Ridged, twin-line poplar wastewater disposal area (on the left) and covered distribution ditch (on the right) *(Photo: Zsuzsanna Uri)*

Figure II.11.6: Dehydrating ditch with latch for directing the wastewater
(Photo: Zsuzsanna Uri)

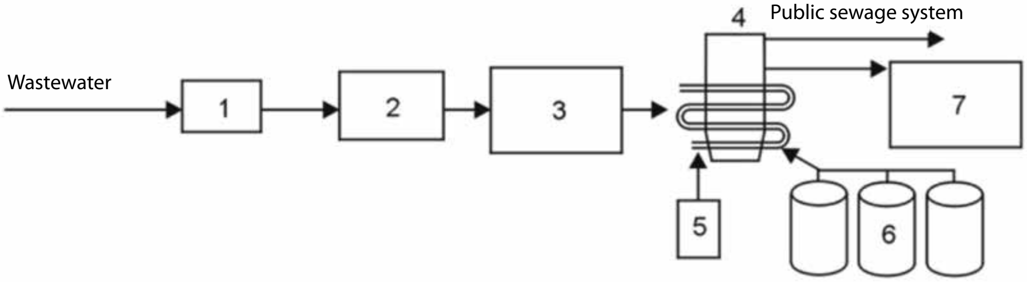
Figure II.11.7: Groundwater control well
(Photo: Zsuzsanna Uri)

Wastewater can only be disposed of on an area if the operator has the legally-required water management operation permit. Its disposal must not damage the soil or ground water. 3 monitoring wells operate across the area of the poplars (Figure II.11.7), from which once a year samples are taken to examine for pollution. 5 times a year soil research suitability tests are carried out, and, if necessary, the soil loading capacity figures are modified.

II.11.5. Wastewater treatment in the dairy industry – a case study

90 percent of the water the dairy industry uses is of drinking water quality. Four fifths of the fresh water is used in the technological processes and 5 percent is used for cooling. 30-35 percent of the technology-related consumption occurs with milk processing and 60-65 percent with cleaning and

disinfecting. The industry is a medium-level water polluter. Pollution of the used water is caused by milk and milk remains (whey, buttermilk, butter, cheese and cottage cheese pieces) and rinsing water. The wastewater treatment technology of the dairy industry mostly depends on the place of disposal. If the disposal point is a public sewage system, flotation pre-treatment is commonly undertaken, while in the case of natural water the typical solution is one or two-step biological treatment. Figure II.11.8 shows potential treatment options for water that is directed into sewage systems.



1. Lifting unit 2. Drum screen 3. Balancing pool 4. Pipe flocculator and flotation equipment 5. Polymer dosage unit 6. Acid and alkaline containers 7. Sludge container pool

Figure II.11.8: Flow chart of the flotation pre-treatment of the wastewater of the dairy industry
(Source: Zsuzsanna Uri, 2014)

Figure II.11.9: Pipe flocculator (on the left) and polymer dosage device (on the right)
(Photo: Dávid Besenyei)

The technology-related wastewater travels under gravity through the plant collection sewer system into the transload shaft. From here a submersible pump takes it to a drum filter. From the drum filter the wastewater flows into a buffer pool that is situated under the building where two submersible mixers balance the quantity and quality features of the wastewater. From the buffer pool the filtered wastewater is pumped by the transloading pump into the flotation pipe flocculator (Figure II.11.9). The coagulant, the polyelectrolyte (BOPAC) and neutralizing agents necessary for the pre-treatment are added here. The dissolution of the polyelectrolyte is ensured by the continuous operation of dosage equipment (Figure II.11.9). Depending on the pace of use, the equipment automatically mixes the polymer in a preparation container. The dosage container then stores the ready-to-use polyelectrolyte. During the mixing stage the falling polymer is moistened and then dissolved by the system. In the pipe flocculator the emulsions that have been treated with the chemicals and the pollutant flocs mix with the injected compressed air. Due to the resulting high pressure the air is present as microbubbles. In the pipe flocculator the microbubbles with their high specific adhesion surface get stuck to the created flocs and float later to the surface in the flotation spaces. The flocculator has a pH control device with a permanent flow. This device ensures the automatic dosage of the chemicals necessary for neutralization. The chemicals are added from a 3-m^3 and a 2-m^3 containers (Figure II.11.10) with built-in chemical dosage pumps. At the beginning of the process 40 percent alkaline (NaOH) and 10 percent hydric chloride is fed into the system. The containers are equipped with vent stubs (airing ends). When the system is filled up, any overflow of chemicals will enter a trap trough.

Figure II.11.10: Acid and alkaline containers
(Photo: Dávid Besenyei)

From the flocculator the wastewater flows into the flotation equipment (Figure II.11.11), where, due to the upward moving force of the dispersed water, the thickened pollutants of the wastewater float to the surface and some heavy pollutants sink to the bottom of the equipment.

Figure II.11.11: Flotation equipment
(Photo: Dávid Besenyei)

Special plate systems with reverse current ensure the correct opposing movement of upward floating and settled materials and the wastewater mixture. The removal of the scum produced on the surface is carried out by a skimming machine whose speed can be adjusted. The sludge produced at the bottom of the container can be removed by opening the time controlled pneumatic butterfly-valve that is fixed to the bottom of the flotation unit. The flotation equipment has a pneumatic control system which manages the valve that moves the bottom sludge and also signals the air supply and recirculation pressure. During the flotation, two types of sludge are produced: floating sludge (on the surface) and settled (bottom) sludge. The mixed dry material content of the two produced sludge types is 5-10 percent. The amount of liquid sludge is 10-20 m^3/d; its dry matter content is 800-1100 kg/d. A reinforced concrete pool of 40 m^3 is used for the temporary buffering of the two types of sludge. The pool has a mixed area and any overflow can leave via a filtered wastewater buffer. The buffer capacity is maintained for 2-3 days. The level switches of the pool signal when the buffer needs to be emptied. When this occurs the transportation hose is connected to the sludge removal hose end in front of the building, the mixer in the sludge buffer is turned on and the removal pump is started. After transportation the trap trough must be flushed to reduce the odour impact.

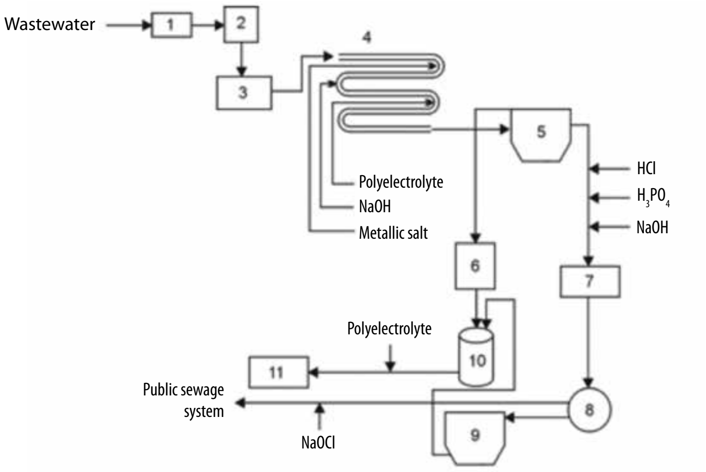
In the other plant of the company a biofilter operates to reduce the wastewater treatment related odour impact. The raw material of the filter filling is specially pre-treated grape stalk and pre-treated tree roots that are torn lengthwise. The automatic biofilter unit is equipped with its own moistening equipment.

II.11.6. Wastewater treatment at the animal protein processing plant – a case study

Animal protein processing plants collect and eliminate the by-products of animal origin produced across the country. The wastewater generated in these plants contains water from the so called black zone (overflow water from the receiving trough, wastewater from the cleaning of machines and floors or pavers and of vehicles), and also biofilter spillwater, wastewater from the fat and blood lines and vapour condensate from the air condensers.

The mixed wastewaters from the wastewater lines listed above are characteristically highly polluted. The very high organic matter content, significant quantity of floating material and fat content and high ammonia content of the wastewater create a lot of obstacles for the cleaning equipment. From among numerous potential processes Figure II.11.12, shows the pre-treatment system of an animal protein processing plant.

The wastewater treatment equipment that is used consists of mechanical, physical-chemical and biological treatment phases in this order.



1. Machine bars 2. Drum screen 3. Balancing pool 4. Pipe flocculator 5. Flotation system with dissolved air 6. Sludge collector 7. Anoxic pool 8. Biological system SBR operation 9. Sludge thickener 10. Sludge container 11. Sludge separator

Figure II.11.12: Flow chart of the wastewater treatment of an animal protein processing plant

(Source: Zsuzsanna Uri, 2014)

The untreated wastewater first flows through a machine screen with a 5 mm gap diameter, and then through a drum filter with a gap diameter of 0.75 mm. The filtered water flows into the aerated balancing pool that is equipped with a mixer, and then, after having been balanced, it is sent to a pipe flocculator. The pipe flocculator (Figure II.11.13) is a reactor through which the water can flow and at the same time a place where coagulation, flocculation and the adjustment of the pH level are carried out under turbulent flow conditions. To support flocculation, polyelectrolyte (Flocstar 202 L) to encourage coagulation iron(III) sulphate, and to adjust pH levels NaOH, are added into the pipe system. The type and amount of the chemicals that are added depends on the level of pollution of the wastewater. The wastewater that leaves the pipe flocculator flows through a distribution pipe system into the flotation equipment mixed with dissolved air.

The flotation unit (Figure II.11.13) is of a compact, low design equipment with a lamella separator, in which the wastewater flows in the opposite direction to the inflow point towards the conveying trough. Vaporization of the dispersed air results in the production of microbubbles. The microbubbles adhere to the flocs and fat drops in the wastewater and due to their upward moving force they are transported to the surface. The sludge floating on the surface is removed with a skimming machine and taken to a sludge collection container.

Figure II.11.13: Pipe flocculator (on the left) and flotation equipment with dissolved air (on the right)
(Source: ATEV Zrt Hódmezővásárhely plant, 2014)

The wastewater that leaves the flotation equipment enters a continuously mixed anoxic pool. The desired proportions of C:N:P are defined and adjusted – as needed – using phosphoric acid before the water reaches an anoxic pool. From the anoxic pool the wastewater enters a sequencing batch reactor (SBR) operation biological system. The SBR object (Figure II.11.14) consists of two pools that take the shape of concentric circles. The inside pool is separated into two identical parts by a wall. From the anoxic pool the wastewater first flows into the outer ring pool, which is constantly aerated. In the next step, treatment continues in the inner pool. In one of the inner pools of a semi-circle shape the settling process takes place. At this time aeration is stopped. During this time, in the other pool nitrification takes place in the presence of the continuous supply of air. The two pools change their functions periodically while in the outer pool the direction of current changes.

Figure II.11.14: SBR object *(Source: ATEV Zrt Hódmezővásárhely plant, 2014)*

The volume of the excess sludge that is produced during biological treatment is reduced with a gravitational thickener. The sludge, with a dry matter content of 6-8 percent, leaves the flotation unit and is mixed with 3-percent dry matter content biological excess sludge that is pumped from the thickener and after a short storage period and homogenization is transported to the separator (Figure II.11.15). To increase efficiency, polyelectrolyte is added to the sludge. The centrifuged sludge of 20-23 percent dry matter content is transported to a composting plant.

Figure II.11.15. Sludge separator
(Source: ATEV Zrt Hódmezővásárhely plant, 2014)

The wastewater that is treated is conveyed into the municipal sewage system. NaOCl solution is added to the delivery pipe for disinfecting purposes.

II.12. Human and animal health considerations of using the by-products and wastes of the food industry

(György Vincze)

When by-products of plant or animal origin are processed and utilized and the compounds and materials produced from them are used in food products and fodder, there is a risk that biological agents (e.g. pathogenic microorganisms or prions) or poisonous substances (e.g. mycotoxins) can enter the food chain, threatening the health of domestic animals and people. By-products of animal origin may carry any of the infections that are transmitted from animal to animal or from animal to humans if the collection, processing or elimination of the by-products do not meet the requirements described in legal regulations.

In food products of animal and plant origin and in by-products the following hazardous materials may be present and may threaten animal and human health:

1. Biological, microbiological hazards (e.g. prions, viruses, pathogenic bacteria, fungi (mycotoxins), parasites).
2. Chemical (chemical, toxicological) hazards (e.g. natural and synthetic poisons, antibiotics and yield-enhancing hormones and additives used in the food industry).
3. Physical hazards (e.g. environmental, technological, anthropogenic, pests).

This chapter describes the animal and human health implications of the utilization of by-products and wastes of the food industry.

II.12.1. The connection between microorganisms and food hygiene

Hygiene means protecting humans and animals against various germs. Fodder production is part of the food chain; that is, the regulations that apply to food production must be also applied to fodder production. From the legal perspective, fodder production is equivalent to food production. This is why the White Book of food safety also addresses fodder production. In addition to defining strict quality standards, the Book makes it compulsory to set up a quality assurance system that covers all the aspects of the food production chain, from animal farm to the consumers' table.

Organic materials, whether they are food products, fodders or by-products of plant or animal origin all make excellent mediums for microorganisms if the external environmental conditions are optimal. Environmental and public health issues arise if pathogenic organisms start to multiply. Apart from humans, this may also lead to the infection of domestic animals or even wild animals: what is more, in the latter case (as wild animals move over large areas), it may result in an infection becoming widespread.

Some of the multiplying microorganisms can generate toxic metabolic products. In many cases these toxins have significant resistance against environmental effects and may cause infection even if the microorganism that has produced them is no longer present.

The most common pollutants of food, fodder, their plant or animal based raw materials and their by-products are the following:

– Bacteria. These prefer habitats with high levels of moisture and close to neutral pH. Under unfavourable conditions some bacteria can produce particularly persistent forms such as endospores which are usually highly resistant.

– Molds. These tolerate a wide range of moisture content and pH. Some species produce mycotoxins, which are harmful to health, poisonous, carcinogenic, mutagenic or teratogenic.

– Pathogens without a cellular structure formation:

– Prions. Prions are simple but "strong-willed" protein molecules which make their molecule partners from abnormal structures, thus blocking some of their functions. They usually lead to a lethal infection.

– Viruses. These have various structures. They are agents that can identify the host cell and then infect it. They are metabolically inert when independent of a host.

The following chapters provide details about the most common and most dangerous infectious agents that can be transmitted through by products generally, and by-products of animal origin.

II.12.2. Illnesses caused by bacteria

Food products, fodders, their raw materials, by-products and wastes provide ideal conditions for the growth and reproduction of microorganisms and bacteria. Products and by-products of animal origin may become polluted by microorganisms that live in the air, water and soil at several points on the way 'from the animal farm to the table'. In the stomach and intestines of domestic animals there are large numbers of microorganisms, some of which may infect the food or fodder raw materials. In many cases, the bodies of healthy-looking domestic animals contain large numbers of pathogenic microorganisms, especially the liver, kidneys, lymphatic glands and spleen.

For an infection-causing agent to stay in a reproductive condition, several conditions must be fulfilled at the same time; e.g., there must be available nutrients, a suitable moisture level, an appropriate pH and reduction potential and the absence of inhibitors and highly competitive microorganisms.

As mentioned above, foddering is part of the food chain, which means that the microbiological limit standards that apply to food for human consumption are also applied to fodders. If these regulations are adhered to, meat production will not be harmful to health. Table II.12.1 shows the microbiological limits for fodders in Hungary. Chapter II.13.2.2 describes the standard techniques for microbe examination.

Table II.12.1: Microbiological limit standards for fodders *(Source: Decree 65/2012)*

	Reference method	Upper Limit ("M")
1. Pathogenic microorganisms		
- Salmonella sp.	MSZ EN ISO 6579*	0/25 g
2. Microorganisms that signal technology-related and hygienic conditions		
- E. coli (except heat-treated fodders)	MSZ ISO 16649-2*	100/g
- Clostridium perfringens (only in heat-treated fodders)	MSZ EN ISO 7937*	100/g
3. Microorganisms that indicate environmental pollution		
- Number of mesophilic aerobic microbes (only in granulated fodders)	MSZ EN ISO 4833*	1 million/g
- Enterobacteriaceae sp. (only in the case of heat-treated fodders)	MSZ ISO 21528-2*	1000/g

"M" – upper threshold; * - latest version of the standard

For products made from by-products of animal origin the following microbiological standards apply (i.e. samples taken at processing plants while the products are stored or when the final products leave the premises must meet the requirements of the following standards):

Salmonella: in 25 g no traces; n = 5, c = 0, m = 0, M = 0
Enterobacteriaceae: in 1 g n = 5, c = 2, m = 10, M = 300
where:

n = number of samples to be examined;

m = threshold limit value of bacteria number; the result is satisfactory if the number of bacteria in all samples is not more than m;

M = the maximum number of bacteria; the result is unsatisfactory if the number of bacteria in one or more samples is M or over M, and

c = number of samples in which the number of bacteria may be between m and M; the sample is considered satisfactory if the number of bacteria in the other samples is m or less than m (Regulation 142/2011/EU).

The microbiological quality of fodders depends on the bacteria and fungi they contain. The microbiological classification, as far as marketability is concerned, is designed to determine if the product:

– has the typical microflora,
– contains microorganisms that imply poor conditions; that is, the product is not fresh any more,
– contains pathogenic microorganisms.

The microbiologically harmless conditions of fodders of animal origin are ensured by not exceeding the microbiological limit values (see above). It is a basic requirement that proper fodders and fodder raw materials must not contain pathogenic microorganisms. The number of pathogenic bacteria is not determined directly (except Salmonella). Their presence is suggested by indicator flora. If the number of microbes is over any of the quality limit values, the fodder batch must be considered unsuitable and the cause for its unsatisfactory condition must be identified.

The total germ number (plate count) characterizes microbiological condition generally, and refers to the total number of living aerobic mesophilic germs that can reproduce (reproducing germ number/g fodder).

The Escherichia coli number determines the number of coli bacteria which can reproduce even at 44 °C. The number indicates the bacteria number per sample gram, and readings over the limit value can imply fresh faecal pollution. As excrement may contain various germs (viruses, bacteria, parasites), if the samples show high numbers of E. coli, the germ-free status of the material cannot be guaranteed. High E. coli numbers may indicate low levels of general hygiene, unsatisfactory disinfection techniques or later faecal contamination (e.g. by rodents or birds).

The sulphite reducing clostridia number refers to the sum total of anaerobic protein decomposition bacteria, the majority of which belong to the group of clostridia. This parameter also indicates the general contamination of the fodder but it may also be a sign of anaerobic decomposition. If the number of sulphite reducing clostridia is very high, it may be necessary to identify their types, as one of them is the facultative pathogenic Clostridium perfringens, which may cause lethal enteritis (this may appear in improperly heat-treated fodder of animal origin).

The pathogenic Clostridium botulinum may produce botulinum toxin and, as a result, cause serious poisoning.

If C. botulinum contamination is suspected, the toxins must be identified. Fodder poisoning due to Clostridium toxin is very rare and is usually a food hygiene-related issue (e.g. poisoning from sausages). The high clostridia content of fodder of vegetable origin is usually not a problem as poisoning can only be caused by other contaminated material being mixed in. In the case of animal protein meals, over the limit numbers of Clostridium indicate improper disinfecting techniques, a situation which must be taken seriously.

II.12.2.1. Salmonella enteritidis (S. Typhi, S. Typhimurium) - salmonellosis

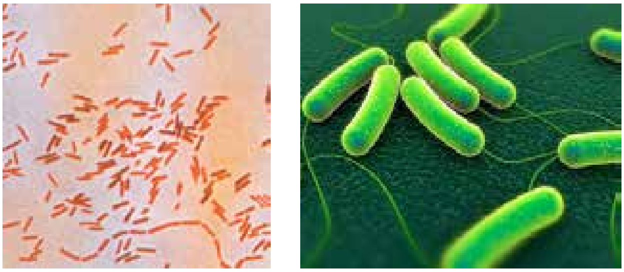
Salmonella (Figure II.12.1) is a facultative anaerobic, Gram-negative, non-sporogenous, endotoxin producing bacterium, which is able to reproduce over a wide temperature (5-47 °C) and pH (3.6-9.5) range, although at 55 °C they die in 1 hour and at 60 °C in 20 minutes. To trigger infection, the minimum infection dosage is 10-100 (S. Typhi) cells (in the case of several species ~10^6 cells).

Salmonella is naturally present in the microflora of the intestinal canals of animal species. In most cases the infection does not cause any symptoms except in specimens with weak immune systems. It is a very well-known zoonosis; that is, a germ that can be transmitted from animals to humans. Ongoing, large scale loss of liquid (dehydration) from vomiting or diarrhoea represents the biggest danger to those infected, especially children. The right antibiotic-based therapy (penicillin derivatives) can cure the infection.

Without proper therapy, the cells may enter internal organs and also the blood. The infection causes a high fever and enlarges the liver and spleen. If the bacteria reproduce in large numbers in the intestines, they may cause its perforation.

The main sources and transmitters of the infection are raw food materials of animal origin such as poultry and other meat, the internal organs of animals, milk and dairy products, eggs and improperly washed vegetables. It is also very important to note the prevalence of Salmonella infection through eggs. About 30 percent of all egg producing poultry is infected.

Salmonellosis does not have to be reported to the authorities; however, to improve food safety the European Union aims to reduce the poultry stock infection levels down to about 5 percent in the framework of the Salmonella control programme.



(a) *(b)*

Figure II.12.1. Salmonella Typhi (a) light microscope and (b) electron microscope image

(Source: (a) http://textbookofbacteriology.net/salmonella.html; (b) http://salmonellatyphi.org/)

II.12.2.2. Escherichia coli

E. coli (Figure II.12.2) is a bacterium that typically can be found in the intestines and is a permanent part of human intestinal flora. As an enteric bacterium it is considered the public health indicator of faecal contamination in food products, surface and sub-surface waters. It is Gram-negative, does not produce spores and belongs to the facultative anaerobic rod-shaped bacteria group. As it is gram-negative, among the molecular elements of the cell wall it has endotoxin and antigen components. Both the endotoxin and antigen molecule parts show great variation depending on their serotype. The number of individually known and distinguishable serotypes is over 2500. Despite their high variability, they are permanent elements of intestinal flora and most E. coli strains are pathogenic; that is, they do not usually cause illnesses.

(a) (b)

Figure II.12.2: Escherichia coli (a) light microscopic and (b) electron microscopic images
(Source: (a) http://img.medscape.com/pi/emed/ckb/infectious_diseases/211212-217485-344.jpg; (b) http://fineartamerica.com/featured/e-coli-bacteria-david-mack.html)

Depending on how the illness is caused, the infection strains can be classified into 5 major groups:
– enteropathogenic E. coli (EPEC),
– enterotoxin producing E. coli (ETEC),
– enteroinvasive E. coli (EIEC),
– enterohemorrhagic E. coli (EHEC),
– enteroaggregative E. coli (EAEC).

Most human illnesses are caused by the enterohemorrhagic E. coli (EHEC). The dose needed for infection very low: only 100-1000 cells. Experience shows that the most important types are E. coli O157:H7 serotypes, which are able to produce toxins typical of the Shigella strains (Shiga like toxins (SLT) I and II) which cause bloody diarrhoea, especially among children and elderly people. The faeces of infected people contain large amount of fresh blood. In some cases, or without treatment, there may be various other effects, one of which is haemolytic uremic syndrome (HUS), which damages the kidneys. The illness may result in up to 3-5 percent fatalities among those infected. The infection spreads mostly when the contaminated food is consumed but may also be transmitted by contaminated water, fresh, unpasteurized milk and lettuce. The best way to prevent infections is to maintain a high level of hygiene and use appropriate food processing techniques (cells die at over 72 °C).

II.12.2.3. Clostridium perfringens

Clostridium perfringens (Figure II.12.3) is a Gram-positive bacterium with a capsule, it is unable to move actively. It is rod-shaped and spore-producing. Within the Clostridium genus there are a lot of pathogenic strains (C. tetani, C. botulinum), which cause illnesses with different mechanisms. C. perfringens causes fast tissue decay due to its histotoxic effect, mainly in the intestinal tract. Dead tissues must be removed surgically. During their metabolism, large amounts of gases are produced which can lead to gas gangrene (malignant oedema). With C. perfringens there are 5 types (A-E), depending on the toxin produced. If proper treatment is lacking, the toxins generated by the bacteria may cause bacteremia (bacterial cells enter the blood circulation) which may lead to shock or even death.

Although C. perfringens can reproduce over a wide range of temperature (15-50 °C), C. perfringens typically reaches high numbers in meat products that are allowed to cool down slowly and are stored for a longer period before consumption. A minimum of 100-1000 bacterium cells must get into the body to cause infection.

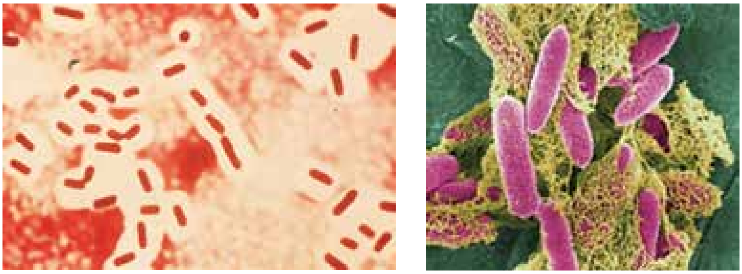

(a) (b)

Figure II.12.3: Clostridium perfringens (a) light microscopic and (b) electron microscopic images
(Source: (a) http://www.microbeworld.org/component/jlibrary/?view=article&id=1502;
(b) http://www.marlerblog.com/case-news/a-clostridium-perfringens-multiple-sclerosis-ms-link/)

Vegetative cells die at a temperature as low as 65 °C; however, spores are much more resistant: their heat resistance differs from strain to strain. To kill spores, heat treatment at 100 °C is necessary, lasting from a few minutes to as long as 4 hours. The most efficient way of preventing infection is fast cooling of food and its storage at a low temperature (-15 °C).

II.12.2.4. Bacillus anthracis – anthrax

Anthrax is an infectious illness caused by bacteria. Under normal conditions it affects all warm-bloodied animals, especially ruminant animals, but may also be transmitted to humans through direct contact with sick animals or infected animal products. It is not transmitted from human to human.

Bacillus anthracis (Figure II.12.4) is a Gram-positive, rod-shaped bacterium that produces spores under aerobic conditions (if oxygen is present). As a spore the bacterium can survive extreme conditions (desiccation, cold-hot, etc.) and revive under more hospitable conditions. The germ creates a capsule which blocks the immune system and produces poisons. Through the blood circulation it can travel around the body and cause menorrhagic inflammation, mainly affecting the tissues of point of entry, the lungs, intestines and skin.

The incubation period and the symptoms are closely connected to the place of infection. Among humans skin anthrax is the most common. In this case the anthrax spores get into the body through tiny wounds. The incubation period is 1-7 days. The infected person develops itchy, small, red spots that later turn into blisters. Later, these blisters merge into a typical, painless anthrax carbuncle with a diameter of 1-3 cm (a malignant pustule). The centre of this later darkens. The lymphatic glands close to the infected area become swollen. If the infected person does not get treatment, the bloodstream may easily become infected. This is why 20 percent of untreated skin anthrax cases are fatal. Antibiotics, however, can cure the illness very effectively.

Under normal conditions, people develop lung anthrax much less often. In this case the person inhales the spores. The incubation period is 1-60 days. At first, the symptoms are similar to having a cold with a temperature. In addition to a high fever and shivers the patient also suffers from shortness of breath and later a rapid chest infection develops with bloody sputum. If untreated, this type of infection can cause death in 1-2 days.

Infection may also take place if humans eat the raw meat of sick animals or drink their milk without having boiled it first. The initial symptoms of the infection are: lack of appetite, fever, stomach-ache, then vomiting with blood, and due to intestine inflammation, blood in excrement. If untreated, 20 to 60 percent of patients die.

(a) (b)

Figure II.12.4: Bacillus anthracis (a) light microscopic and (b) electron microscopic images

(Source: (a) http://www.fao.org/docrep/003/t0756e/t0756e03.htm;
(b) http://www.nature.com/news/2009/090225/full/news.2009.120.html)

II.12.3. Molds and their toxins

Mould number refers to the number of growth-producing fungi particles (propagules) per gram. In the case of fodders of animal origin, fungi propagules get into the product from the air space in the production unit (passive mixing). They have the opportunity to reproduce (mould) if the moisture content of the product is slightly higher than is necessary for safe storage (12-15 percent). The moulding of animal protein meals is usually caused by moulding in the storage area (Aspergillus, Penicillium species).

As far as fodder and food safety is concerned, it is not the fungi infection but rather the toxic materials produced by the fungi and their poisonous effects that should be taken care of. Mycotoxins are the secondary metabolic products of cells. They are not necessary for building fungi cells or operating them, but they are the by-products of metabolic processes. In general, toxin production is a response to the stress the cell experiences.

The fungi toxins in the animal or human body may cause serious poisoning, mycotoxicosis. Mycotoxins are of several different types chemically, and so behave in different ways in the body. While some of them go through the intestinal tract and resist enzymatic effects and finally leave the body with the excrement in an unchanged form, others go through metabolism in the body and during the process usually become less toxic derivatives (however, there are counterexamples too: toxic detoxification) and leave the body partly with the excrement and partly in the urine. Some mycotoxins are apolar, which means that they may accumulate in animal tissues with high fat content and may be secreted with (e.g.) milk. The latter explains the food safety importance of dealing with fungi toxins. The toxins absorbed from the stomach-intestine tract may enter the liver and be detoxified (partly). This is the reason why the process, in the case of several toxins, may lead to liver damage. Some toxins leave the body through the secretory system and may cause damage to the kidney while doing this. Statistics show that some mycotoxins also have mutagenic, carcinogenic, teratogenic, immunotoxic, neurotoxic, cytotoxic and antimicrobial effects.

Nowadays, over 100 mould fungi species are known to produce toxins and the number of toxins that have been identified is over 1000. The appearance of some infectious species depends on the moisture content of the stored crops and the humidity of the place of storage: on products with as low a moisture content as 14 percent, Aspergillus, at a moisture level of 16 percent Penicillium species and at 20 percent Mucor species are likely to multiply. In addition to the above, the following general fungi must be mentioned: Fusarium, Cladosporium, Alternaria, Trichothecium, Byssochlamys and Sclerotinia.

The best way to prevent mycotoxin poisoning is to prevent mould fungi multiplication during the growth, harvesting, storage and drying of plants and their processing; that is, practically from growth to consumption.

As the poisonous impact of mycotoxins may influence the whole food chain, the European Union determines mycotoxin limit values for fodders in Regulation (576/2006/EC). These limits do not indicate compulsory standards but provide recommended limit values.

International recommendations for mycotoxin limit values:

576/2006/EC recommendation:

T-2 and HT-2 for toxins – without sufficient reliable data – recommended values are not determined.

576/2006/EC recommendation (deoxynivalenol, DON):

- Grains and grain products, except for corn by-products	8 mg/kg
- Corn by-products	12 mg/kg
- Additional and whole meal fodders	5 mg/kg

576/2006/EC (zearalenone):

- Grains and grain products, except corn by-products	2 mg/kg
- Corn by-products	3 mg/kg
- Full value fodders designed to pigs	0.9 mg/kg

576/2006/EC (fumonisin B1 and B2 together):

- Corn and corn products	60 mg/kg

576/2006/EC (ochratoxin A):

- Grains and grain products	0.25 mg/kg

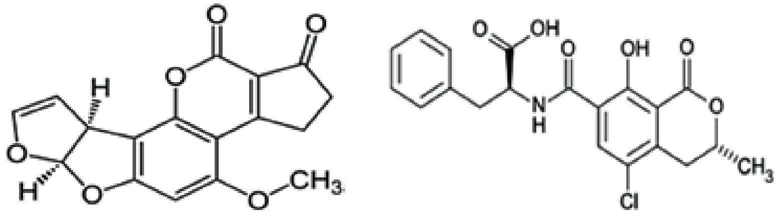
II.21.3.1. Aspergillus toxins

Among mycotoxins, the aflatoxin produced by the species belonging to Aspergillus genus (A. flavus and A. parasiticus) represents the greatest potential hazard to human health. These fungi can often be found in the harvested and stored crops of grains, almonds, walnuts, peanuts and sorghum and also in products made from them. In addition, they may also present in dried fruit and oily seeds and spices. The fungi cells usually begin to multiply if a pest attacks the crops, their drying period is very slow with a high moisture level, or when storage conditions are not dry enough. Aflatoxin is heat stable and survives cooking or microwave treatment but decomposes when exposed to UV radiation (Figure II.12.5). It has various forms. In the milk of cows that eat contaminated fodder the metabolized forms of aflatoxins can be isolated. The basis of the biological effect of aflatoxin is that, having absorbed from the intestinal tract a derivative produced in the liver (epoxide), it causes mutation of the genetic substance which may lead to the formation of tumours.

In the case of acute aflatoxin poisoning the symptoms may be liver damage and tissue death. In serious cases, the poisoning may be fatal. If a person is exposed to lower doses for a longer period the following clinical symptoms may present: lack of appetite, rapid weight loss, abnormality of the nervous system, immunosuppressive effect, yellow discolouring of the mucous membrane, liver deformation and muscle twitching. Poisoning may also lead to oedema in body cavities and bleeding in the kidney and intestines, which is followed by tissue decay.

Another species of the Aspergillus genus, A. ochraceus, produces a chemically different toxin, ochratoxin (OTA and OTB types are known) (Figure II.12.5). This toxin is produced not only by Aspergillus species (about further 10 species) but also by some Penicillium (P. verrucosum) species. The OTA type of the toxin is highly significant as this form contains chlorine, which makes is 10 times more poisonous than usual.

Experiments with animals have proven that it is a carcinogenic and immunosuppressive compound, which having been metabolized leaves animal bodies slowly and damages kidneys mostly by causing the necrosis of the renal tubules.



aflatoxin B1 (a) *ochratoxin A (OTA) (b)*

Figure II.12.5: Aspergillus toxins
(Source: (a) http://upload.wikimedia.org/wikipedia/commons/e/ee/%28%E2%80%93%29-Aflatoxin_B1_Structural_Formulae_V.1.svg; (b) http://www.mdpi.com/2072-6651/4/4/244/htm)

II.12.3.2. Fusarium toxins

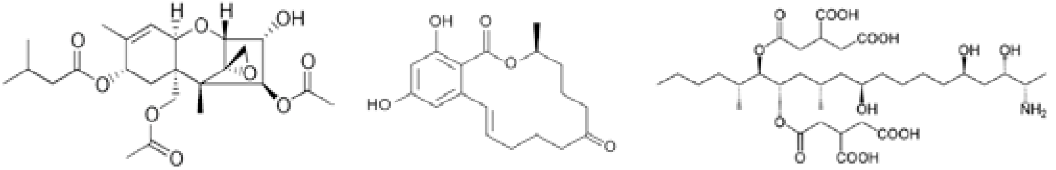
Fusarium species are found all over the world. They are mostly toxin producing molds (fungi) which are able to create more than one type of toxin. As arable land fungi, they require a substrate with a high moisture level (20-23 percent) and water activity (aw: 0.85-0.90).

Among mycotoxins produced by Fusarium species, it is mainly the members of three groups that are significant: trichothecenes, zearalenone and fumonisin (Figure II.12.6).

Fusarium species produce nearly 200 trichothecene framed mycotoxins. Their most important representatives are dezoxynivalenol (DON), nivalenol, the T-2 toxin, and their metabolites. The most efficient is the T-2 toxin, which is also the most frequent contaminant of crops infected with Fusarium. The T-2 toxin dissolves in fat very easily, goes through the intestine canal unchanged and leaves the body, although smaller proportions may enter the liver after absorption, where toxic metabolites are formed. The most common symptoms are its dermatotoxic effects, which means that wound develop in the mouth mucous membrane and the gullet, and finally, the tissue may die. There are other effects that are not visible to the eye like hindered protein synthesis (in the liver, bone marrow, thymus and spleen), blocked liver transformation processes and a disrupted immune system.

Several Fusarium species can produce zearalenone – such as F. graminearum, F. culmorum, F. avenaceum, F. poae, F. sporotrichoides, F. tricinctum and F. equiseti. Due to the structural similarity (between the toxin and oestrogen), zearalenone mainly causes reproductive problems in animals. Zearalenone is closely linked to the oestrogen receptors, which results in disorders in sexual development, the follicular phase and the spermatogenesis processes, lower testosterone levels and numbers of sperm and an increase in feminine features. However, the mutagenic, hemotoxic and genotoxic effects of zearalenone have also been proven.

Zearalenone becomes even more dangerous as it goes through toxic detoxication after having been metabolized in the body, when it forms a metabolism product that is more poisonous than the original compound (α-zearalenol). The entero-hepatic cycle blocks it from leaving the body. It can travel from the liver (together with bile) into the intestinal canal but be reabsorbed at a later point in the canal and return to the liver.



T-2 toxin (a) *zearalenone (F-2 toxin) (b)* *fumonisin B1 (c)*

Figure II.12.6: Fusarium toxins

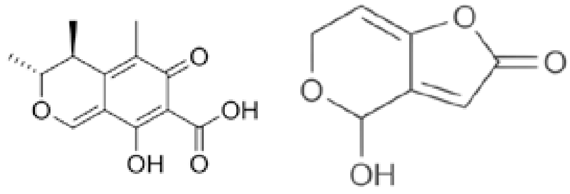
(Source: (a) http://upload.wikimedia.org/wikipedia/commons/4/45/T-2_mycotoxin_flat.png;
(b) http://www.fermentek.co.il/zearalenone.htm;
(c) http://upload.wikimedia.org/wikipedia/commons/e/e7/Fumonisin_B1.svg)

Fumonisins produced by Fusarium species contaminate corn for fodder and human consumption. The toxin has 8 known versions. Almost all animal species are sensitive to them, especially pigs, horses and people. Fumonisins have various physiological effects. Animal are usually killed by hydrothorax and wet lung caused by the infection. Their carcinogenic effects have been proven in animal experiments and they are likely to affect humans in a similar way as in areas where corn is part of the daily diet but Fusarium infection levels are high, throat cancer develops 30 times more frequently than average.

II.12.3.3. Penicillium toxins

Citrinin (the kidney toxin) (Figure II.12.7) produced by Penicilliums mostly appears on grains: 'yellow rice' (Japan) but it is also frequent in Europe. It was originally isolated from P. citrinum growth and this is where the name comes from, but its main site of production is the ochratoxin-forming P. verrucosum. P. expansum may also produce it, so it may appear together with patulin. Its formation largely depends on the temperature (typically 25-30 °C). In itself it has only a weak effect; however, with ochratoxin it acts synergistically and creates a powerful kidney damaging compound. Its kidney damaging mechanism is different from that of ochratoxin. Kidneys become enlarged and discoloured and cysts may form in them.

Patulin (Figure II.12.7) can be produced by various Penicillium and Aspergillus species. It has been isolated from mainly P. expansum and A. clavatus growths (its former name came from clavacin). Chemically, its structure is a saturated unsaturated 5-membered lactone. It is stable in an acidic environment and decomposes in the presence of alkalis.



citrinin (a) *patulin (b)*

Figure II.12.7: Penicillium toxins

(Source: (a) http://upload.wikimedia.org/wikipedia/commons/d/d9/Citrinin.png;
(b) http://upload.wikimedia.org/wikipedia/commons/1/11/Patulin_structure.svg)

Fungi are psychrotolerant; that is, they can produce toxins at low temperatures (optimal 20 °C). It is interesting that the most intensive toxin production has been found on fruit at a low temperature when both P. expansum and Byssochlamys fulva decay stimulating moulds were present.

In Hungary it is most likely to occur on fruit that have been affected by green rot. This is why, in many laboratories of processing plants, testing of fruit juices, mashes, jams and concentrates for the presence of patulin is routine.

Patulin has various physiological effects. On one hand it increases the permeability of arteries, and at a higher dosage it may even cause internal bleeding. On the other hand, it also causes symptoms in the nervous system. Its carcinogenic effects in more complex organisms has not been proven.

II.12.4. Pathogens without cell structures, prions – prion illnesses

Although prions are not the most common contaminants of products and by-products of animal origin, they are still quite significant as their appearance revolutionized the regulatory system for the processing of by-products of animal origin. Currently, there is no efficient therapy available to treat spongiform encephalopathy, so the only opportunity to reduce risk is to prevent the infective agent from spreading.

The other often-used name for prion illnesses is TSE Transmissible (Contagious) Spongiform Encephalopathy. The term refers to several rapid-course illnesses with similar symptoms and pathological features that cause, at the moment, incurable neuro degenerative damage. The most common prion illnesses are scrapie among sheep, mad cow disease among cattle and Creutzfeldt-Jacob disease among people.

In the 1980s it was proven that a coded protein in the infected animal, called a prion, can accumulate in the brain tissue of infected animals and people, taking on an abnormal structure which is closely connected to pathogenicity. The word prion is an abbreviation of the expression proteinaceous infectious particle and its shorter version 'protein only'. The deformed protein itself is able to cause illness and multiply without DNA.

In the 1990s it was shown that the infectious prion protein that enters the body attacks the nervous system, and forces prion proteins with a normal structure that are naturally found on the surface of nerve cells to become deformed.

A research group finally answered the question that used to be a major focus of public attention: whether the encephalopathy of animals is transmissible to other animal species or humans; i.e. whether the illness can jump species. Transgenic mice that due to genetic modification were made to produce human prion proteins were infected with encephalon extracts from sick cattle. The incubation period was longer than usual but the typical symptoms developed, which means that the deformed prion proteins of the cattle could force normal, human prion proteins to change structure and cause illness.

II.12.4.1. BSE, Bovine Spongiform Encephalopathy among cattle

The history of spongiform encephalopathy in cattle goes back to the middle of the 1980s, when the histological examination of the encephalon of 17 sick cows showed spongiform degenerative brain parts similar to the symptoms of scrapie of sheep. However, no known pathogens could be found in the cadavers that could have been connected to the symptoms experienced. The illness became an epidemic in 1988 and over 1 million stocks had to be killed in Great Britain to contain the epidemic.

It was finally found that fodder was responsible for the infection, as in order to increase the protein content during its production the fodder had been mixed with the processed cadavers of sheep, some of which had been infected. The direct reason, however, was that the production process had been changed in order to save the protein content: namely, fat-removing organic dissolvent extraction and high temperature treatment were not undertaken. This meant that the pathogenic prions that entered fodder with the infected tissues (which are normally quite resistant to denaturing physical and chemical impact anyway), maintained their pathogenicity. As a result of the sustained use of the contaminated fodder the scrapie-causing infectious prions crossed the protective wall that normally exists between species, and through adaptation created a new version of the illness: BSE Bovine Spongiform Encephalopathy.

The infectious particles that were isolated from sheep with scrapie and cattle that had died of BSE were found to have similar features, the most important of which are: resistance to heat treatment, to enzymatic metabolism (partial protease resistance), to the disinfecting effects of traditional disinfectants and resistance to UV radiation. From the brain homogenates of two different sources concentrates with high pathogenicity could be extracted using purification techniques. The extract contained prion proteins with a deformed structure, identified as being amyloid fibres. They consisted of proteins only and electromicroscopic images indicated that they were identical.

As there is extensive evidence that the illness can be transmitted, it was no surprise that among ruminant animals and predatory species at zoos, the adapted versions of scrapie appeared and affected numerous types of animals. Today it is common knowledge that humans are not immune to animal prion illnesses.

II.12.4.2. Limited use of by-products of animal origin

After having analysed the reasons and consequences for the 1980-1990s British 'mad cow disease' epidemic, in 1997, for the first time, the European Union defined limitations for the feeding and processing of ruminant animals. On 30th June 1997 The European Union decided (Regulation 97/534/EC, amended 98/248/EC) to remove so-called SRM Specified Risk Materials completely and forever from the food and fodder chain in order to prevent the BSE epidemic from spreading in the future.

The most important point of the Regulation determines that by-products and slaughterhouse wastes of ruminant animal origin cannot be used either for human or for animal consumption. Animal parts that can only be disposed of safely are detailed in the title 'Specified Risk Materials'.

The member states of the European Union and their regions, non-EU countries or their regions must be categorized into one of the following three BSE categories:

- countries with little BSE risk,
- countries with controlled BSE risk,
- countries with undefined BSE risk.

Member states with an undefined risk of BSE and non-EU countries and undefined BSE risk regions cannot export or store fodder containing the protein of mammals intended for domestic animals or animal fodder intended for mammals – except for dogs, cats and furry animals – which contains processed protein of mammal origin (see Chapter II.4).

Based on these regulations, Specified Risk Materials cannot be used at all. In accordance with Regulation 142/2011/EU Appendix V and Regulation 1069/2009/EC these materials must be removed and eliminated. These materials cannot enter the area of the European Union.

Materials with very high infection hazards

The following tissues must be considered specified infection risk materials if they come from bovine animals from controlled or undefined risk member states or third countries or regions:

- the skulls, except jaws of animals over 12 months old, including brain, eyes and spinal marrow;
- for animals over 30 months, the backbone except the spinous process and transverse process of the tails, necks, lumbar vertebrae, excepting the middle rump bone crest and rump bone wings, but including spine base nerve knots; and
- the tonsils and intestines of animals of any age from the duodenum torectum and mesentery.

II.12.5. Dangers caused by viruses – swine fever

Swine fever is a highly infectious viral illness contracted by domestic and wild pigs and presents with symptoms of fever, weakness of the back part of the body and bleeding all over the body. Cases of swine fever must be reported to the authorities. It should be noted that the virus does not harm other domestic animals or humans. Only domestic and wild pigs have a high level of sensitivity to it.

Epidemiologically, it is significant that the virus is highly resistant to environmental effects but is sensitive to heat: the virus dies at a temperature of 80 °C. As the virus is also very sensitive to an alkaline pH, alkaline disinfecting materials can be efficiently used.

Infection takes place through viruses present in the saliva, urine and other discharge or possibly excrement from sick animals.

If the virus enters the body through the mouth, it multiplies mainly in the tonsils and 24 hours after the infection occurs it appears in the blood and multiplies in the circulating lymphocytes and then accumulates in the spleen, lymphatic glands, muscles and the wall of smaller arteries. This is why it causes organ deformation and bleeding. During pregnancy it may get into the embryo which often results in spontaneous abortion.

The clinical condition of the illness depends on the virulence of the strain of the virus and the immune system of the infected animal. The incubation period is between 8 and 22 days but some cases may be longer. The proportion of sick animals is usually high, and the proportion of fatalities is between 10 and 30 percent. Sick pigs usually die after having been ill for 1-2 weeks.

Chronic illnesses are very rare. In such cases, on the thinner skin parts, sloughing crusty areas, underdevelopment and diarrhoea and weight loss are the symptoms. If animal survive the illness, the immunity they develop lasts for years.

The main responsibility of animal health authorities is to prevent the illness. If there is evidence of swine fever, the Authority prescribes:

1. Slaughtering the infected stock.
2. Closing down the affected local and regional area and determining a protection zone.
3. Regulating and monitoring proper disinfecting techniques.
4. Regulating trade in pigs (fairs, markets etc.).
5. If necessary, ordering vaccinations.

Slaughtering, consuming or storing the infected or suspiciously ill (with fever) animal does not pose a risk to humans; however, the leftovers of infected products may cause further infection if fed to pigs (e.g. in kitchen waste).

II.13. The chemical and microbiological analysis of by-products and waste of the food industry (Kalmárné Eszter Vass, László Simon, Szabolcs Vígh)

Similarly to with other technological processes, food production also generates by-products and waste materials. These materials are also renewable natural resources as their reuse can reduce our non-renewable and renewable energy consumption. Reuse, however, may present a chemical and microbiological risk (see Chapter II.12). Through carrying out chemical and microbiological examinations, any possible toxic materials and infectious microorganisms must be detected in fodders, composts and food additives (e.g. gelatin) produced from by-products of the food industry, as during reuse the concentration of any hazardous materials must stay under the pre-determined limit values. Chemical and microbiological examinations are also necessary for determining the composition of wastewaters of the food industry and also for monitoring the efficiency of any treatment.

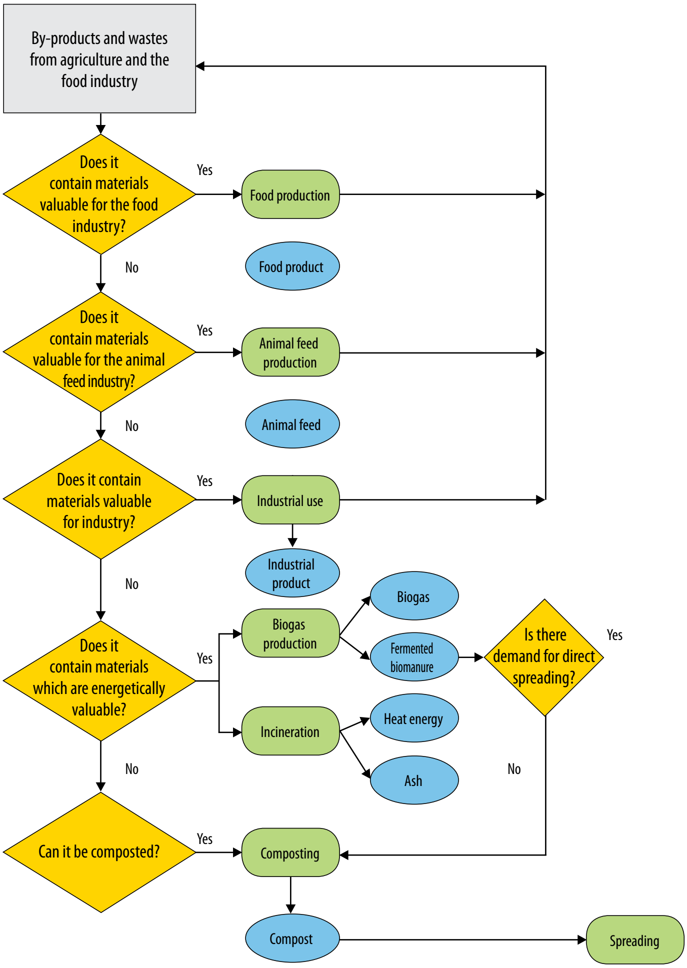


Figure II.13.1: Decision tree for the utilization of by-products and wastes of the food industry

This chapter describes the most important chemical and microbiological examination processes for the by-products and waste materials of the food industry, and also their technical analytical background – together with a description of some physical testing procedures.

II.13.1. Examination of the by-products and wastes of the food industry based on the nature of their utilization

The by-products and wastes of the food industry virtually always contain some materials suitable for the production of food and animal feed, industrial use or energetic purposes or materials that are valuable and can be reused in agricultural production (see Chapters II.6-II.9). When the ways of reuse are considered, it must be determined which recycled products are of the greatest value (Figure II.13.1).

The by-products and wastes from reuse technologies may be recycled as basic materials for other technological processes until the by-products and wastes of the last reuse technology cannot be utilized again in agricultural production. If the by-product or waste of the food industry still contains materials reusable for food production, it will mainly be used to produce food. If it can only be utilized as animal feed, animal feed will be produced from it. If it is only reusable for industrial purposes, it will be utilized in that area. Only if these options are no longer possible can it be used as a yield-increasing material, compost or soil improver, or to produce energy – as biogas or fuel (Figure II.13.1). The order of examination of the elements of the decision tree illustrated in Figure II.13.1 may change as relevant economic considerations and environmental priorities also change. Decisions related to the choice of reuse options are made based on a combined consideration of economic and environmental priorities.

II.13.1.1. Reusable by-products and wastes from the food industry

The by-products and wastes of the food industry are utilized – as shown in Figure II.13.1 – in several different ways. The method of reuse may depend on whether the produced by-product or waste is to be utilized for food production, industry, or as animal feed, for energetic purposes or in the production of compost. The concrete choice of reuse option also depends on whether the main and the by-products of the reuse technology are to be used by the producer or are meant to be sold on the market. If it is possible for the producer to reuse the products themselves, then this is preferable. For example, grape marc is first used to extract grape seed oil and in the next step alcohol is produced. Finally, the mash wash from the distillation industry is used to produce biogas, and then the biogas as well as the incinerated alcohol provide the energy necessary for distillation. Depending on the reuse technology that is used there are different rules that should be considered related to the input and output products of waste utilization. Different legal regulations exist about the permitting, storage, transportation, sales and use of the different products.

Table II.6.1 contains details about the reuse opportunities for by-products and wastes from the main branches of the food industry.

Table II.6.1 indicate that one specific by-product or waste material from the food industry may be used in numerous ways (consecutively or in parallel) and technological processes.

The producer basically has two different ways to reuse the by-products and wastes of the food industry: reuse on the spot, or transportation to be reused at another place. Depending on the quantitative and qualitative features of the by-products and waste, reuse on the spot is recommended if the final product that is produced can later be sold or used by the producer themselves. If there are large variations in the amount and composition of the organic wastes and by-products of the primary production technology, as well as in the amount and value of the reusable final products extracted from them, the specific by-products and wastes should be reused in processing units that are specialized at recycling these materials. In the case of some special by-products of the food industry (e.g. the by-products of grape processing, wine production and by-products of animal origin) of over a designated amount the European Union regulates their collection, treatment in specialized processing plants and reuse.

II.13.1.2. Required analytical inspection processes based on the reuse method for the by-products and wastes of the food industry

Food industry: due to the large variation in the by-products and wastes that are produced and the valuable materials that can be extracted from them there is no analytical method that can be universally applied to them. Depending on the reusable products, specialized laboratory examinations are necessary. If there is data available about the amount of waste and by-product, the composition and volume of the reusable product that can be specifically produced using the determined processing technique can be calculated based on professional literature and the experience of other producers with reusable material production. The inspections required for the introduction of the recycling technology and for the classification of the produced final product are carried out by independently accredited laboratories.

Animal feed production: The by-products and wastes of the food industry are either of vegetable or of animal origin. Those of vegetable origin can be reused as animal feed either directly (while fresh) or after processing, while by-products and wastes of animal origin can only be reused indirectly after further treatment and processing (see 1069/2009/EC decree). Food industry plants usually do not have animal farms; consequently, by-products of vegetable origin that can be reused as animal feed are usually transported elsewhere for further use. The place of reuse in the case of by-products and wastes of vegetable origin can be animal feed mixing plants or animal farms directly. The place of recycling and processing in the case of by-products of animal origin are plants that are specialized in the processing of these materials. The products made in such places can be used as animal feed in a limited way, and only according to regulations (see Chapter II.4).

The materials are handed over based on their quantitative criteria. The reuse opportunities for separate by-products or animal feed ingredients are well known from professional literature and practice. No further inspections are carried out concerning their content, either by the supplier or the receiver. The quality of animal feed and its usability are examined by external, independent, accredited laboratories. There are limit values for inorganic and organic micro pollutants of specific animal feed ingredients that originate from the food industry or other industries. Animal feed ingredients that originate from the by-products of the food industry are highlighted in particular.

Energetic utilization: The energetic utilization of the by-products and wastes of the food industry refers to biogas production (Chapter II.9.1) and incineration (Chapter II.10.6). The pH of the main materials and additives of biogas, its dry matter content, organic dry matter content and C/N ratio are all factors that influence the volume of biogas and must be examined before reuse. For utilization through incineration the amount and energy content of the reused by-products and wastes are the important factors.

Recycling: The by-products of biogas production are fermented bio manure and biogas plant fermentation liquid. Composting – similarly to biogas production – is one of the biological waste treatment techniques. As a result, the quality of compost also depends on the pH of the ingredients, its dry matter content, organic dry matter content and C/N ratio.

II.13.2. Examination methods for the by-products and wastes of the food industry

Industrial food plants do not and cannot have the laboratory tools and equipment necessary for examining all of the compounds listed in regulations. However, they can carry out some simple examinations that do not require more complex equipment but which are essential prior to the reuse of the by-products. The other examinations are carried out in accredited specialized laboratories that have the necessary equipment. The chemical and microbiological examinations required for the reuse of by-products and wastes of the food industry – necessitating the use of expensive laboratory equipment and analytical knowledge – can only be done in accredited laboratories. The majority of industrial food plants do not have such laboratories so, if needed, they usually have the accredited laboratories carry out these examinations for them.

The following chapters contain details about the most important chemical and microbiological examination methods and also the instrumental analysis of by-products and wastes of the food industry, the products and animal feed produced from them and those of the wastewaters of the food industry.

II.13.2.1. Chemical and physical examination

Sampling

Determining the physical, chemical and biological features of material systems is indispensable for the production and exploitation of material systems, for the quality control of products made through the use of different technological systems and also for the use-related monitoring of by-products and wastes (of the food industry) left behind at the end of the use of technological production and usage processes.

The material systems created during food production and usage are almost without exception heterogeneous systems; that is, they consist of several phases and parts and the parts are not dispersed homogeneously within the whole system. Accordingly, it is not possible to examine the total amount of products which will be created before use. On the one hand, this would be extremely expensive (and pointless), while on the other hand, it is not possible to examine, for example, the chemical components for each can as there would be nothing left to consume. Therefore, to determine quality parameters in each case a sample must be taken from the material system that is to be examined.

There exist general rules about how samples are taken. However, for each case – depending on the character of the product, the production technology, the examination method and of course the goal of the examination – there are specific regulations. When samples are taken, both general and specific regulations must be followed together in order to obtain reliable and valid results that can be reliably assessed.

When samples are taken it must be ensured that the sampling is representative: that is, it shows the average characteristics of the unit that is being examined. This is simple in the case of liquids and gases but may be rather difficult in the case of solid heterogeneous systems. The place of sampling, the number of samples and the total amount of samples must be determined in a way that the sample – based on the average of the sample parts (after mixing) – allows accurate insight into all the features of the examined system.

When samples are taken it must be ensured that external conditions should not influence either the composition of the sample or its physical, chemical and biological parameters. When the sampling tools, sample storage containers, transportation and storage conditions are chosen it must be ensured that the sample does not undergo any harmful environmental impacts as far as the examination is concerned. In some cases this means that the sample needs to be preserved or pre-processed.

The most critical point of the analysis – especially environmental analysis – is when the sample is taken and is prepared. In most cases it is not a problem to take enough samples to allow for a possible repeat of the examination, if necessary. The sampling itself, however, in most cases cannot be repeated. In the case of environmental samples, sampling often takes place in extreme conditions. Sampling depends on the usually heterodisperse substance from which the sample is taken. Its physical state, consistency and quantity are all important.

Sample preparation

After arriving at the laboratory, a sample must be prepared for measurement. This means that the sample is received and is given a code that makes its identification possible at a later time. At this point drying, shredding, solving, unbinding and several other steps associated with analytics may be performed. During the sample preparation process general regulations are always adhered to, while the process must also be fit for the specific, concrete job; that is, the nature of the examined sample, the examination methodology and the goal of the examination should all be carefully considered.

Determining the dry matter content

Dry matter content can be assessed in several ways. The most commonly-used process is called the drying cabinet technique. In this case the sample is dried at 105°C until it reaches its volume stability. Then the remaining dry matter is weighed and the dry matter content is determined in proportion to the original volume of the sample. The resulting figure is provided as a percentage.

$$\text{Dry matter content (g/100g)}= \frac{m_2-m_0}{m_1-m_0} *100$$

where:

m_0 = weight of the measuring container (g),
m_1 = weight of the raw sample and measuring container (g),
m_2 = weight of dry matter and measuring container following drying at 105°C (g),
m_2-m_0 = dry matter weight following drying at 105°C (g),
m_1-m_0 = weight of the raw sample (g).

There also exist fast, instrumental methods for determining dry matter content. They are carried out using specialized equipment according to the instructions provided in the relevant equipment manuals.

Determination of organic dry matter, heat loss and raw ash content

Following the determination of dry matter content, the organic dry matter content is determined through heating. A dried sample whose weight is known is heated in a heating oven for 2 to 3 hours until it reaches its volume stability at 600-800 °C. It is then measured again and the resulting figure is provided as percentage of the dry matter content.

$$\text{Organic dry matter content (g/100g)}= \frac{m_1-m_2}{m_1-m_0} *100$$

where:

m_0 = weight of the measuring container (g)
m_1 = weight of dry sample and measuring container before heating (g)
m_2 = weight of dry sample and measuring container after heating – weight of heated remains and measuring container (raw ash) (g)
m_1-m_2 = weight of heat loss (g)
m_2-m_0 = weight of heat remains (raw ash) (g)
m_1-m_0 = weight of dry sample before heating (g)

Heat loss takes place in the dried sample due to the presence of volatile and non-volatile organic matter and volatile inorganic matter. The figure is determined based on the volume loss during the heating process. If by-products and wastes of the food industry are to be reused, it is usually enough to determine their heat loss based on their organic matter content.

Raw ash is the material left behind after the incineration of animal feed under the proper conditions. Any differences between raw ash and real ash (ash that is soluble in hydric chloride) may indicate sand pollution which most often occurs with poor quality fish meal. Raw ash content may also be increased by the salt content of protein meal (e.g. in fish meals). The ash content of animal protein meals usually comes from bones.

Determination of moisture content

Moisture content is determined using the drying cabinet method. However, it is not the weight of the remaining dry matter that is measured but that of the water that leaves. Then the moisture content is calculated as a percentage of the originally-measured figure or of the measured dry matter content.

Moisture content as percentage of the original measured figure (g/100g)= $\frac{m_1-m_2}{m_1-m_0}$ *100

where:

m_0 = weight of measuring container (g)
m_1 = weight of raw sample and measuring container (g)
m_2 = weight of dry matter and measuring container after drying at 105°C (g)
$m_2 - m_0$ = weight of dry matter content after drying at 105°C (g)
m_1-m_2 = weight of moisture that leaves (g)
m_1-m_0 = weight of raw sample (g)

Determination of energy content

The energy content of organic materials destined to become fuel is expressed using their calorific value – the combustion heat reduced by the vaporization heat of the water derived from the moisture that leaves the fuel during the incineration process and the incinerated hydrogen. The calorific value is determined in laboratories under standardized conditions with the use of a specialized instrument – a calorimeter. Calorimeters may be isothermic (i.e. operate at a standard temperature), anisothermic (they measure changes in temperature, operate at a changing temperature) or adiabatic (in the extreme case of anisothermic operation the calorimeter can maintain the temperature of the environment). The required calculations are carried out by computer software that is installed in the equipment.

Determination of pH

pH refers to a dimensionless chemical parameter and characterizes the acidity level of a specific solution.

pH $= -\log_{10}[H_3O^+] = -\lg[H_3O^+]$

pH is determined with a so-called potentiometric method using a pH sensitive glass electrode. Following the calibration of the pH measuring instrument, a glass electrode is placed into the sample to be examined in a way that the electrode is completely submerged into the liquid but does not touch the wall of the container. Then the value shown on the instrument is recorded (Figure II.13.2).

Figure II.13.2: Instrument for measuring pH
(Source: http://ttk.pte.hu/analitika/letoltesek/jegyzet/ch03s01.html)

Determination of raw protein content

The protein level of animal feed may be characterized by its nitrogen content as proteins with very different amino-acid composition and molecule structures all contain an average of 16 percent nitrogen. The raw protein content of animal feed is measured based on the nitrogen content, assessed using the Kjeldahl method. A sample is corroded with sulphuric acid in the presence of a catalyser (copper compound). Compounds that contain nitrogen turn into ammonium-sulphate, from which ammonia can be extracted with alkali. Its volume can be measured through submersion in acid. Following corrosion, the acidic solution is alkalinized with sodium hydrate solutions. The ammonia is distilled (Figure II.13.3) and is collected in sulphuric acid, whose volume is known. The additional amount is titrated with a sodium hydrate measuring solution.

Figure II.13.3: Parnas-Wagner water vapour distillation equipment for ammonia distillation for determination of raw protein content

(Source: http://www.agr.unideb.hu/~kremper/nitrogen.doc)

Raw protein content is calculated using the following formula:

$$\frac{(V_0 - V_1) \times c \times 0{,}014 \times 100 \times 6{,}25}{m}$$

where:

V_0 = decrease in NaOH volume (ml) during blind examination,

V_1 = decrease in NaOH volume (ml) when sample is titrated,

c = sodium hydrate concentration (mol/l),

m = weight of the sample (g).

The calculation of the protein content from nitrogen is based (100/16=6,25; N x 6.25=raw protein content) on the assumption that all the nitrogen content of animal feed comes from protein. As this is only approximately true (since nitrogen is present in several other compounds that are not proteins, such as DNA, RNA, coenzymes, etc.) the calculated value is called raw protein for easy differentiation.

The protein content of animal feed can also be quickly measured using (NRS) near infrared spectroscopy.

Determination of raw fat content

The fat and oil content of wastewaters, wastewater sludge, vegetable and animal oil and also animal feed can be measured through a process of organic dissolver extraction and then by measuring the volume of the extracted material. In the case of water samples, extraction is carried out by simple shaking in the case of sludges and solid materials with a so-called Soxhlet extractor (Figure II.13.4).

Figure II.13.4: Soxhlet-extractor
(Source: http://www.fisher.co.uk/1/1/25084-extractor-b-811-soxhlet-beakers-adapters-230v-50hz-1250w.html)

The volume of fats/oils is most often determined using extraction techniques. The essence of the method is that lipids are extracted with organic dissolvers (e.g. diethyl ether, petroleum ether, hexane or pentane) from other food components. The classic Soxhlet process takes 6-18 hours on average. Following extraction the volume (weight) of the dissolved fat can be determined by vaporizing the organic phase. The fat content is usually calculated by determining the volume of fat extracted from the sample. The result takes the form of a percentage of the dry matter content. The Soxhlet method is an accepted, standardized process that is used in most areas of food industrial and agricultural analytics.

To help control rancidity the peroxide content and acidity number of the fat are examined. The peroxide number shows the peroxide content: in one kg of fat the number of ml units in 1 mol natrium thiosulfate solution equivalent to the iodine released from potassium iodide by peroxide (milli-equivalent peroxide/kg fat). The peroxide number helps to specify the number of aldehyde and keton bonds created during the oxidation of unsaturated fatty acids. The peroxide number shows the quality (freshness or rancidity) of the fat in the sample. The acidity number shows the hydrolysis of triglycerides and can be measured through titration. The acidity number shows the KOH mg required to neutralize 1g of fat; that is, the acidity number refers to the amount of fatty acids titrated with KOH which are created during the breakdown of triglycerides.

Determination of raw fibre content

Raw fibres are viscous materials that are indigestible to animals and humans. In animal feed science raw fibre refers to the indigestible and unsolvable materials that cover the wall of vegetable cells (e.g. cellulose, hemicellulose or lignin). In relation to human consumption and feed for pet animals (dogs, cats) the concept of 'raw fibre' is extended to include solvable but mostly indigestible viscous materials (glucans and pectins) which are called dietary fibre (see also Chapter II.10.1).

During determination of raw fibre content the fat-free organic matter content of animal feed that is insolvable in an acidic or alkaline environment is measured. If necessary, the sample is degreased and then treated with a specific solution of hot sulphuric acid and potassium hydrate in turn. The remaining material is filtered with a glass screen, then dried and incinerated at 475-500 °C. The loss of volume due to incineration corresponds to the raw fibre content of the examined sample.

Determination of sugar content

During the analysis of animal feed mixtures, food products, by-products of the food industry (e.g. molasses or dried sugar beet slices) the amount of reducing sugars and, following inversion, the total sugar content is determined. The figure is expressed in glucose (dextrose) or when applicable is multiplied by a factor of 0.95 and is expressed in beet sugar (sugar). The sugar is extracted with diluted ethanol and the resulting solution is refined using Carrez-I (a solution of zinc-acetate and acidum aceticum) and Carrez-II (a potassium-ferricyanide solution). After the extraction of ethanol and before and after inversion the amount is measured using the Luff-Schoorl method. The Luff-Schoorl solution involves the use of citric acid, sodium carbonate and copper (II) sulphate. Using the Luff-Schoorl method the so-called reducing sugar content can be determined in the samples. The basic principle behind the method is that reducing sugars (glucose, fructose, lactose and maltose) reduce the copper (II) ions to copper (III) ions in an alkaline medium. The amount of additional Cu(II) ions is determined using the iodometric method. By using the method, from the amount of natrium thiosulphate reduced during titration the concentration of the reducing sugars can be calculated.

Determination of C/N ratio

In order to determine the carbon-nitrogen (C/N) ratio of by-products and wastes of the food industry that contain organic matter, the total carbon and nitrogen content of the by-product and waste must also be determined. The C/N ratio can be calculated from this data. The examination can be carried out simply, quickly and accurately with a so-called battery analyser (Figure II.13.5). The essence of the method is that the organic matter is incinerated in a surplus of oxygen at 850-950°C. Then the carbon and nitrogen containing gases that are created are bound in suitable adsorbents and are removed from the adsorbent. It is then led to detectors which measure heat conductivity and the total amount of carbon and nitrogen based on changes in the level of heat conductivity. From this the C/N ratio can be determined.

Figure II.13.5: Battery analysis equipment *(Photo: Eszter Kalmárné Vass)*

Element composition determination

There are regulations about the limit values for toxic element content (As, Cd, Co, Cr, Cu, Ni, Hg, Pb, Se, etc.) of animal feed ingredients from the food industry, mixed feed materials and composts and wastewaters from the food industry.

Plasma emission spectrometry or inductively coupled plasma atomic emission spectrometry (typically abbreviated to ICP, ICP-AES or ICP-OES) provides information about the element composition of the examined samples. Similarly to atomic adsorption spectrometry plasma emission spectrometry is also a relative method; that is, the quantitative result it produces is based on a comparison with samples that contain the examined element in a concentration that is known to the tester. The ICP method makes it possible to simultaneously determine the concentration of 20-25 elements from mixed animal feed, composts, wastewaters of the food industry and other environmental samples. The sensitivity limit for determination is 10^{-4}–10^{-7} % (µg/cm^3–µg/dm^3), while one calibration curve can include a dynamic concentration range of 5-6 orders of magnitude. The elements that can be determined are all of the metals, transitional metals and, from the group of non-metals, sulphur and phosphorus.

Determination of presence of polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dioxins and furans, mycotoxins and vegetable toxins

There exist governmental decrees that regulate the concentration limit values of micropollutants like polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), dioxins and furans (PCDD/F), mycotoxins and vegetable toxins in animal feed ingredients of the food industry, feed mixtures, composts and wastewaters from the food industry. To maintain high public health standards it is indispensable to decrease the amount of these pollutants so that they are acceptable from a toxicological perspective. The compounds mentioned above that put animal and human health at risk can be efficiently determined using different chromatographic methods such as gas chromatography (GC). The method that is used to analyse the quality and quantity of volatile, complex samples that are not sensitive to heat is called gas chromatography – mass spectrometry (GC-MS).

Gas chromatography is widely used to determine the presence of organic micropollutants (e.g. PAH, PCB, PCDD/F, aromatic carbohydrates, pesticides), mycotoxins and also antioxidants, flavour and aroma materials, volatile components (alcohols, aldehydes, fatty acids, ethers) in food products as well as vitamins. The technique makes it possible to detect very small amounts (micrograms, milligrams) of pollutants or useful materials in the by-products and wastes of the food industry in a very short time.

Determination of other food components

Some by-products and wastes of the food industry contain valuable components, food elements and other compounds (see Chapters III and VI) which can be extracted and further used for industrial purposes (see Chapter II.10.1). Their concentration can be easily measured with a technique called High performance liquid chromatography, abbreviated to HPLC). Its advantage over gas chromatography is that it is also suitable for measuring non-volatile compounds. The HPLC method can be used to detect organic micropollutants (e.g. pesticides, polycyclic aromatic carbohydrates, surface active agents, etc.) and also macromolecules with biochemical significance and dissolvable, natural materials. The method is suitable for extracting and detecting proteins, polysaccharides, organic acids, amino-acids, lipids, volatile fatty acids, glycerines, alcohols, colorants, vitamins and antioxidants in food products and the by-products of the food industry. This involves a very sensitive analytical process. A few microliters of a sample are enough for the detection of nanograms of a substance.

In addition to the above-mentioned ICP, GC and HPLC techniques (for more information, see (traditional textbook) 'By-products and wastes of the food industry' ed. by László Simon) there are other methods available for determining the components of the by-products and wastes of the food industry such as photometry and spectrophotometry, NIR near-infrared spectroscopy and several other analytical methods.

II.13.2.2. Microbiological examination

Salmonella (see Chapter II.12) is one of the most important germs among those which cause zoonoses: illnesses spread by food products and the by-products of the food industry. The family of Enterobacteriaceae includes Salmonella species and a number of other species such as Escherichia coli, Yersinia pestis, Klebsiella and Shigella. The bacteria of this family are part of normal human and animal intestinal flora. In addition to this, they are also present everywhere in nature such as in surface waters, wastewaters, on the surface of plants and in decaying materials. For this reason, in animal feed that contains the by-products of the food industry, and in products containing components from by-products of animal origin (heat-treated animal feed) limit value regulations specify the number of units which indicate technological and hygienic conditions concerning Salmonella species among pathogen germs and those of Escherichia coli and Clostridium perfringens among microorganisms, and also those of the Enterobacteriaceae spp among the microorganisms that indicate environmental pollution, and finally, mesophilic aerobic microbes (see Chapter II.12, Table II.12.1).

II.14. The Quality Assurance system for goods produced from by-products and wastes of the food industry

(Ferencz Szigeti, László Simon,
Bodnárné Renáta Sándor)

Nowadays it is becoming more and more important to process the by-products and wastes of the food industry under controlled conditions, which necessitates the introduction of quality assurance systems that can be also widely used when other agricultural products are processed. This chapter firstly describes the need to use food safety and quality assurance systems, and then interdependent quality management systems are introduced. A few examples will illustrate the need to use a HACCP in plants that process the by-products and wastes of the food industry. Finally, findings about used cooking oil life cycle assessment will also be discussed.

II.14.1. The need to use food safety and quality management systems in the food industry

One of the most significant objectives of the European Union concerning food production is to ensure the quality of food, most importantly in terms of food safety (including animal feed safety which is related to animal feed produced from the by-products and wastes of the food industry) throughout the whole food supply chain (Figure II.14.1). This means that the programme must be implemented from primary production to end consumer; that is, 'from arable land to the table'. The related EC decrees are the following: 852/2004/E decree on food hygiene; 183/2005/EC on promotion of safety; 882/2004/EC on the microbiological, physical and chemical safety of animal feed.

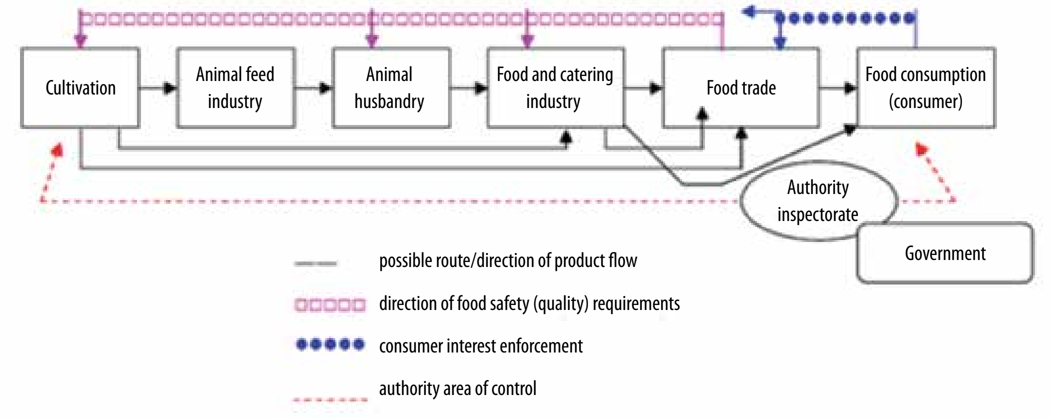


Figure II.14.1: Players in the food supply chain and possible relationships between them
(Source: Holló-Szabó, 2006)

Quality and food safety demands are mainly communicated towards agriculture (cultivation, animal husbandry) by commerce or the food industry, rather than by the consumer. The responsibility of the players in the food supply chain – especially of the producers of agricultural products – is constantly increasing as, due to globalization, the food supply chain is increasingly crossing national borders or even continents. This is also true of animal feed produced from the by-products of animal origin. On the one hand, fish meal imported from Denmark and Norway is mixed into animal feed by Hungarian animal feed producers. On the other hand, meat and bone meal produced by ATEV companies are exported from Hungary to the Far East (Laos, Cambodia) as well as to Russia to produce pet food or to be used as soil improvers. Experience shows that all these materials are fed to food-producing animals. These animal products which are made outside Europe may then indirectly return to Europe through being imported where such feeding practices are banned, which results in the creation of an unfair competitive advantage and possible risks to health.

Accordingly, this means the players in the food supply chain are responsible for maintaining the proper safety of food products and animal feed and this responsibility is also shared by the government in charge. The designated authorities (Animal Health Service, National Public Health and Health Officers' Service, Main Consumer Protection Centre and the Food Safety Office) carry out regular checks to protect consumers' health and monitor the activities of the players in the food chain supply.

In order to ensure the safety of food products, food safety and quality management systems, along with checks on authority control must be introduced and applied to all players in the food supply chain and all the connected elements, while efficient cooperation between these players is also required for operations to proceed successfully.

Experience over the last few decades has shown that the introduction and operation of an efficient food safety and quality management system is the best guarantee for the long-term and continuous implementation of food safety standards. Therefore, all the players in the food supply chain are expected to construct and operate a quality management system that guarantees the quality and food health safety of the products they process and/or market (including animal feed and by-products of the food industry and their indirect effects)

The application of Hazard Analysis and Critical Control Points (HACCP, see Chapter II.14.3) related to food production and distribution has been compulsory in the European Union since 1995

(currently, 852/2004/EC Decree on Food Hygiene describes the relevant compulsory regulations). The decree 183/2005/EC on animal feed hygiene describes the requirements for enterprises operating in the animal feed industry to introduce and apply written processes based on the principles of HACCP, which they have also been required to do since 2006. Decree 882/2004/EC has also required authorities to construct a unified animal feed control system since 2006. The regulations of food and kitchen waste are to be interpreted together with decrees 1069/2009/EC and 142/2011/EU on health rules regulating by-products of animal origin for non-human consumption and the products made from such ingredients. According to decree 1069/2009/EC, businesses dealing with the processing of by-products of animal origin, transformation of by-products of animal origin into biogas or compost, treatment and storage of by-products of animal origin of different categories and the products made from these components in the same plant or factory and the production of pet food are supposed to introduce, implement and maintain a written process or processes based on the principles of Hazard Analysis and Critical Points Control (HACCP) (see also Chapter II.14.3).

II.14.2. Interrelated quality management systems

In the single European market quality and safety standards include GHP, GAP, GMP good practice guidelines, the HACCP food safety system, ISO 9001 and ISO 22000 international standards and the related quality management systems and TQM – Total Quality Management systems – all of which are typical of the food production industry and form an interrelated system (Figure II.14.2).

Good Hygiene Practice - (GHP): includes reference to basic hygienic measures and processes that are designed to decrease the natural flora of ingredients, eliminate pathogenic germs, prevent their multiplication and prevent pollution from outside sources. For each specific sector these measures and practices must always be applied to safeguard the external conditions of production and to maintain a continuously high level of food safety.

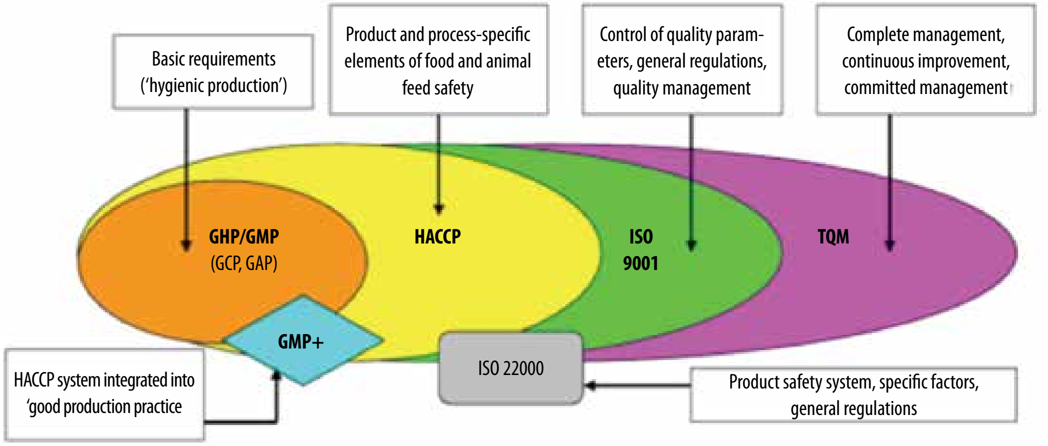


Figure II.14.2: Complex food safety and animal feed quality (safety) programme
(Source: Holló-Szabó, 2006)

Good Manufacturing Practice – GMP (or e.g. Good Agricultural Practice - GAP): This contains all the processes and regulations that are designed to ensure the ongoing safety and quality of the final product. It provides practical guidance and advice about how to adhere to the relevant regulations, food safety and quality requirements and rules. For EU member states, these guidelines have had more significance than before as the compulsory regulations are not detailed enough and these guidelines contain feasible and acceptable ways of fulfilling the regulations of the field. The basis of GMP guides are GHP guides.

Hazard Analysis on Critical Control Points – HACCP: This refers to a scientifically-developed regulation system that can be generally used but is mainly applied in the area of the food industry. It defines hygienic requirements that make it possible to avoid microbiological, biological, chemical and physical hazards. HACCP is a food safety hazard management system that is based on general good production, distribution and hygiene practice. It can be applied independently or as part of a full quality management system. The aim is prevention. The goal of HACCP is the establishment of clear processes and the monitoring of risks and hazards. One of its most important elements is the determination of critical control points (CCP). By regulating these control points the danger of failures and damages can be eliminated or risks can be minimized. At the control points the risk factors and sources of danger are examined. The elements of the process necessitate the determination of procedures that guarantee suitable conditions and any corrective work that is needed to minimize sources of danger and risk.

European Union decree 852/2004/EC makes the application of GHP and HACCP systems compulsory for all activities related to food products.

ISO 9001:2008 standard: Related to the activities and operation of the organization, this determines the necessary organizational structure, responsibilities, resources, planning, production, control and development processes that make a complex quality management system possible. ISO 9001 quality management system ensures the quality of the activities and processes of the food industry business rather than the quality and safety of the products themselves. This way the requirements of the food safety system become integrated into the quality management system, which, therefore, also contains general regulations that go beyond the requirements of food safety. When the system is developed the general requirements of ISO 9001 must be adapted to the conditions of the specific food and animal feed industry and processes.

Following the introduction of the food safety and quality management system, a TQM system can be implemented as a further step in the development of an organizational management system in order to use the resources of the organization more efficiently (Figure II.14.2).

Total Quality Management – TQM is an organizational management concept that allows the most efficient use of the available human and material resources at an organization in order to produce safe, high quality products.

ISO 22000:2005 'Food safety management systems' (FSMS) standard is a management system standard that includes the whole of HACCP and all management system elements that may be important in a FSMS system. Accordingly, enterprises with ISO 9001 can easily apply it; however, it can be also used separately as an independent system. As ISO 22000 determines unified regulations related to HACCP plans, this ensures that HACCP introduced within the frame of FSMS fulfils all the requirements. While HACCP is not a certified standard itself, FSMS based on ISO 22000 is, and it is also possible to integrate it with other management systems (ISO 9001, ISO 14001). While it is compulsory to build up and apply a HACCP system, using FSMS based on ISO 22000 is optional. If an enterprise chooses to get ISO 22000 standard certification, following the introduction of FSMS and certification it will also automatically fulfil the European Union requirements related to HACCP. Therefore, companies that have this certification can expect the authorities to acknowledge that their system fulfils food safety requirements.

ISO 14001:2004 Environmental Management Systems (EMS) standard defines a system of requirements that – if fulfilled by business – makes it possible for a company to evaluate and control the impact it has on the environment, and by decreasing such impacts it takes a step towards targeted environmental harmonization.

EMS is a system the producer introduces in order to:

- ensure that their product (and its packaging) does not pollute (at over the permitted levels) the environment, either when the product is used or when it is disposed of,
- ensure that the production methods that are used do not pollute the environment more than is permitted,
- ensure the production process uses materials and energy resources in the most economical way possible.

The application of the ISO 14001:2004 standard in the food industry and the processing of the by-products and wastes of the food industry: Companies active in the food industry have made significant steps to be more environmentally friendly in recent years. In the last decade the recycling of aluminium cans of drinks and multi-layered packaging materials (plastic-aluminium-paper) has significantly increased. More and more food products are packaged in recycled materials (e.g. muesli is packaged in boxes made from recycled paper). The by-products and wastes of animal and vegetable origin are reused as animal feed and compost (see Chapters II.7.7 and II.10.1), industrially reusable compounds are extracted from them (see Chapters II.8 and II.10.2), and they are energetically utilized following biogas production and pyrolysis or thermal cracking, or through direct incineration (see Chapters II.9, II.10.6 and II.10.7.1). Further development is necessary to reduce the high energy demand of the canned food production and cooling-freezing industry and in the area of the transition from fossil based energy sources to renewable resources. Companies with ISO 14001 standard certification have reduced their noise and air pollution.

The ISO 14001 standard is important for food industry companies, therefore hopefully its implementation will be more popular and faster than that of ISO 9001. It directly addresses issues such as environmental sustainability, the application of environmentally friendly technologies, sustainable development, etc., all of which are becoming more and more important for humanity. The ISO 14001 standard will probably solve the problems that exist with the environmental management of the food industry: e.g. wastewater treatment and disposal and the recycling of packaging materials.

II.14.3. Practical application of HACCP in plants that process the by-products and wastes of the food industry

1069/2009/EC and 142/2011/EU decrees that replace regulation (EC) 1774/2002 define the registration, permission, operation, health and hygiene requirements of biogas plants that utilize by-products of animal origin not intended for human consumption. One of the basic principles is that this is the direct responsibility of the operator and owner or their representative. The health risk posed by digested sludge and biogas plants can be reduced by fulfilling reception standards (e.g. by rejecting units that are potentially problematic as far as health risks are concerned) and hygienic operating requirements (e.g. 'the principle of clean and unclean sectors', pasteurization of substrates to be processed, etc.). Figure II.14.3 shows the conditions for approval by the authorities for the operation of a biogas plant.

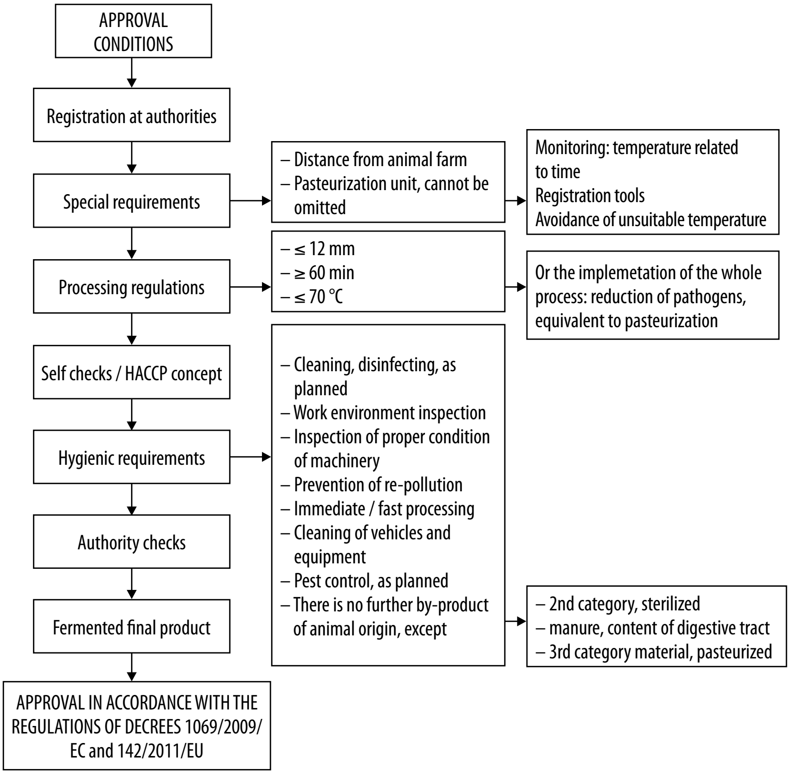


Figure II.14.3: Conditions of approval for biogas plant operation
(modified by Kirchmayr and colleagues, 2007)

II.14.4. Use of Life Cycle Assessment in the food industry

Life Cycle Assessment, LCA, also called life cycle estimate or life cycle evaluation or examination, is designed to examine the potential impact of a product or service on the environment throughout its whole life cycle. The term life cycle of a product refers to the whole phase of life from the extraction of the necessary raw materials and their preparation to production and finally to use of the product and the reuse or treatment of any waste that is created after the product has been used. In the case of a process or service, the life cycle examination focuses on material and energy use and on the environmental impact of the process itself. When the environmental impact is examined the use of resources, human health and the condition of the ecosystem should all be considered. The analysis may concentrate on a product, process or service whose potential environmental impact is assessed during the analysis. LCA is applied in the food industry based on the ISO 14040 standard.

II.14.4.1. The goal and necessity of life cycle assessment

The goal of life cycle assessment (LCA) is to describe, understand and raise awareness concerning the connection between the environment and possible environmental impact during the whole life cycle of a product (technology or service) or in one of its stages from the extraction of raw material to production and use to final disposal after the used product has become waste material, thus making it possible to consciously reduce these effects.

The function of life cycle assessment is to provide numerical information for use in design, development, labelling, a comparative study or consumer decision-making about environmentally friendly products. The basis is the lifecycle of a product from the extraction of the raw materials to the disposal of waste products (or selected important elements) of this process. This is also called a product system and creating a definition of this is the first, main step of the process. In the next step, a complete list of material and energy parameters are defined for the selected processes and then information aggregation takes place. Life cycle assessment is often carried out when it is possible to choose between products, processes, services and systems with the same function but a different level of impact on the environment. When environmental impact is assessed, it is important to consider the effect on human health and the condition of the ecosystem, including the use of resources.

Life cycle assessment is the process of assessing the environmental burdens related to a product or a process. The assessment shows that each stage of the life cycle of products, processes and services leads to environmental, economic and social effects.

It starts by creating a quality and quantity-based definition of input and output material and energy flows used throughout a process. Based on this data it is possible to estimate the environmental impact of a product or process and also to systematically evaluate and to study the opportunities for environmental development. LCA covers the complete life cycle of the product, packaging or process 'from the cradle to the grave' or recently, rather 'from cradle to cradle'. Today the complete life cycle starts with the mining and extraction of raw materials to the production and the reuse and recycling of the product (at this point a raw material is created, hence the term 'from cradle to cradle').

LCA is a tool for analysing environmental criteria and estimating the potential environmental impact of one specific product. To achieve these goals, LCA:

- creates an inventory of the most important inputs and outputs of a product system,
- evaluates the potential environmental impact related to this data, and
- interprets the results of the inventory and the effect estimate phase with a focus on the goal of the study.

Life cycle assessment supports:

- defining potential improvements for environmental conditions at different points in the life cycle of a product,
- decision making in industry, government and non-governmental organizations,
- the better understanding of environmental problems and opportunities to improve environmental performance,
- environmental marketing activity.

II.14.4.2. Steps in a life cycle assessment

Figure II.14.4 illustrates the stages of the whole life cycle of a product in detail. Based on this, the life cycle of a product can be divided into the following main stages: extraction and processing of raw materials, production, transportation, distribution, use, reuse, recycling, waste disposal: treatment, disposal.

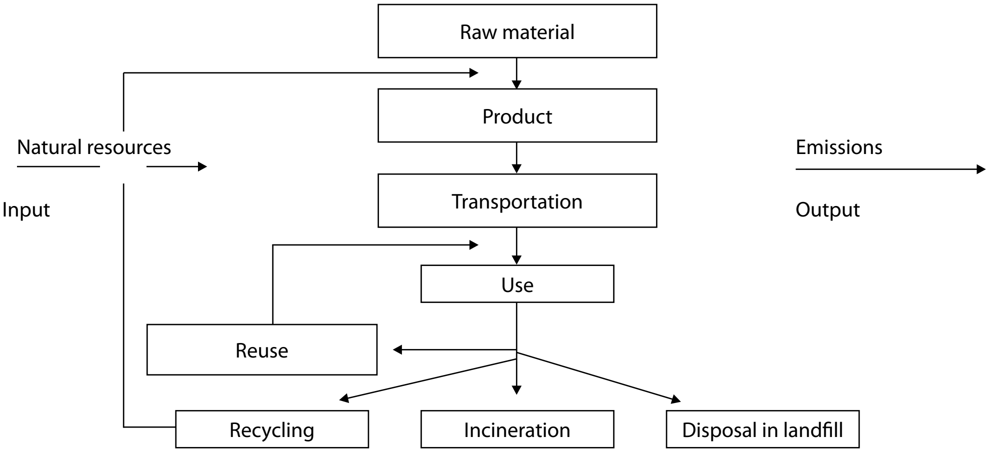


Figure II.14.4: Stages in the life cycle of a product
(Source: http://www.agr.unideb.hu/ktvbsc/dl2.php?dl=59/1_eloadas.ppt)

The life cycle phases must be taken into consideration when the environmental connections of a product and their possible environmental impact are determined. Among them, the following must be highlighted:

– the outgoing and incoming points of the production or service process,
– distribution and transportation,
– energy use and production (fuel, electric and heat energy),
– use of the products and the protection of the consistency of the material itself,
– wastes arising from the processes and elimination of the product,
– processing of the products that are used (reprocessing, reuse, recycling, energy extraction),
– auxiliary material production,
– production, maintenance and deconstruction of any production equipment.

It is useful to illustrate the system using a flow chart and to describe each module in detail. In practice there can be no life cycle assessment without a well-structured and detailed flow chart. When each module of the process is described it must be clearly stated where the specific module starts, what operations and modifications are carried out in that phase and where the phase ends.

Life cycle assessment consists of defining the goal and object followed by a so-called inventory analysis (creation), then effect analysis (examination, estimate) and finally, an interpretation of the result. Figure II.14.5 shows – based on ISO 14040-14044 – the main steps in a life cycle assessment.

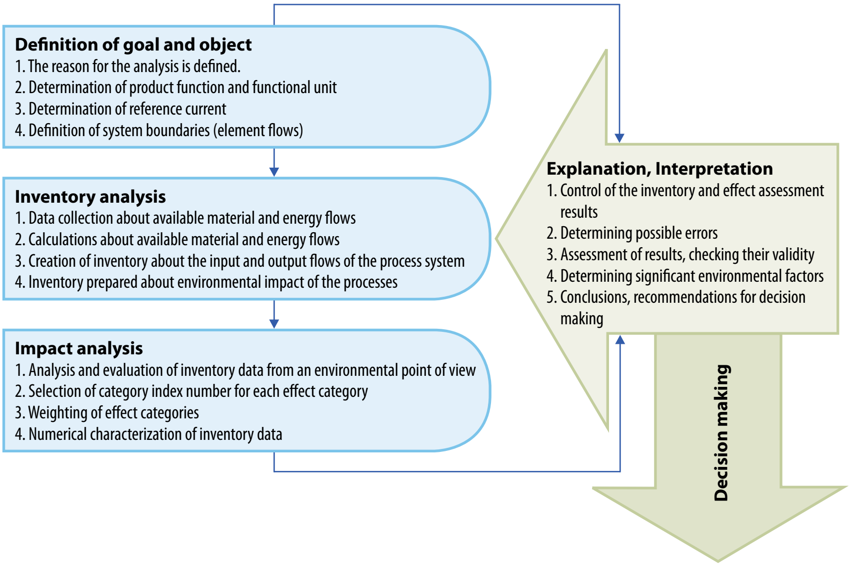


Figure II.14.5: Main steps in life cycle assessment
(Source: http://www.matarka.hu/koz/ISSN_20629737/2k_1sz_2012/ ISSN_2062_9737_2k_1_2012_009-020.pdf)

The first phase of the life cycle assessment is to define the target and object. The phase involves the following steps:

- defining the goal of the examination,
- defining system boundaries,
- defining data quality,
- determining functional units,
- making assumptions.

The first phase of LCA assessment involves defining the goal of the examination (including its depth), the correct determination of the system to be examined, setting of boundaries and their definition, limits, setting boundaries for data quality and data collection and determining functional units and assumptions. It is very important to determine the system boundaries. In this step decisions are made about what functional units and related material and energy flows will be examined. Figure II.14.6 shows a typical template for the LCA assessment of food products which also includes the examined subsystems (functional units) and typical material and energy flows. In the template the letter 'T' refers to transportation. The household processing and consumption of food products relates to further energy and water consumption.

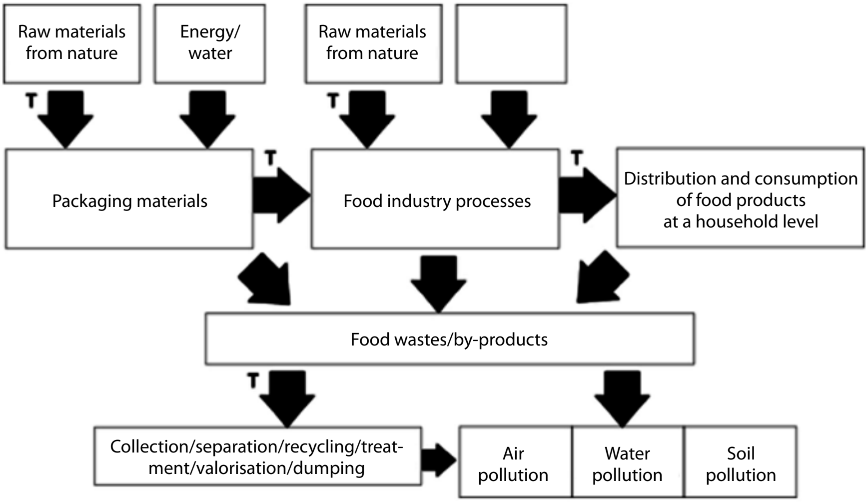


Figure II.14.6: Template for LCA assessment of food products
(Source: based on Herrero and colleagues, 2013)

The definition of the goal and its object is significant and has a significant influence on the result of the life cycle assessment. The goal of the examination determines the necessary elements of its application; e.g., who will able 13.

Table II.14.1: Environmental effect categories (CML 2001, 2010. November)
(Source: http://www.matarka.hu/koz/ISSN_20629737/2k_1sz_2012/ISSN_2062_9737_2k_1_2012_009-020.pdf)

Name of effect categories	Effect category interpretation	Equivalent
Global Warming Potential (GWP)	Extent to which different greenhouse gases contribute to global warming compared to one unit of CO_2	kg CO_2 equivalent
Acidity Potential (AP)	Acidity in relation to SO_2	kg SO_2 equivalent
Eutrophication Potential (EP)	Level of eutrophication	kg phosphate equivalent
Human Toxicity Potential (HTP)	The maximum allowed concentration level of materials poisonous to the human body, equivalent to 1.4 dichlor-benzol (DCB)	kg DCB equivalent
Photochemical Ozone Creation Potential (POCP)	Ozone-producing ability of volatile organic compounds	kg ethylene equivalent
Ozone Depletion Potential (ODP)	Mainly due to halogenous carbohydrates, as the referent ingredient R11 is selected	kg R11 equivalent
Earth Eco Toxicity (TETP) **Marine Eco Toxicity (MAETP)** **Fresh Water Eco Toxicity (FAETP)**	Poisonous to plants and animals, DCB (dichlor-benzol) equivalent	kg DCB equivalent
Abiotic Resource Depletion (ADP)	Includes metallic minerals	kg lead equivalent
Abiotic Resource Depletion – fossil resources (ADP)	Includes declining fossil energy sources	kg MJ

Environmental effects can be normalized and weighted in order to express the environmental effects as a single environmental index number. Normalization supports the better understanding of the relative extent of the effects. All the effects of the life cycle of a product are compared to the total effect calculated for this category (e.g. the European average of environmental effects). The normalization practices differ depending on the methods applied to analyse the life cycle. The factors used to weight the different effect categories vary depending on environmental effect categories and also countries. Central Europe, global warming potential is most significant. Normalization and weighting is recommended for internal communication. Using it in external communication is less advisable.

At the last stage of the LCA analysis the results are interpreted. At this stage the information obtained in the previous stages of work is identified, expressed in numbers, checked and evaluated. The interpretation of the results (LCA development analysis) involves the systematic evaluation of the necessity and opportunities for reducing environmental effects during the complete life cycle of the product, process or service. The goal of LCA is thus to facilitate the exploration and evaluation of environmental effects during the whole life cycle of a product/process/service and help with exploring their potential reduction opportunities. A further goal might be the comparative analysis and evaluation of the environmental effects of products/processes/services from different perspectives. This method can help make life cycle assessment an important tool for environmental development. The ultimate goal of LCA is to help decision makers come up with conclusions and recommendations that are in harmony with the goal of the study.

II.14.4.3. Areas of application of LCA

Originally, LCA was developed as a decision support tool in order to help distinguish between products and services from an environmental point of view. In addition to this, it can be used in the following areas:

– for product development and repair for internal industrial use,

– for internal strategic planning and corporate policy decision support in industry,

– for external use for communication and marketing,

– for defining and shaping public administration strategies and governmental policies in the area of eco labelling and waste management.

The result of life cycle analysis can be used for the following purposes:

– for determining the material and energy requirements of a system, its level of emissions and exactly calculating its potential environmental effects.

– for determining the points within the life cycle of a product, process or service where the resource demand, emission levels and environmental effects can be most efficiently reduced.

– for comparing the inputs and outputs of the examined system to alternative products, processes or services.

LCA helps with the development of new products, processes or services so long as LCA is considered a planning tool for improving the quality of the environment. LCA also helps with understanding the advantages and risks of changes affecting a product, its packaging or a related process. It makes documentation and evaluation of environmental load and potential environmental damages easier and also helps with their integration into corporate environmental policy.

There are numerous barriers that hinder the faster and more widespread use of life cycle assessment, the most important of which are the following:

– the complexity of the methods and processes,

– the cost and time demand of the assessment,

– the reliability of the databases that are used.

II.14.4.4. Life cycle assessment for the collection of used residential cooking oil and its transformation into biodiesel

During agricultural production and food industrial processing, large amounts of organic wastes and by-products are created whose life cycle can be lengthened by biological (microbial, enzyme) and chemical transformation (e.g. transesterification of vegetable oils and animal fats using methanol or ethanol to produce biodiesel). The product that is created (e.g. biogas and biofuel, see Chapters II.9 and II.10.6) can be utilized as an energy resource or in compost (see Chapters II.7.7 and II.10.1) or be reused as a product of high value by other industries for producing functional food and dietary products (see Chapters II.8 and II.10.2), cosmetics or medicines.

Biodiesel is biofuel made by transforming vegetable oils or animal fat. It consists of fatty acid alkyl esters. These were originally produced from vegetable oils (soya, sunflower, rapeseed, palm, olive, corn, hazelnuts, etc.) which are also suitable for human consumption. As it is a problem that large areas of land may no longer be used for food production because they are being used to grow raw materials for biodiesel, scientists have started to examine the reuse of vegetable oils which are not suitable for direct human consumption (e.g. jatropha, karanja, neem, cotton and microalga oil) and on certain wastes (e.g. used cooking oil and fat, old engine oil, animal fat and wastewater sludges). The biodiesel made from different wastes and by-products has a significantly smaller effect on global warming, ozone depletion and lower energy demands than diesel made from crude oil, while its acidity and eutrophication potential is slightly higher (see Table II.14.1).

The use of used cooking oil as a raw material for biodiesel on the one hand decreases production costs and, on other hand, also offers a solution to reducing environmental load (see Chapter II.5.3). At the same time it also offers a solution for the utilization of waste. International LCA analyses agree that the use of oils and fats as biodiesel raw materials also reduces emission of greenhouse gases compared to diesel, and are responsible for reduced levels of sulphur. All studies agree that processing used cooking oil is most efficient in this regard. Greenhouse gas emissions are decreased by 69-88 percent. The processing of vegetable oils (e.g. rapeseed or palm oil) leads to a decrease of 40-65 percent, while processing animal fat (e.g. beef tallow or poultry fat) results in a decrease of 72 percent. The use of wastewater sludge leads to a reduction of 75 percent. The transformation of used cooking oil into biodiesel is the best solution as far as the emission of greenhouse gases and environmental load are concerned. The amount of used cooking oil that is available is rather small. The amount of used animal fat that is available is greater but its transformation into biodiesel is more complicated.

As the dietary customs of developed countries are becoming more modern, and as a response to health recommendations, food production technologies and ingredients are changing. As a result, the needs related to the use of vegetable cooking oils have also changed. At the moment for example in Hungary about 140 thousand tons of cooking oil is used and an estimated 35 percent of this becomes waste. The rest gets into food or evaporates. According to 142/2011/EU decree used cooking oil is considered to be a waste of the food industry – therefore, in restaurants, catering units and kitchens (HoReCa: Hotel-Restaurant-Catering) the oil must be collected and treated (see Chapter II.5.3). However, this rule does not apply to used cooking oil from domestic residents, although this amount accounts for ~66% of the total amount. Rather than using official HSO (heated second-hand cooking oil) collection points, residents pour a significant amount of this oil into the wastewater sewage system – where it causes problems with the sewage systems and at wastewater treatment plants – while significant quantities enter waste bins, increasing the load on waste dumps. Disposal through incineration and soil pollution is more typical of countryside practices. It is likely that residents are unaware of the damage that can be caused by unprofessional 'disposal' of HSO.

In EU there are currently several companies that collect residential HSO. Collection points may be located at the following places:

– selective waste collection vehicles and waste collection yards of local governments,

- petrol stations of oil companies,
- at companies specialized in waste management, etc.

When the system of collecting HSO from large catering units was launched an examination of waste recycling solutions also commenced as the oil collected is a potentially significant amount of raw material. In spite of this, no municipal HSO collection system has been constructed over the last years or decades which has had comparably successful results compared to the Western European residential average (~1kg/person/year). The collection of used cooking oil from households is influenced by several factors:

- the cost-effectiveness of the waste management (collection) system,
- the environmental awareness of authorities,
- the environmental awareness of household residents,
- social advantages (new workplaces, education etc.).

HSO as a waste can be used in several ways. Due to its calorific value it has been used for a long time to produce energy. However, in recent years the opportunity to use it as biofuel has become more pronounced. Biodiesel made from used cooking oil is fatty acid methyl ester (FAME) and is mixed into diesel in proportions of 5 v/v% in EU member states. Examination shows that using up to 20 percent biodiesel will cause no harm to an engine, although when mixed in in greater quantities an engine may have ignition problems.

Used cooking oils as wastes can be reused in the following ways:

- energetic utilization,
- biodiesel production,
- other opportunities: e.g. pyrolysis (see Chapter II.9.2).

When exploring this specific issue the idea of conducting an environmental examination of this material came up. The most suitable method for this is currently life cycle assessment.

In order to reduce environmental impact, the exact effects caused by the product/activities must be known. Life Cycle Assessment – LCA (see above) was developed to determine these effects. The method makes it possible to examine a product, process or service and its potential environmental impact during its whole life cycle (from extraction of raw materials to the stage when it becomes waste).

There are several impact assessment methods. The analysis shown below was carried out with the help of the CML 2001 (November 2010) method and examined the following areas (from the effect categories listed in Table II.14.1):

- global warming potential (GWP),
- acidity potential (AP),
- eutrophication potential (EP),
- photochemical ozone creation potential (POCP),
- ozone depletion potential (ODP),
- abiotic resource depletion reduction (ADP).

The Basic parameters of life cycle assessment, which form the basis of the analysis are:

- area of municipal collection: 700 thousand people,
- amount collected: 0.97 kg/person/year (1.45 litre/person/year),
- type of container: 3-litre polypropylene bucket,
- yearly bucket loss: 15 percent,
- collection vehicle: 12 t capacity car; at loading: yoke lever,
- 10 percent of the collected oil is residue, which is used for biogas production.

The goals of life cycle assessment for used cooking oil:

- Comparison of the different 'End-of-life' alternatives: HSO enters the sewage system, HSO enters communal waste, HSO is utilized as biodiesel.

- System limits: 'from factory gate to the grave/cradle'.
- Functional unit: 1 kg used cooking oil collected from residents.
- Comparison of fuel alternative: production of biodiesel from HSO (own system), biodiesel production from HSO (Ecoinvent database process, see http://www.ecoinvent.ch/), biodiesel production with primary raw material (from rapeseed specifically produced for this goal), and traditional diesel production processes.
- System limits: 'from cradle to factory gate, or from factory gate to grave/cradle'.
- Functional unit: 1 kg fuel.

The life cycle assessment was carried out according to the regulations of the ISO 14040 standard. After data collection and systematization the processes were modelled. For the modelling of collection systems the Austrian HSO collection system, and for processing the data, data from a Hungarian HSO processing plant were used. The collection area included a few relatively large towns and some smaller villages. Residents received a 3-litre plastic container from the company which collects HSO in which to collect the material. If the collection bucket was worn out the collection company replaced the container on the premises where the waste is handed over. The first step of the HSO utilization process is to pre-treat the material, which basically involves mechanical screening. Following this pre-treatment stage the material is utilized in clean form. Life cycle assessment also includes the cleaning of the containers and the replacement of damaged parts. As a result their washing and the production of new containers influences the environmental impact of pre-treatment. Biodiesel is produced at the processing stage from pre-cleaned HSO. During the technological process, methanol, potassium methylate, additives and water are mixed on the right level and in the right proportions to produce biodiesel. As useful by-products, glycerine and soapy water are produced.

Effect analysis

Based on the examination carried out with the CML 2001 effect assessment method the following conclusions can be made about the process from the collection of municipal used cooking oil to its pre-treatment and processing to the production of useful materials (biodiesel and other utilizable by-products):

- During the pre-treatment stage, in most effect categories the most relevant factors in terms of the creation of environmental load were the electrical energy used during the process and the amount of polypropylene used to replace the damaged containers.
- During the utilization step the materials used (methanol and potassium methylate) and electrical energy increase impact, while the positive environmental effect that is created has to do with the production of glycerine and soapy water as a by-product, in addition to biodiesel.
- In the case of the three life cycle stages (collection, pre-treatment, and biodiesel production) in all effect categories the most significant environmental pollution takes place during production. If the process is examined with the whole life cycle concept in mind – that is, the environmental effect of the cooking oil before it is used (vegetable oil production, product use – frying), almost without exception in all effect categories the environmental effects of vegetable oil production become more significant, while the environmental effects of other stages of the life cycle are much less.

Comparative analysis

Comparison of end-of-life opportunities

The goal of the comparative analysis is to show the environmental impact of various disposal methods (HSO being poured into a waste or sewage system) and of utilization (biodiesel production) (Figure II.14.7) in exact numbers, and proportions that are comparable.

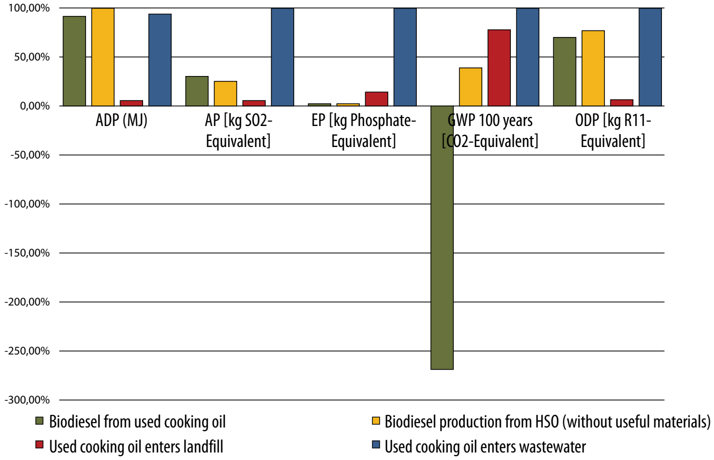


Figure II.14.7: Comparison of 'end-of-life' opportunities for used cooking oil
(Source: Bay-Logi Kft., 2013)

In almost all the effect categories examined HSO that enters the sewage system has the greatest effect – with the exception of ADP which, due to the additives used during the production of biodiesel, creates the greatest load on the environment. For some categories biodiesel production has quantitatively greater impacts than, for example, disposal at a landfill. However, it must be highlighted that when biodiesel is made, a new and useful product is created, while in the case of disposal this raw material is lost.

Comparison of fuels

In the following case four different diesel fuels are compared. One of them is produced from vegetable raw materials – rapeseed – while two others are made from used cooking oil (one is a self-developed process, the other one is a process described by the ecoinvent database) and the fourth one is a product from a fossil energy source (Figure II.14.8).

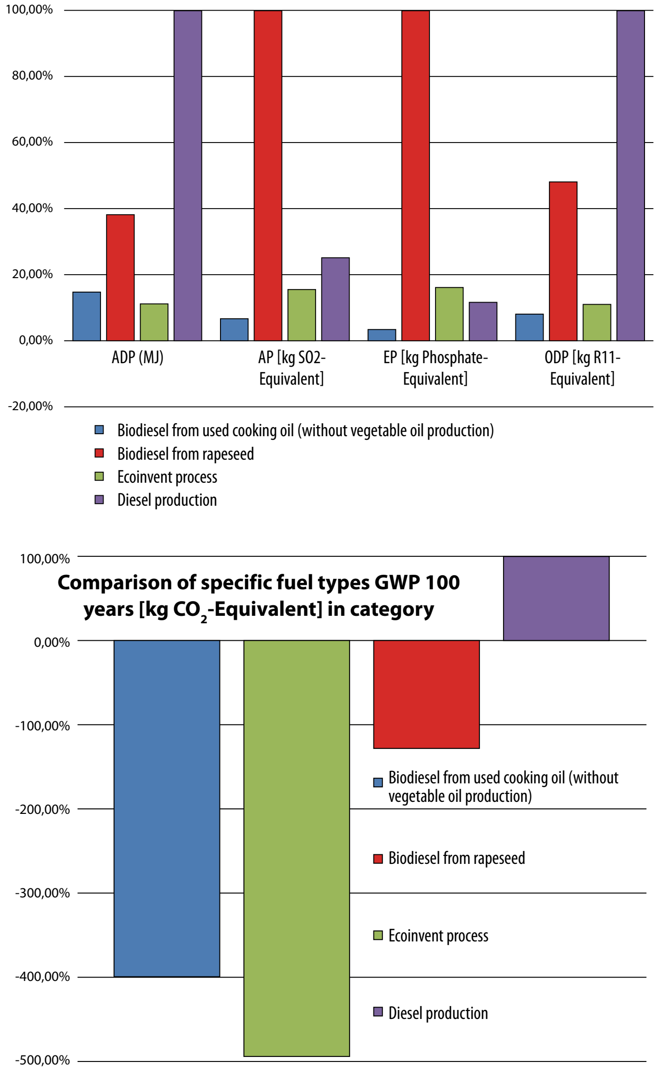


Figure II.14.8: Environmental comparison of fuels made from different raw materials
(Source: Bay-Logi Kft., 2013)

In all the effect categories examined producing biodiesel from used cooking oil is the most efficient solution from an environmental point of view – there are only slight differences between the two processes with the same goal. In the categories of resource depletion (ADP), ozone depletion (ODP) and global environmental warming potential (GWP) fuel production from crude oil logically creates the biggest load to environment. In the categories of acidity potential (AP) and eutrophication potential (EP) production from rapeseed causes high environmental impact – in the first case (AP) this happens due to the amount of ammonia and nitrogen oxides that are emitted, and in the second case (EP) due to inorganic emissions which enter the atmosphere and waters; that is, nitrates and nitrogen oxides cause serious environmental pollution (Figure II.14.8).

On a Central European level (that is, including Hungary) a lot of attention must be paid to moderating the impacts of global warming. The use of cooking oil waste definitively has significant environmental advantages. Environmental savings are nearly 3-4 times those of when biodiesel is produced from rapeseed produced specifically for biodiesel. There is extensive evidence that the utilization of HSO is beneficial for the environment for the following reasons:

- the amount of waste that is created is reduced,
- decreased load on landfill,
- sewage system will be cleaner,
- simplified treatment at wastewater plants,
- new, useful and marketable products are created,
- the new product is better in many ways than the same product produced directly at an industrial plant.

This life cycle assessment has proved that the collection and utilization of municipal used cooking oil is a useful process. The strategic goal for the future is to increase the amount of municipal waste that is collected.

III. BIOLOGICAL WASTE TREATMENT

III.1. Introduction (László Aleksza)

Consumption and other human activities result in the production of a great amount of biologically degradable (henceforth: biodegradable) waste, which when treated professionally can play an important role in maintaining the organic matter content of soils, as well as being an excellent base material for biogas and compost production.

The necessary legal regulations are present in developed countries; it provides a clear definition of biowaste and biodegradable waste. Based on the above, biowaste is defined as being a biologically degradable waste that originates from parks and gardens, food and kitchen waste from households, restaurants, diners and small enterprises or similar wastes from food processing plants. Biodegradable waste refers to all kinds of waste with organic content (including biowaste) that degrades or is degraded biologically in an aerobic or anaerobic way. Thus, beside municipal biowaste, biodegradable waste includes sewage sludge and agricultural-food industry wastes as well.

Legal regulations also specify the principle of promoting the separate collection and utilization of biodegradable waste so as to ensure that the purest material is returned to the natural organic matter cycle, and for decreasing the biologically degradable content of municipal waste that will be landfilled.

According to regulations, the biodegradable fraction of municipal solid waste (MSW) should be reduced by 1 July 2016 to 35% of the amount generated in 1995.

According to the practices of the European Union, the landfilling of untreated biodegradable waste as part of MSW is unfavourable both from an environmental and operational perspective. Taking the hierarchy of waste management into account, mechanical-biological waste treatment is necessary before landfilling, thus countries with more developed waste management practices – these include Poland and Slovenia – prohibit the landfilling of biologically unstabilised wastes.

Naturally, beside the introduction of selective waste collection, the production as well as the complete agricultural utilisation of good quality compost gained from biodegradable waste are also important as rotation farming can be ensured only through these practices. The connection between waste management and agriculture must be strengthened and the opportunities offered by the use of compost have to be exploited for sustaining the organic matter content of soils.

With regard to sewage sludge, it is an important consideration that with the development of the level of sanitation the amount of sewage sludge that is generated has also increased around the world. In developed countries the toxic content of sewage sludge is typically significantly below the prescribed limits and shows a tendency to decrease. The limits are no longer especially relevant as the most influential limiting factor in authorizing the agricultural utilisation of sewage sludge is its nitrogen content, rather than its toxic content, which is lower by an order of magnitude.

Data available related to by-products and waste in the agriculture and food industry is extremely diverse and the dissimilar use of terminology (concerning by-products and waste) by different experts (agricultural and environmental) presents some challenges. In many cases the agricultural profession uses the term 'by-products' for nascent materials (e.g. farm manure, straw and crop residues), but in some cases environmental data about these materials are (should be) supplied during reporting processes as these materials also have similar waste codes (EWC).

As a realistic objective, a reuse rate of 95-97% of all agricultural and food industry wastes could and should be achieved by 2020 in EU. The total utilisation of by-products of crop production (straw, crop residues, crop cleaning residues, etc.) will be achieved partly in the field of nutrient circulation, by increasing the organic matter and nutrient content of soils, and partly in energy production. As regards animal husbandry and the food production industry, 60-70% reuse rates for by-products of animal origin can be guaranteed for producing the primary commodity of forage. 30-40% of all by-products of animal origin can be utilized as soil amelioraters (compost, other soil melioration products) and energy carriers (in biogas plants, cement plant co-incineration). The greater utilization of food refuse (from public catering, catering and perhaps households) and food with expired use-by dates is of high priority and can be ensured with the use of similar methods to those mentioned above. Waste of plant origin and the by-products of the food industry can be turned into useful products through composting and biogas plants.

III.2. The chemical and biological processes of biological waste treatment (aerobic and anaerobic systems) (Katalin Posta)

III.2.1. The microbiological correlation between aerobic and anaerobic treatment, mesophilic and thermophilic systems

Waste is broken down into its organic components mainly with the help of bacteria and fungi through a biological waste treatment process which involves a series of interdependent biological and chemical reactions. Spontaneous chemical processes are of no real significance but depend on the quality of the waste and its biological components. Biological degradation is a natural process: only the time it takes, its efficiency and direction can be modified by maintaining certain parameters throughout the process of waste treatment.

External environmental circumstances have a significant effect on biological activities and their regulation. Basically, every circumstance that has an effect on the vital processes or the multiplication of microorganisms will also influence the waste treatment process. These circumstances can include the following: the oxygen content of the media; the moisture content, pH and the chemical structure of the material undergoing degradation; and the presence of any toxic compounds in the media.

The composition of the spontaneously-forming microbial participants of the consortium primarily depends on the oxygen content of the media. Two systems may occur based on the oxygen content of the media: aerobic, with the presence of oxygen; and anaerobic, without oxygen (Figure III.2.1). The two systems can be described by their different energetic processes and differing levels of microbiological diversity: anaerobic degradation is an endothermic process in which mesophilic organisms primarily participate, while aerobic degradation is exothermic and caused primarily by thermophilic organisms that thrive at relatively high temperatures.

How are such conditions generated? In an aerobic system nearly 50% of the chemical energy stored in the organic wastes goes to create the cells of the microorganisms participating in the process, while 40% of the energy is spent on generating heat and only 5-10% remains in the chemical bonds of the end product. However, in anaerobic systems only 5-6% of the energy is spent on new cell creation, 1-2% goes to heat generation and 90-95% remains in the chemical bonds of methane and other combustible gases. The following two equations sum up the most important energetic elements in the processes:

Anaerobic: $C_nH_aO_b + (n-a/8-b/4)\,H_2O \rightarrow (n/2-a/8+b/4)\,CO_2 + (n/2+a/8-b/4)\,CH_4 + NH_3 + H_2S$
Aerobic: organic matter + $O_2 \rightarrow$ new cell + $CO_2 + H_2O + NO_3^- + SO_4^{2-}$ + heat + compost

The widest variety of organic materials (plant and animal) can be treated and disposed of with the help of aerobic microorganisms during composting (see more details in Chapter III.2.2.). The end product is an organic matter that can help maintain and improve the fertility of the soil. However, anaerobic decomposition can also occur in an aerobic organic degradation system as oxygen is not necessarily evenly distributed throughout the compost.

The microorganisms are supplied with oxygen and electrons from two sources during composting: the oxygen from the air and the latter from the organic or inorganic compounds of waste. If the oxygen content of the compost decreases to below 10%, then the aerobic microbiological processes slow down and the organisms meet their oxygen demands from the oxidation of organic matter.

In this situation degradation takes place anaerobically while methane and other gases are created (Figure III.2.1). The main objective of composting is to create a humus-like material that is capable of providing a supply of nutrients, and not the creation of combustible gases.

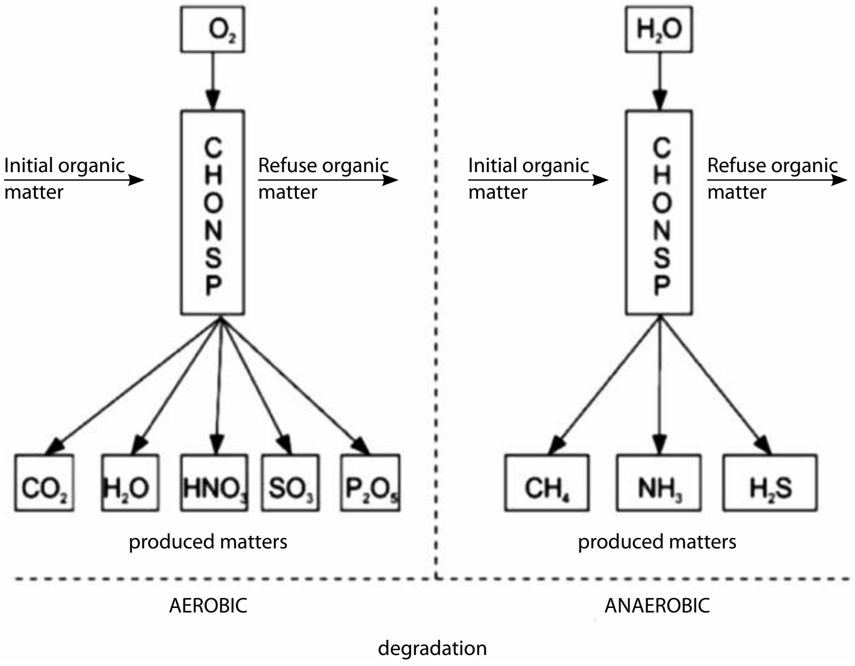


Figure III.2.1: Aerobic and anaerobic degradation *(Barótfi 2000)*

To a certain degree, transition between aerobic and anaerobic systems is possible. The thermophilic and mesophilic processes that are present in both systems cannot be changed or supplemented in a composting process. The majority of microorganisms in the anaerobic degradation process function under mesophilic circumstances, but operating the system at a higher temperature (thermophilic) has numerous advantages. Reactions take place more quickly, the substrate is more accessible, gas production is greater and the decay of the pathogenic organisms is more efficient than when it occurs at a mesophilic temperature. Nonetheless, processes that occur at a higher temperature are less stable, controlling them is more difficult and they are more sensitive to changes in the environment. Additionally, the majority of the organisms responsible for the degradation processes are mesophilic, thus the presence of microorganisms that are fond of heat is a prerequisite.

Anaerobic biological degradation is a complex process which is catalysed by enzymes that were created by anaerobic microorganisms (for more detail, see Chapter III.2.3.). The anaerobic degradation process involves four sub-processes (hydrolysis, acid formation, acetic acid formation and methane formation) which are often merged into only two sub-processes (acid formation and methane formation) as hydrolysis is categorised as part of acid formation because the same acid-forming bacteria are responsible for the process. The first step in degradation is hydrolysis, during which time, depending on the quality of the initial matter (in terms of the quantity of carbohydrates, proteins and fats), the polymer molecules are transformed into simpler compounds with the assistance of the exoenzymes of the microorganisms that are transported into the external media. Smaller-sized molecules enter the cells and form aliphatic acids with a small number of carbon atoms and other types of compounds in the acid formation phase. In the acetic acid formation phase the carbonic acids are then turned into acetic acids which can be directly transformed into methane by methane-forming bacteria. Acetic acid-forming acetogenic bacteria can be very diverse and can thus tolerate changes in their environmental very well. On the other hand, methanogenic microorganisms multiply slowly and are very sensitive to environmental conditions: a fluctuation of only 1-2 °C in temperature can block their development, leading to a halt in the operation of the process. This is why maintaining the appropriate living conditions on an ongoing basis for methanogenic bacteria is crucial.

Anaerobic degradation is done by a special community of bacteria, the composition of which varies in mesophilic and thermophilic systems (Tables III.2.1 and III.2.2).

Mesophilic system		**Thermophilic system**	
Name	Description	Name	Description
Acidovorax sp.	Facultative hydrogen consuming chemolithotrophic bacteria that have a role in degrading xenobiotics.	Thermotogaceae sp.	Rod-shaped bacteria are capable of utilizing simple and complex carbohydrates.
Nostocoida sp.	It is able to provide, among other things, acetate, pyruvate, propionate, glucose, fructose, mannose, lactose and glycerine.	Coprothermobacter sp.	Moderately thermophilic bacteria which are isolated from digesters rich in protein and supplied with sewage-water. Utilize gelatine and casein.
Smithella sp.	Strictly anaerobic, it primarily utilizes propionate and butyrate.	Bacteroidetes sp.	A very widespread group.
Bacteroidets sp.	Most widespread in anaerobic digesters.		
Choroflexi sp.	Utilizes very diverse organic matter.		

Table III.2.1: The composition and characteristics of Bacteria of microbe communities in mesophilic and the thermophilic pilot digester plants *(Kardos 2012)*

It is well known that maintaining a thermophilic temperature (<55 °C) is more effective at producing biogas than a mesophilic temperature because the gas yield and the methane content of the biogas increase in the former due to the faster reaction speed. However, the disadvantages of using a thermophilic system cannot be neglected. For example, the increase in expenses as a result of the need for heating, the change in the size of the reactor, as well as the fact that the system is extremely sensitive to the blocking effect of toxic heavy metals and changes in the nutrient content. The main reason for the sensitivity of the system is due to the fact that a thermophilic community contains fewer species than a mesophilic one and thus the relationships (in terms of which species is dominant) is unbalanced (Tables III.2.1 and III.2.2). Mesophilic systems can react to changes in operational parameters more flexibly and their adaptation to a new environment is quicker.

Mesophilic system		Thermophilic system	
Name	Description	Name	Description
Methanosaeta sp.	They are widespread sphere-shaped microbes that utilize only acetate.	Methanosarcina sp.	They utilise acetate, methanol, methylamine, carbon-dioxide and hydrogen.
Methanoculleus sp.	Sphere-shaped microbes that utilize hydrogen, carbon-dioxide, often formic acid and rarely alcohols.	Methanothermobachter sp.	Sphere-shaped microbes that utilize hydrogen, carbon-dioxide, rarely formic acid and alcohols.
Methanosarcina sp.	They utilise acetate, methanol, methylamine, carbon-dioxide and hydrogen.		

Table III.2.2: The composition and characterisation of Archaea of microbe communities in mesophilic and the thermophilic pilot digester plants *(Kardos 2012)*

III.2.2. The stages of composting, the significance of the thermophilic phase

Composting is the name for the aggregate of biological, chemical and physical processes which occur under aerobic circumstances. It is a guided organic matter treatment and recycling method in which the organic waste matter-degrading microbe community is usually able to develop without the addition of any inoculating agents. The organic polymers degrade into simpler compounds in the process, and, due to the activity of microorganisms, create compost with a high nutrient content which is also free from weed seeds and pests.

A vast range of organic wastes can be composted. They include wastes from agricultural and food industry production, manures of different origin, municipal and industrial wastes and the sewage sludge generated from municipal wastewater.

The composting process involves distinct changes in temperature and chemistry, thus four phases can be identified. Taking into account the phase of waste matter transformation, three main phases remain, as the mesophilic and thermophilic stages of degradation can be considered to be a single phase (Figure III.2.2).

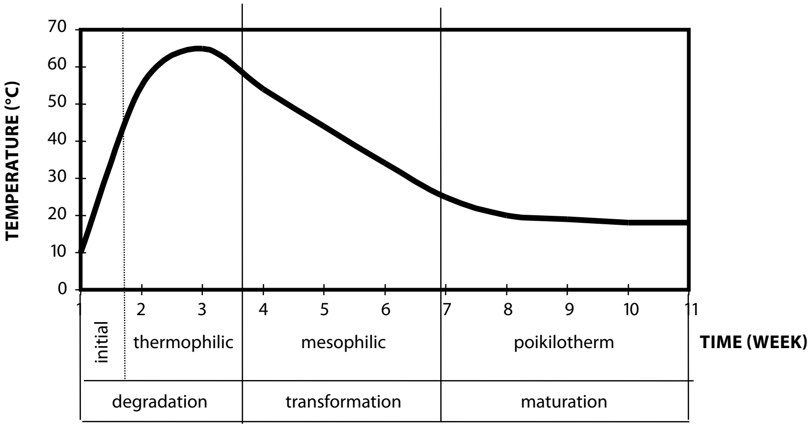


Figure III.2.2: Temperature changes during composting *(Alexa – Dér 2001)*

III.2.3. The degradation phase

The first and introductory phase of composting is brief and is dominated by mesophilic organisms at an optimum temperature of 25-30 °C. The time-span of the process is significantly influenced by the quality of the initial biowaste: it may last only a few hours with easily degradable matter, but it may take several days in the case of materials that do not degrade so easily.

Through the process of intensive metabolism the rate of chemical reactions in the media decreases due to the effect of hydrolysis. Additionally, the temperature starts to increase together with fast growth in the number of microorganisms as the microbiological degradation of the easily degradable organic matter begins (Figures III.2.2 and III.2.3). The rapidly increasing temperature (which results from the intensive microbial metabolic processes) slowly becomes unsuitable for the initial mesophilic microorganisms which are gradually replaced by thermophilic ones. The temperature of the media in this thermophilic phase of degradation rises above 70-75 °C. Metabiosis occurs between the mesophilic and thermophilic microorganisms at the beginning of the phase, but later on at higher temperatures only those organisms that are capable of degrading compounds remain active during the thermophilic phase. Some of the thermophilic microorganisms are able to do this by altering the composition of aliphatic acids in the phospholipids of their cell membranes. The ratio of saturated aliphatic acids with a higher melting point increases, thus ensuring the optimal level of membrane dependent transporters and enzymes. In normal circumstances a so-called temperature 'plateau' is created after the temperature maximum is reached. This plateau exists for several days, providing an opportunity for the development of good quality compost.

Ammonia is released in the process of the degradation of compounds with nitrogen content – especially proteins –, increasing the rate of chemical reactions of the compost. Correspondingly, the initially acidic media gradually become alkali. The majority of human, animal and plant pathogens die and the weed seeds lose their ability to germinate at temperatures of over 60 °C in the thermophilic phase. However, higher temperatures (≥ 85 ˚C) which last for a longer period may cause irreversible changes to the compost, resulting in unfavourable outcomes. Instead of transformation and maturing processes, carbonisation (pyrolysis, autooxidation) takes place which hinders or even stops microbial activity from occurring.

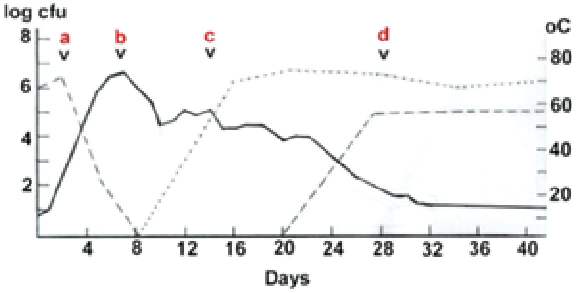


Figure III.2.3: Changes in the temperature and micro-fauna of composts *(based on Chang and Hudson 1967)*

Straight line – temperature of compost; dashed line – mesophilic organisms; dotted line – thermophilic organisms; a, b, c, d – temperature phases; CFU - colony forming unit

III.2.4. The transformation phase

During the transformation phase the quantity of easily degradable nutrients decreases, the degradation processes slow down and the temperature drops, re-creating a favourable atmosphere for the activities of mesophilic microorganisms. At this stage the non-easily degradable organic matter (cellulose, lignin, keratin, etc.) provide the necessary nutrition and energy for the mesophilic organisms (the majority of the easily degradable compounds have already been consumed during the thermophilic phase). The volume of the compost decreases to two-thirds of its original size and humification begins. The condensation of the mono-, di- and triphenol compounds, originating primarily from the degradation of lingocellulose, play a major role in humus formation.

The mycelium web of the fungi community bind ammonium in the transformation phase and the unpleasant odours that often accompany composting processes decrease due to the increase in nitrification. The transformation phase can last several weeks (e.g. 5-6 weeks) depending on the quality of the initial matter.

III.2.5. The maturation phase

The maturation phase begins as a result of the continually decreasing temperature. This is the last phase of composting in which the humification of the organic matter is completed, ensuring the dark colour of the compost. At this point microbial activities are performed by – besides mesophilic microorganisms – psychrophilic bacteria and Aspergilla which prefer a lower (15-20 ˚C) temperature. Additionally, there is a significant increase in the number of actinomyces, which can be useful when determining the maturity of the compost.

Furthermore, the appearance of common soil-dwelling creatures can be observed (mites, ants, worms, Collembolas, etc.) that contribute to the further physical breaking up of the compost. Worms take an active role in mixing the mineral and organic matters of the compost. While the compost worm (Eisenia foetida) appears during the earlier phases at higher temperatures, the earth worm (Lumbricus terrestris) is more likely to be found in the mature compost.

III.2.6. The compilation of composting base materials

C/N ratio, size of particles, moisture and nutrient content are all crucial parameters in compiling a compost heap. Their specific parameters depend on the materials to be composted. The optimal C/N ratio is 25-35:1. If this ratio is too low or too high microbial activities will begin only after surplus materials have disappeared. By reducing the particle size of the compost, the total volume of waste can be decreased and at the same time surface area can be increased. Water is also an important factor, as it influences significantly the degradation of the organic matters. Based on empirical experience, a moisture level of 40-60% is best. If moisture content is below 40%, microbial activities slow down and the multiplication of the microorganisms will cease, while a moisture level of over 60% expels oxygen from the pores in the material and may result in the creation of extremely unpleasant anaerobic processes.

III.2.7. Microorganisms during composting

The 'microbial consortium' which is formed spontaneously during composting will be based on the quality of the waste materials, while bacteria and fungi also determine its development. The hyphae of the fungi, along with the hydrolytic activity of the microorganisms, assist in the mechanical and also the physical degradation of the materials to be composted by weaving around them. Some of the fungi that can be isolated from the compost are mesophilic but the most important ones are thermophilic. They include the following: Aspergillus spp, Chaetomium spp., Chrisosporium spp., Fusarium spp., Penicillium spp., Thermoascus aurantiacus (Figure III.2.4), Thermomyces lanuginosus (Figure III.2.5) and Trichoderma viride. The typical succession of fungi in the composting process is that degradation starts with a Zygomycetes phase, which is followed by emergence of the Deuteromycetes and the Ascomycetes fungi, and the process is finished by the Basidiomycetes fungi. Members of the Rhizomucor spp. are a typical pioneer species but they disappear as the composting proceeds (with an increase in temperature and ammonification) and the Talaromyces thermophilus (Figure

III.2.6) and the Thermomyces lanuginosus (which flourish in relatively high pH and temperatures) appear. Thermophilic actinomyces stands out among the bacteria, as surviving the high temperature of the composting process in a sporal state, they contribute to the plant growth-stimulating effect and pathogen immunisation of the final compost product by producing antibiotics, and through their hydrolytic enzyme system. The most commonly found antibiotics that produce actinomyces in composts are Micromonospora spp, Streptomyces reticuli and S. hygroscopicus.

Figure III.2.4: Thermoascus aurantiacus

Figure III.2.5: Thermomyces Lanuginosus

Figure III.2.6: Talaromyces Thermophilus

The members of the microbial consortium that lead the degradation of organic wastes are responsible for the synthesis of the enzymes which participate in a given task or reaction. These enzymes participate in the degradation process individually, or as elements of a complex process. The degradation of cellulose can be used, as an example, to introduce the steps of this process which build on each other. A number of functionally different hydrolytic enzymes and cellulases are needed for the effective hydrolysis of the cellulose that participates in building up the plant cell walls (Figure III.2.7).

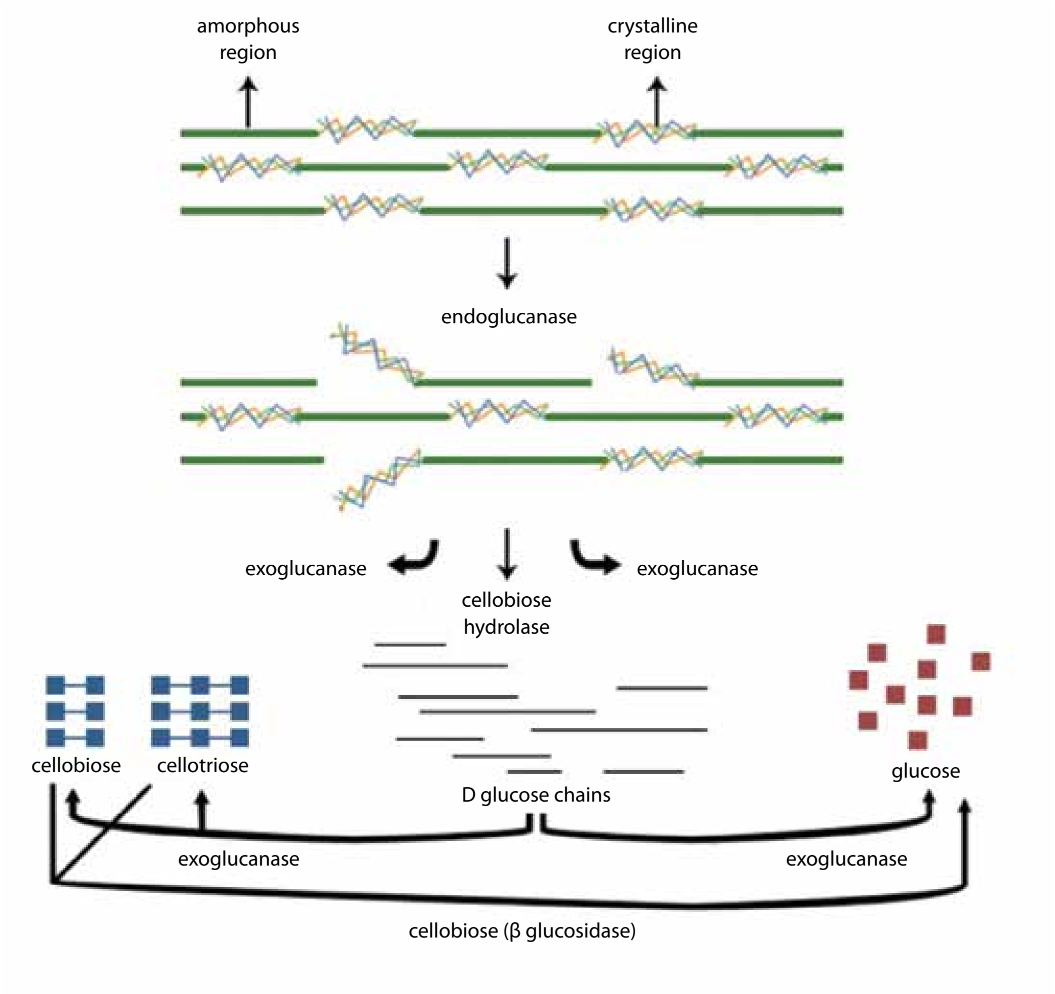


Figure III.2.7: Microbiological degradation of cellulose

Traditionally, there are considered to be three main categories of cellulose. The first one includes endoenzymes; the second exoenzymes, while cellobiases, which create monomers, belong to the third category. The perfect degradation of crystalline cellulose requires the simultaneous presence of all three enzyme groups with their different functions. The amorphous regions of the cellulose chain are split by the endoglucanase (endo-1.4-ß-D-glucan-4-glucanhydrolases), creating free chain ends. This step of the process is followed by the splitting off of cellobiase units by exoglucanases or cellobiose-hydrolases (exo-1.4-ß-D- glucancello-biohydrolase). Finally, β-glucosidases or cellobiases (β glucoside glucohydrolases) prevent the obstruction of the end product by continually hydrolyzing the released cellobiose fractions into glucose.

The distinct cellulases help each other in a synergic way. This is proven by the fact that the activity of mixtures containing different enzyme combinations is greater than would be expected based on the activity of the individual components. In the case of some compost-dwelling microorganisms (with complete cellulose systems) the combined development and presence of all three enzymes may occur, but more frequently the given organisms have only one or two enzymes. Thus the consortium is created through the enzyme groups building on the activities of one another.

Besides cellulose, the structures of hemicellulose and lignin (the building blocks of the plant cell wall) are even more difficult to create and thus a more complex system is required for their degradation. Lignin, which forms 20-30% of the dry weight of woody plants, is made of three dimensional polymers which are phenylpropanoid subunits that are bound by covalent bonds. Due to its complex construction, lignocellulose is exceptionally resistant to degradation processes but it plays an important role in the carbon cycle because of its high carbon and energy content. There are no known microorganisms that are able to utilize only lignin as an energy and carbon source, so it is possible that the de-polymerization of lignin is necessary for obtaining cellulose and hemicellulose. The degradation of lignin involves a process that includes the operation of oxidative enzymes and the following chemical reactions. It is also interesting that the enzymes necessary for the total degradation of lignin (lignin peroxidises (LiP), manganese dependent peroxidises (MnP), glyoxal oxidises (GLOX) and laccase) are formed only in the absence of easily-available nutrients. It is primarily fungi which participate in the degradation of lignin; among them the Merulius, Ceratostomella and Mucor genus are known to cause white rot (which gets its name from the colour of the remaining non-dissolved cellulose frame). The members of the Aspergillus, Trichoderma and Trichothecium genus also participate to a lesser extent.

Hygienisation of the primary material and the destruction of pathogens are prerequisites for the safe production of compost. The thermophilic phase, with its 40 °C plus temperature that terminates pathogenic organisms, plays an important role in this. However, as has already been mentioned during the description of the degradation phase, undesirable reactions may commence if the temperature remains at over 85 °C for a longer period.

III.2.8. The conditions of composting

III.2.8.1. The carbon/nitrogen ratio

As mentioned above, maintaining an appropriate C/N ratio is one of the most important factors when compiling a compost heap because losses (primarily of nitrogen) can be minimised by supplying the appropriate nutrients to microorganisms during the composting process. Based on the nutrient demand of the microorganisms the optimal ratio can be easily determined. The C/N ratio of microbe cells is 5:1. However, enriching the nutrients by nitrogen using the same ratio would be a mistake as the microbes use only 20% of the carbon content of the processed organic material (80% of it is burned to obtain energy). Thus the initial C/N ratio should be 25:1.

RAW MATERIAL	C/N RATIO	RAW MATERIAL	C/N RATIO
tree bark	120:1	chicken manure	10:1
sawdust	500:1	chicken deep litter	15:1
paper, cardboard	350:1	slurry (thin)	2:1
communal waste	35:1	slurry (thick)	10:1
kitchen waste	15:1	cattle manure	25:1
garden waste	40:1	straw (rye, barley)	60:1
leaves	50:1	straw (wheat, oat)	100:1
cut grass	20:1	abattoir waste	16:1

Table III.2.3: The C/N ratio of the most important raw materials

If the C/N ratio is too low, surplus nitrogen is given off in the form of ammonia until a ratio of 25:1 is reached. This process, very typical in the case of the composting of chicken manure, can be easily identified by the intense smell of ammonium. We must note, however, that the already-specified ratio of 25:1 is only hypothetical: in practice the optimal ratio is 30-35:1 due to the presence of the not-so-easily degradable lignin content. If the ratio is too high, the process will only be initiated after surplus carbon has been given off in the form of CO_2.

III.2.8.2. Moisture content

Beside nutrients, the appropriate amount of water also needs to be provided to the microorganisms during composting.

If the mix is too dry, the multiplication of microorganisms will slow down or stop until the necessary moisture is provided. The optimal moisture level for composting is between 40-60%.

If the moisture level is high, the majority of the pore spaces will be occupied by water, expelling the oxygen and triggering the onset of anaerobic conditions which will lead to unpleasant rotting processes, so the moisture level needs to be continually monitored during composting.

III.2.8.3. Oxygen supply

A significant amount of oxygen is required by the participating aerobic microorganisms during the composting processes. The oxygen content must be over 10% during composting. This is especially true for the initially intensive phase of degradation, when, based on calculations, the air contained in a cubic metre of compost is used up. This means that a continuous airflow needs to be maintained from the edge of the windrow to the core zone by loosening the structure of the material, by supplying the appropriate amount of structuring materials and air, and finally by frequently turning the compost.

The oxygen level in the pores of the maturing material is continually measured using a control system. Based on the data received, the air supply is adjusted through the aeration system of the composting equipment.

III.2.9. Anaerobic treatment, phases of biogas production and the factors influencing methane production

III.2.9.1. The phases of anaerobic degradation and biogas production

One of the most dynamically developing procedures for treating and recycling sewage sludge, industrial and agricultural as well as municipal wastes recently is anaerobic waste treatment, which combined with other technologies is also suitable for extracting further valuable side products (e.g. methane) and thus producing renewable 'green energy'.

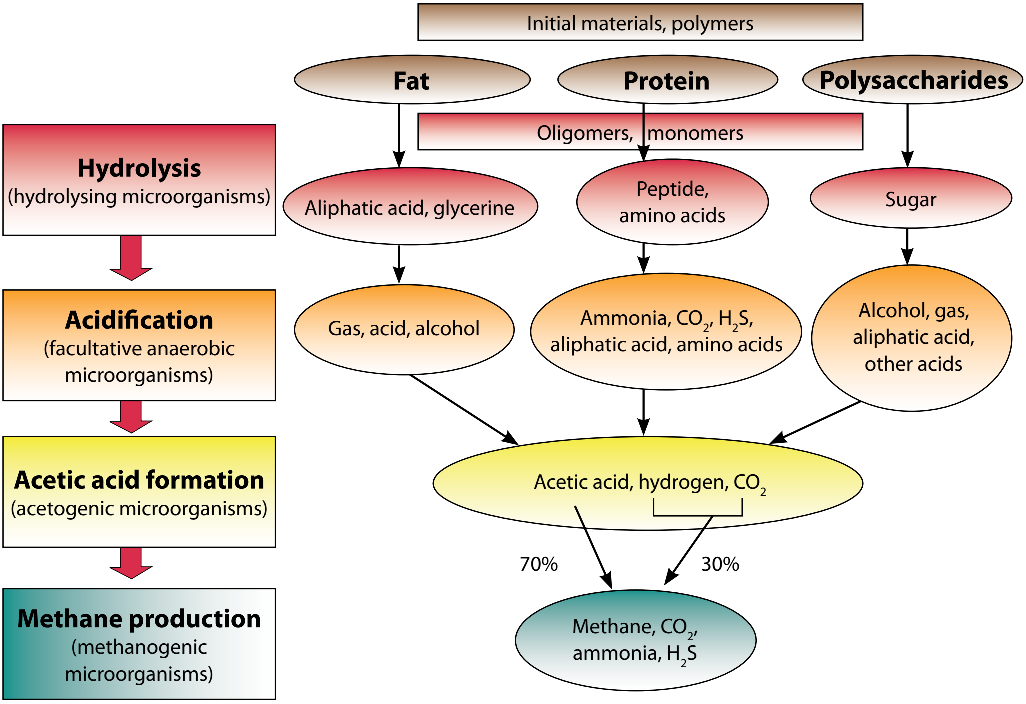
Degradation of solid wastes by microorganisms is called biodegradation while the degradation of liquid wastes is called fermentation. The former is accompanied by rotting and the latter by digestion. Biogas is a gas mixture produced by microbes during the anaerobic (oxygen-free) degradation (fermentation) process of organic matters – municipal sewage sludge, animal manure and agricultural residue – containing methane up to 45-70%. Its other components are carbon-dioxide (CO_2) at up to 30-35%, water vapour and hydrogen sulphide (H_2S) in smaller quantities. Biogas is a result of mainly the syntrophic cooperation of bacteria but some fungi and inferior animal organisms also participate in the degradation of organic matters. Multiplication of these microbes and biogas formation are slow processes in nature. The process initiates spontaneously in every case where organic matter is present in high concentrations in anaerobic circumstances. Marsh gas generated from bottom sludge in marsh lands and swamps, the gases produced in flooded rice fields or in the digestive systems of ruminant animals or whales and the landfill gas generated in landfills are all natural biogases.

Even though biogas was already being used for heating bathing water in ancient Assyria in the

10th century BC, the first biogas fermentor was built only in 1859 at a leper colony in Bombay. Shortly after this, the first European fermentor was established in Exeter, England in 1895 where the biogas generated at the municipal sewage plant was used for street lighting purposes. Presently, Germany is the largest biogas producer in Europe.

Anaerobic degradation is a complex process featured by a chain of catalytic enzyme reactions. The process is divided into four significant phases by most scientific authors (Bitton 1994, Dueblein and Steinhauser 2008, Tamás 1998); their simplified degradation cycles are illustrated in Figure III.2.8.

Figure III.2.8: The process of biogas formation



Biogas formation can be divided into the following four phases:

I. Hydrolysis:

Hydrolysis is the first phase of anaerobic degradation in which the organic polymer compounds of the organic waste with large sized molecules – carbohydrates, proteins and fats – are degraded into simpler compounds, monomers (aliphatic acid, amino acids, sugar, etc.) by bacteria using extracellular enzymes. It is usually Clostridium spp., Bacillus spp. and Pseudomonas spp. that participate in this process (Böhnke et al. 1993).

II. Acidogenesis (acidification):

The second phase, acidogenesis, is an acidic-fermentation biochemical process. With the exclusion of air the products of hydrolysis are degraded into further organic acids (acetic acid, propionic acid, butyric acid), alcohols with smaller molecular weights and aldehydes as well as hydrogen, carbon-dioxide and other gases (ammonia, hydrogen-sulphides).

These enzyme catalytic reactions – just as in the first phase – are catalyzed by the exoenzymes of obligate anaerobic or facultative aerobic fermentative microorganisms (Lactobacillus spp., Propionibacillus spp., Clostridium spp., Proteus spp., Alkaligenes spp., Enterobacillus spp., fungi, etc.).

As a result of acidification, the pH of the media decrease until the bacteria are broken down by their own degradation activities.

III. Acetogenesis:

In this phase the acetogenic Syntraphabacter wolinii, Syntrophomonas wolfei, Syntrophus buswellii, as well as Selenomonas spp., Clostridium spp., Ruminococcus spp., and Desulfovibrio spp. play a crucial role (Dr. Bokányi 2004). As a consequence of the enzymes of the acetogenic bacteria, acetic acid, hydrogen and carbon dioxide are produced in acetogenesis, the third phase of anaerobic degradation.

IV. Methanogenesis:

Methane formation is the fourth phase of anaerobic degradation, which is called methanogenesis. In this phase the organic acids are degraded into methane, carbon dioxide and water by a larger group of methane-producing microorganisms, while another group transforms a portion of the earlier created carbon dioxide into methane with the help of hydrogen generated by the acetogens:

$$\begin{aligned} 4\,H_2 + CO_2 &\rightarrow CH_4 + 2\,H_2O \\ CH_3COOH &\rightarrow CH_4 + CO_2 \\ 4\,CH_3OH &\rightarrow 3CH_4 + CO_2 + 2H_2O \end{aligned}$$

There are a great number of strains (~50) of methanogenic microorganisms (archaeabacteria) which enable anaerobic biodegradation over a wide temperature range (ranging between 15 and 55 °C) with a moisture range of 60-99%. These approximately 50 methanogenic strains have been classified into the following 5 orders by Dublein and Steinhauser (2008): Methanobacteriales, Methanococcales, Methanomicrobiales, Methanosarciales, Methanopyraceae. During fermentation the Methanocaldococcus jannaschii methanogenic bacteria strain is the most frequently occurring, which belongs to the Methanococcales order.

90-95% of the carbon of the organic wastes can be transformed into biogas. There are sulphate-reducing bacteria in the system which produce hydrogen sulphide from sulphate and other different sulphuric compounds. Though hydrogen sulphide reacts to iron and other heavy metal salts, creating insoluble sulphides, a small amount of hydrogen sulphide always remains in the biogas.

Biogas can be utilized in numerous ways. Buildings, agricultural constructions (e.g. greenhouses) can be heated by burning it. In larger quantities, electrical power should be produced from it. Biogas can also be employed as an alternative fuel for cars, trucks and buses, but before use it must be cleaned of its hydrogen sulphide, sulphur dioxide and water vapour content. After this is done, it can be used in the same way as condensed natural gas.

III.2.9.2. Factors which influence methane production

As the participating groups of bacteria of the different phases of the balanced anaerobic degradation process multiply in dynamic equilibrium, anaerobic degradation and thus the operation and optimisation of the biogas production becomes possible only by knowing the living conditions of the microorganisms and the abiotic factors that influence the process. This balance can easily be disturbed by changes in the environment that result in the aggregation of temporary products that block, slow or even halt the whole process (Kárpáti 2002). Temperature, nutrient supply, moisture content, pH, the presence of toxic materials, etc. are all environmental factors that are critical for the microorganisms participating in the anaerobic degradation process (Malina and Pohland 1992).

These factors are detailed below:

Temperature

One of the most significant abiotic environmental factors that influences living activities is temperature, which at the same time is the single most important factor to manage in biogas production. Anaerobic degradation is an endothermic process, thus heat input into the system is necessary. The two main processes of anaerobic fermentation can be distinguished according to their temperature range:

– the optimal temperature of mesophilic processes is between 30-35 °C;

– the optimal temperature of thermophilic processes is between 50-65 °C. This process is more advantageous and quicker from the perspective of the kinetic reaction, and the degradation of organic matter is greater by 10-20% (Szabó 1999).

The decision about whether a mesophilic or thermophilic process is more favourable in a concrete situation depends mainly on economic and operational considerations.

Due to their greater speed of development and more substantial energy gain, the fermenting microorganisms that undertake the initial transformation of the larger organic molecules ensure greater transformation speeds at a lower temperature (Kárpáti 2002). However, the methanogenic archaea have a longer generation time span, therefore they are more sensitive to changes in temperature than the other participants of the degradation process.

Nutrients

Maintaining a constant composition of mix is a prerequisite for ensuring balanced microbiological activity (Kárpáti 2002). Furthermore, the carbon and nitrogen content as well as the C/N ratio of the organic matters to be used during the production of biogas are also extremely important to the microorganisms. An inappropriate C/N ratio can have unfavourable effects on the fermentation process. Carbon is consumed about 30 times faster than nitrogen by the anaerobic bacteria, so for the sustainability of the microbes the optimal C/N ratio should be 30:1, according to Pesti (2005). Too low nitrogen content obstructs the processing of the carbon stock; if the nitrogen disappears, the bacteria will perish. However, too high a nitrogen content may cause ammonium to accumulate, preventing methane production.

Maintaining the optimal 150:1 carbon-phosphorus ratio of the organic matter that is used is also essential. The other nutrients (sulphur, calcium, magnesium, etc.) are present in all the materials to be biodegraded or fermented in the necessary amounts so do not cause any problems (Kárpáti 2002).

Moisture/dry matter content

Water is essential to both the metabolism of microorganisms and also to the catalytic reactions of enzymes. The optimal moisture content of anaerobic degradation is wider than that of aerobic biodegradation. The dry matter content of the degradable mix may be between 0.1% and 60% (Szabó and Szabó 2006), within which range the following process technology types can be differentiated, based on the dry matter content:

– between 0.1 -5%, wet process,
– between 5 -15%, suspension process,
– between 15-25%, semi-dry process, and
– between 25-60%, dry process.

Chemical reactions

Fermentative and methanogenic microorganisms multiply at an optimal (maximum) speed and have optimum effects at a near neutral pH (Szabó 1999). The chemical reactions of the media of anaerobic degradation occur at between pH=7-7.6 according to Kaltwasser (1983), but according to Bai (Kovács and Bagi 2007) the optimal value is between pH=7-8.5, although acidogenesis and methanogenesis demand slightly different conditions for chemical reactions. The most appropriate pH for the mainly facultative anaerobic acid-producing bacteria is between 5.3-6.8 while it is between pH=6.8-7.2 for the obligate anaerobic methanogenes (Öllős 1991). Methanogenic bacteria are the most sensitive among the different microbe families of the anaerobic system to the pH of the media. If the organic acids are created faster by the acid-producing organisms than they can be transformed into methane by methanogenes, the inhibition of the methane-producing bacteria may occur (pH decreases below 6.0) and the chemical reactions can slow down to such an extent that the process even comes to a halt (Szabó and Szabó 2006).

Unfavourable acidic chemical reactions can be controlled by adding slack lime, sodium carbonate solution or by redirecting filtrate away from the treatment area of the remaining matter.

Inhibitors/toxic matter

Toxic materials often have inhibiting effects at over a certain concentration which is indicated by decreases in the multiplication of the microbes. Basically, a relative diminution of the natural substrate or an increase in fermenting roughage may also have inhibiting effects. Intermediate products in high concentration, such as volatile acids or certain substrates, have an inhibiting effect. Sulphuric hydrates, ammonia, chlorinated hydrocarbons ($c \geq 3$ mg/L), aromatic compounds, aliphatic acids, alkali and alkali earth metals ($C \geq 5$ g/L), heavy metals ($c \geq 5$ mg/L) and cyanides have inhibitory effects or are toxic in relation to the anaerobic degradation process, regardless of their concentration (**Öllős** et al. 2010). Sulphate ions at a concentration level of 0.1 g/L inhibit the activity of methanogenic Archea. Cresols and phenols are extremely dangerous toxic materials from among the strong bactericides and fungicides (Mosey 1976). The inhibiting effect of light which enters the reaction area is also significant.

Particle size

The size of the contact area that is available for participation in an enzyme catalytic reaction is determined by the size of the particles and their distribution (Varga 2010). The particle size and the specific area are inversely proportional. A fine particle size (< 50 mm) and an even distribution are beneficial when handling the material and operating the fermentor (mixing, diversion of the product, etc.). Moreover, breaking down the fibre construction of the fibrous materials is also important.

HRT - Hydraulic retention time

Hydraulic retention time is the average time that the substrate spends in the reactor. Depending on the technology, this is between 20 and 120 days and is influenced by the parameters of the main processes, such as temperature and the characteristics of the biowaste (Varga 2010).

OLR - Organic loading rate

Organic loading rate refers to the amount of organic matter – expressed as COD (chemical oxygen demand) or VS (volatile solid) – loaded into the reactor on a daily basis with reference to its unit volume. The biological conversion capacity of the anaerobic degradation process is expressed by the degree of organic loading. Biogas yield decreases over a certain amount due to the accumulation of inhibitors in the sludge (Varga 2010). It is indeed a crucial parameter as overloading may lead to the halting of the process.

Co-substrate effect

The amount of biogas can be increased by the collective decomposition of different organic wastes (e.g. of agricultural, food industry, abattoir, paper industry, municipal sewage sludge origin) and the degradation of those organic matters, which otherwise degrade with difficulty, becomes easier.

III.2.10. Nitrogen transformation processes

Nitrogen is one of the most essential macro elements and is - among many living and dead cells - an important building block of amino acids (proteins), nucleic acids (DNA, RNA) and some polysaccharides. On average, 3% of the weight of animal organisms is composed of nitrogen, while almost 15% of the dry matter content of plants is nitrogen (Füleky 1999).

A portion of the nitrogen necessary for the synthesis of amino acids originates from soil. Plants, using their roots, take up ions (NH_4+ and NO_3^-) from the inorganic compounds of the soil, which constitute to 1-5% of the soil's nitrogen content, from which only ammonia can be utilized directly. The other way of incorporating inorganic nitrogen occurs with the help of microorganisms. Molecular nitrogen in the air is fixed in the form of organic compounds and amino acids by so-called nitrogen fixing bacteria that live in the root nodule of the legumes. The nitrogen, already in organic form, is bound, changed and transformed through different metabolic processes. Thus nitrogen transformation processes include both degradation as well as building processes in which microorganisms play a very important role.

The degradation and mineralisation of organic compounds with nitrogen content depends on the types of compound to a great extent. In the soil, regardless of the starting material, organic compounds with nitrogen content are broken into smaller pieces by the macro-organisms in the first phase, then the microorganisms initiate an extracellular (outside-of-the-cell) degrading attack with the help of active protein-degrading enzymes. The chosen proteolytic enzymes disunite the easily-available bonds of the peptide chains, breaking them into smaller units. A certain proportion of these units and molecules are already capable of moving across the cell wall and membrane into the cytoplasm, where they are further degraded into amino acids, and then, following deamination, they are transformed into ammonia and other products (Figure III.2.9). This process is often referred to as ammonification, which has a broader meaning than the term ammonification used in microbiology.

aminosav	amino acid
α-ketosav	α-ketoacid
piridoxálfoszfát	pyridoxal-phosphate
piridoxaminfoszfát	pyridoxamine phosphate
α-ketoglutársav	α-ketoglutaric acid
glutamát	glutamate

Figure III.2.9: Process of ammonification in a broader sense [GDH, glutamate dehydrogenase] *(Borsodi)*

Most organisms are capable of building-in the released ammonia in the first phase while glutamine is generated, which is the starting point for the creation of numerous compounds with N content (e.g. amino acids).

Microorganisms can utilize the amino acids created in the process of degradation or they can put them at the disposal of plant or animal organisms.

In anaerobic circumstances, indole, hydrogen sulphide and other ptomaines (putrescine, cadaverine, histamine, tryptamine) are generated during proteolysis. Depending on the circumstances, aerobic (Bacillus putidum, B. cereus, B. megaterium, B. subtilis, Aspergillus niger, Botrytis spp., Mucor spp., Rhizopus spp., Penicillium spp., Trichoderma spp.), facultative aerobic (Proteus vulgaris, P. mirabilis, E. coli) and anaerobic (Clostridium putrificum, Cl. sporogens, Cl. perfringens, Cl. bifermentans, Cl. tetani) bacteria and fungi also take part in the breakdown of proteins.

Chitin is a polymer molecule made up of N-acetylglucosamine, which is the main component of the cell wall of fungi, as well as the exoskeleton of arthropods (Crustacea and Thysanura). These compounds can be found in the soil and also in biowastes, and in spite of their resilience many microorganisms are capable of degrading them. In the process glucose amine and acetic acid are firstly formed, then the glucose amine is transformed into glucose and ammonia by the chitinase enzyme. The role of fungi (Aspegillus spp., Mucor spp., Penicillium spp., Trichoderma spp.) are also significant beside bacteria (Bacterium chininovorum, Flavobacterium spp., Pseudomonas spp.) in the degradation of chitin.

Humus plays a central role in the transformation processes of the polymer compounds with N content as there are about 14,000 billion tons of humus compounds on Earth with 5-6% nitrogen content. Microorganisms (Bactoderma spp., Mycobacterium spp., Nocardia spp.) are also involved in the degradation of complex polymers, which are made up of many different types of monomers. At the same time, ammonia is bound by the side-chains of humus, thus extracting a significant amount of nitrogen from the cycle. About 50% of this temporarily-evicted material can be extracted by acid hydrolysis, which by its slow degradation provides a steady supply of nitrogen to plants.

With the widespread and in many cases excessive use of chemical fertilizers, carbamide degrading organisms have become important in our environment as plants cannot utilize these compounds without the activities of specific ammonifying soil bacteria. These bacteria are the so-called urea bacteria (Sarcina urea, Micrococcus urea, Bacillus pasteurii).

Beside the degradation processes of the organic compounds with nitrogen content, the direct or indirect activities of the soil-dwelling living organisms that are related to these procedures are also important as concerns the microbiological circulation of nitrogen.

Nitrogen circulation can be divided into four steps from a microbiological point of view: ammonification, nitrification, denitrification and biological nitrogen (N_2) fixation. Although biological nitrogen fixation does not typically occur during waste handling and treatment, this step is indispensable as concerns the totality of the nitrogen transformation processes. During this process the molecular nitrogen in the air is incorporated into the organic material of plants.

This transformation can happen in a photochemical way (e.g. due to lightning), but the amount that is fixed this way ($<3\text{x}10^9$ kg N/year) is way below the amount that is transformed through biological nitrogen fixation ($140\text{x}10^9$ kg N/year). The prokaryotes that fix the molecular nitrogen in the air can be free-living (Azotobacter spp, Azospirillum spp.), associative, or form a temporary association or be symbiotic nitrogen fixers. Based on assumptions, there is great difference in the quantity of nitrogen that is fixed depending on the participation of the different types of associations. The free-living microorganisms in the soil can fix 7-15 kg of nitrogen per hectare annually, while the ones that live in symbiosis with legumes can fix 70-300 kg/hectare/year. In an abiotic way, a maximum of 15-30 kg of nitrogen enters the soil (Birkás 2006).

Fixing the nitrogen of the air requires a lot of energy and can take place in aerobic as well as anaerobic circumstances. However, the crucial enzyme involved in the process, nitrogenise, functions only in anaerobic media. Nitrogenise is a complex of two enzymes (one of them is an Fe-protein and the other is an Fe-Mo-protein), and is closely related to another hydrogenase enzyme, which ensures the activity of the hydrogen molecule.

$$N_2 + 8H^+ + 8e- + 16ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16Pi$$

70% of total biological nitrogen fixation is undertaken by symbiotic nitrogen fixers, while 30% occurs through the activity of free-living or associative ones (Paul 1988). Among the symbionts the host plant-specific Rhizobium, Bradyrhizobium and Shizorhizobium species are the most significant actors. These are baculiform saprophyte bacteria, found independently in the soil. Migrating into the cortex of the plant roots they transform into bacteroides and induce root nodule formation. The full period of time of the formation of a nodule until the start of nitrogen fixation is about 2-3 weeks, while the old nodules become inactive in a month and then fall apart (Szabó 1989).

Microbial processes are essential to the circulation of nitrogen, and as environmental factors (moisture, temperature, pH, soil texture) influence microbial communities they also have an effect on the N balance (Figure III.2.10).

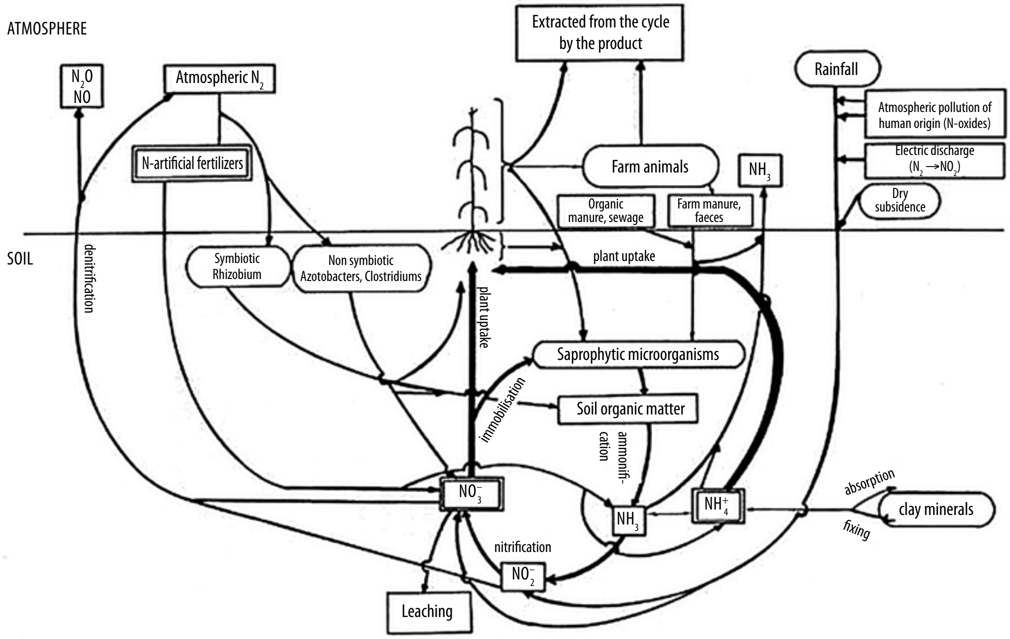


Figure III.2.10: The nitrogen cycle *(Birkás, 2006)*

In aerobic media, the fixed nitrogen in the organic molecules is transformed into ammonia, which has a toxic effect, by the ammonification activities of microorganisms. When soil is in a balanced state, practically no ammonia can be found at all. Some portion of the NH_3, originating partly from ammonification and partly from the natural environment and wastes, is utilized by bacteria that gain the necessary energy for their building processes from the oxidation of ammonia. As a result of the process, nitrite and nitrate are produced. This process is called nitrification and the participating microorganisms are called nitrifying bacteria. All of these bacteria are aerobic, Gram-negative, chemolithotrophic organisms, so they are only found in soils with a good air supply and a neutral medium.

$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$ (e.g. Nitrosomonas spp.)
$2NO_2^- + O_2 \rightarrow 2NO_3^-$ (e.g. Nitrobacter spp.)

The biological function of nitrification; that is, the liberation of energy from the oxidisable N-compounds, is to gain energy for the production of ATP. It results in the creation of totally-oxidised forms, which are important nitrogen sources, using no energy. Nitrate assimilation is one of the main processes of the biological cycle: annually, about $2x10^{13}$ kg N is assimilated.

Beside its benefits, the disadvantages of nitrification should also be mentioned. Nitrates form salts which are easily soluble in water and which can be easily lixiviated from top soil so they are not accessible to plants as nutrients. Furthermore, if they enter natural water courses in greater quantities they can change their ecosystems in an unfavourable way. Their build up in food and fodder plants may lead to the poisoning of humans and animals (methaemoglobinaemia) which can be especially dangerous to infants.

The C/N ratio has a decisive influence on the fate of nitrogen in the degradation of the organic matter of soil. If the C/N ratio is larger than 30 (carbohydrate effect), the dynamic N uptake of microbes decreases the nitrate content of the soil. In the case of a 20-30 C/N ratio there will be enough nitrogen for the degrading organisms, but with a smaller ratio of C/N mineral nitrogen will be liberated at the be ginning of the degradation process (Birkás 2006).

Denitrification, just as in the case of ammonification, is approached in a variety of ways; it can be de-fined in a wider and a narrower way.

In the wider sense (which is called assimilative denitrification), body proteins and other organic matter with N content are synthesised from the nitrate taken up by the microorganisms. This is called reciprocal nitrification, in which reduction takes place until ammonia is produced.

The narrower definition refers to the process which occurs when the nitrate is totally reduced to the molecular level of nitrogen. This dissimilative form is created by facultative anaerobic organisms which utilize the nitrate (nitrite) as a terminal electron acceptor in anaerobic circumstances, and the generated gaseous products (N_2O, NO, N_2) are released into the air.

Although prokaryotic organisms play a multiple and in some cases exclusive role in the nitrogen cycle, some other participants should also be mentioned. Certain fungi participate in certain processes of the cycle, the reduction of the assimilatory nitrate can be done by algae and vascular plants too, and the key enzyme involved in ammonia assimilation is glutamine-synthetase (GS), which is widespread in living organisms (Borsodi).

Denitrification involves a multiple-step enzymatic reaction chain. The end product of the final process is molecular nitrogen, but depending on the environmental circumstances and the type of bacteria which participate, some of the interim products may also be considered end products, as described below:

$$NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

The most common denitrificators belong to the Pseudomonas and the Thiobacillus genera (Pseudomonas aeruginosa, Thiobacillus denitrificans). As denitrification requires a lot of energy in an anaerobic environment, the nitrate-reducing enzyme system will not even develop if there is an easily-available nitrogen source.

Chemical denitrification takes place in an acidic pH (pH: 5.5) environment, while biological denitrification occurs at a pH of between 6-9. In ideal environmental circumstances, denitrification processes take place in the autumn and winter in Hungary, when the higher moisture level of the soil is more favourable for the anaerobic processes, and the plants are utilizing less nitrate due to their resting phase (Helmeczi 1994).

The loss of soils due to denitrification may be equivalent to 30% of the artificial fertilizer that is applied (Birkás 2006). An even greater problem is that the nitrogen oxides that form have a great influence on atmospheric chemical processes. For example, dinitrogen oxide is a 320 times more potent greenhouse gas than carbon dioxide, thus contributing to global climate change (Borsodi).

III.2.11. Organic matter transformation processes in aerobic and anaerobic systems, humus materials in compost

The degradation and transformation of organic matters during biological waste treatment is similar to the degradation and transformation processes of organic matter that take place in soils. The main difference is in their intensity and speed. The transformation of organic waste materials and dead organisms consists of the processes of degradation and synthesis, building upon each other. Degradation or disintegration can be divided into three phases. In the first biochemical phase simple compounds are generated as a result of chemical processes (hydrolysis, oxidation). This step basically happens at the same time as mechanical shredding, and occurs when the microbiological degradation of the degradable organic matter is affected by meso-, macro- and megafauna entities. The now smaller and more easily-accessible organic matter is further degraded by the extracellular enzymes of bacteria, actinomycetes and fungi. Based on the oxygen supply of the media, two systems can then develop: in the presence of oxygen, an aerobic one; without it, an anaerobic. Different energetic processes occur according to the systems. Anaerobic degradation is an endothermic process with the usual participation of mesophilic organisms, while the aerobic process is exothermic and the organisms that cause it are thermophilic. In aerobic circumstances, energy is provided by the respiration of the aerobic organotrophic microorganisms; that is, the oxidation of nutrients.

The further utilization of glucose, a typical monomer generated at the degradation of organic matters, is also significantly dependent upon the presence of oxygen. 2872 kJ Mol energy is released when glucose is burned aerobically, while in anaerobic circumstances this process will last only till the glucose becomes lactic acid or another simpler acid, releasing only 197 kJ Mol energy. In general, it can be stated that most of the energy is "utilized" in aerobic systems, while a great percentage of it remains in the energy of methane and combustible gases in the case of anaerobic systems.

However, a lack of oxygen may also occur temporarily in an aerobic system and the oxygen demand of microorganisms will be supplied by the reduction of organic compounds. At this point, rotting starts, accompanied by an unpleasant smell. The degrading organic matter becomes bluish-grey in colour and only a small amount of heat is released. The acids which are generated, especially ulmic acid, put a stop to the degradation process of organic compounds.

The easily-degradable organic matter quickly mineralizes under optimal conditions – the organically-bound chemical elements transform into mineral forms that the plants can take up, or in an anaerobic media CH_4 is released of a weight equalling one quarter of the COD (chemical oxygen demand) of the organic matter.

Beside the degradation processes that occur during the transformation of organic matters, there are building and synthesizing ones too. Therefore the degradation (mineralization) and the building (humification) processes have a close relationship (Figure III.2.11).

The essence of humification is that poorly-degradable polymerized compounds (remnants) bind with compounds that have nitrogen content and together form dark-coloured stable compounds and humus materials with large molecules. Lignin plays a crucial role in this process as humus is created by the condensation and polymerisation of the degradation products of lignin. If conditions do not vary the quantity of the degraded and the created humus is the same, so the organic matter in the soil is in constant dynamic change due to mineralisation and humification processes.

Because lignocellulose, lignin which comprises the frame of the plant in composting, is one of the poorly-degradable polymers, the phenomenon of humification must be taken into account when composting. The intensity of humification is enormously influenced by the composition of the organic remnants (C/N ratio), the external environmental conditions, as well as the temperature, the moisture content and the pH of the soil.

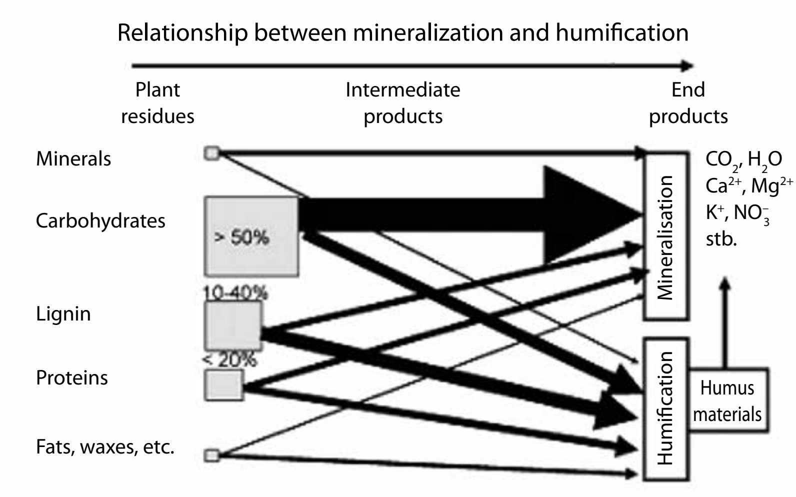


Figure III.2.11: Schematic of the correlation between mineralisation and humification
(Stefanovits and colleagues 1999)

Real humus materials have an extremely complex and diverse construction, their structure is non-unified and they are classified based on their behaviour in relation to alkalis and acids. There are the fulvic acids that dissolve well in both alkali and acid, humic acids that dissolve easily in alkali conditions but not in acid, and the humic substances that do not dissolve at all in cold acid or alkali either. The molecular weight of the compounds, as well as their polymerization, condensation and nitrogen content, increase from fulvic acid to humic substances, while the acidity and solubility of the humus compounds decrease because of the decreasing number of active radicals.

In spite of their stable structure and resilience, humic substances are also direct and indirect nutrients for plants. Humus as a nutrient supply is significant primarily as a source of nitrogen. The majority of amino-nitrogen forms that mineralize the most easily are attached to humic acids (Figure III.2.12). The mineral nitrogen forms (nitrate and ammonium), which can be directly utilized by the plants, are primarily generated by the transformation of the aminos in the humus materials during ammonification and nitrification (see Chapter III.2.3, Nitrogen transformation processes). It is known that, besides nitrogen, humus contains phosphorus and sulphur through organic binding, which – similarly to nitrogen – are released slowly and become accessible to plants through this continuous process of release.

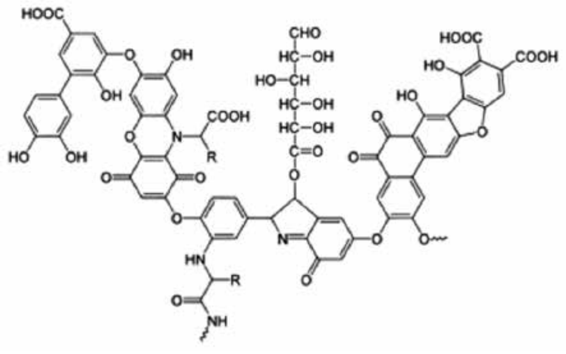


Figure III.2.12: Composition of humic acids

Furthermore, humus has an important role in shaping the physical characteristics of the media (soil) and in regulating its nutrient management. Humus is capable of binding micro and macro elements because of its great absorption capacity, and releasing them in a way that is regulated by external factors. Humic elements are able to bind elements that have toxic effects on plants as well as other materials (e.g. remnants of pesticides) that are harmful to them, thus protecting the plants from the harmful effects of the toxic materials. As humic acids are insoluble in water containing salt with diprotic ions, the best, so-called crumbly soil structure is produced in their presence. Humic elements improve the buffering capacity of the soil and, as a consequence, any harmful effects on the soil are attenuated; moreover, soil warms up more rapidly due to their colour as the rays of the sun are absorbed better by darker colours (also, the radiation of soils that are rich in organic content is greater). Because of their immense capacity for absorption, humic elements improve the water management of soil as soil which is rich in humus can bind and store more water. The water and heat management features of soils with high organic matter content also interact with each other. Due to the fact that soils which are rich in humus have greater water-storage capacity, and because damp soils have a higher heat absorption capacity, it is less probable that such soils will warm up fast. The biological activity of the soil is improved by the organic matter in the soil, and hormones and enzymes are activated because of their relationship with the organic molecules.

III.3. Composting technologies, operations and equipment (Sándor Dér, György Füleky)

Composting technologies can be categorized in many different ways. The categorization presented here is based on the relationship of the composting procedure to nature. Based on this, open and closed composting systems can be differentiated. The complexity of the technical processes which are applied, the mechanical equipment and the buildings are determined by the above-mentioned relationship.

III.3.1. Open systems

III.3.1.1. Passive composting

This is the least complex procedure from a technological point of view. It is used properly only in the case of stable, non-rotting wastes of plant origin with a high carbon-nitrogen ratio. Maturation occurs in large windrows of a trapezoid shape (5-10 m wide and 2-4 m high). Basically, the process is static, so there is usually no further interference with the windrows during composting apart from stockpiling. In practice, the static windrows are turned a maximum of twice and moistened if necessary during maturation, but the passive nature of the process management is maintained. Oxygen supply to the substrate is provided through the pores by diffusion. The time span of the process is between 6 months and 3 years depending on the raw materials, the size and moisture content of the windrow, as well as the temperature of the environment.

Passive composting is a slow process and because of this it requires a large space; however, the related demand for work and machinery is low. The composting site needs to be equipped with technical safeguards for the protection of groundwater. As a result, real opportunities for passive composting are usually low as the costs of building the appropriate protective casing are very high.

III.3.1.2. Windrow composting

This is one of the oldest and most frequently-applied methods of composting. The raw materials are stacked into a windrow with a triangular or trapezoid cross section and are restacked and regularly turned. The material is mixed and homogenized and aerobic conditions are guaranteed by turning, while the "captured" heat, the vapour and the gases are allowed to leave the windrow.

A windrow with a triangular cross section is the most favourable in practice from the perspective of maturation. The optimal size of the windrow is determined by the following factors:

- composition of the substrate;
- moisture content;
- aeration and gas exchange;
- size of the turning machine.

The compostable organic matter can be transformed into appropriate quality compost in 8-10 weeks if the conditions are right. Such intensive microbial activity requires an approximate moisture content of 50% during the process, appropriate porosity and a theoretically optimal windrow size, which is 3 m wide and 1.5 m high. With a windrow of this size the pressure on the ground in the middle of the windrow is not too high and the appropriate porosity can be guaranteed. Use of the right turning machine is also a prerequisite for this windrow size. In practice, the size of the windrow is determined by the size of the turning machine so windrows with a triangular cross section are typically between 1.8 - 6.5 meters wide and 0.8 - 3.0 meters high.

For a better use of space a trapezoidal windrow is used, mainly in the case of green wastes. These have a trapezoidal cross section of variable length and width, while their height is between 2.5-4.0 m.

III.3.1.3. Aerated windrow composting/static pile

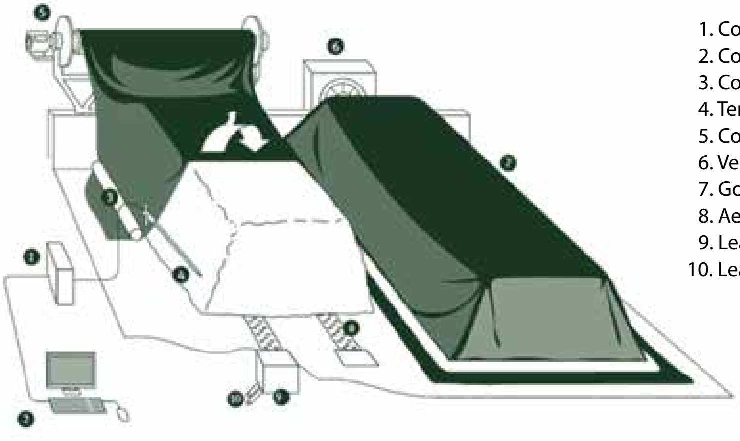
The principle of aerated windrow composting (or Aerated Static Pile - ASP) relies on maintaining a constant oxygen level to meet the demand of microorganisms for their survival within the windrow. There are several methods for injecting air into the system. Most commonly, perforated rigid pipes are embedded or aeration drains are sunk into the windrow. Air is blown in by a ventilator or a pump and thus each minute of the composting process is controllable. In an ASP system the feedback is the temperature or the oxygen content of the compost, and the ventilators are switched on and off based on this information. The aeration process in an aerated windrow composting (or ASP) system may involve a blowing or a sucking system. In a blowing system the air is blown into the windrow and the gas exchange products exit into the environment from the entire surface of the windrow. With a sucking system the gas exchange products are sucked out from the windrow and air enters through the surface of the windrow as a result of the vacuum that is created. In the case of the latter system the gases which are sucked out of the windrow can be guided to a gas treatment system (gas washer and biofilter).

In a sucking system there is no need for further involvement (turning or moving) apart from stacking the heap and preliminary mixing.

III.3.2. Closed composting systems

III.3.2.1. Aerated composting systems with a semi-permeable membrane

In this recent variation of aerated windrow composting, the system is closed by a semi-permeable membrane cover. This system has three important elements; beside the cover material the controlling equipment and the aeration systems are also crucial. The active aeration system supplies the microorganisms that participate in the composting process with oxygen and aeration is continuously controlled by feedback information about the temperature and oxygen level of the material. A special membrane cover guarantees that the system remains closed for composting. The air permeability of the cover needs to be between 1.5-6.5 m^3/m^2h and the diameter of the pores cannot be larger than 0.2 µm. The vapour permeability of the cover cannot exceed 19.5 m^2 Pa/W in either a new or used condition, and it must be able to withstand a minimum of 50 kPa water pressure.



1. Control
2. Computer with SCADA software
3. Cover fastening weight
4. Temperature probe
5. Cover winding operative
6. Ventilator
7. Gore™ Cover material
8. Aeration pipe
9. Leachate collection reservoir
10. Leachate gutter

Figure III.3.1: Conceptual scheme of the Gore™ Cover semi-permeable membrane composting system

With this technological procedure the windrows are stacked to a height of 2-3.5 m and a width of 6-9 m, while their length can vary between 20-50 metres. They are supplied with computerized operating technology that controls aeration based on pre-defined temperature and oxygen content limit values during the four week long intensive maturation period.

The numerous disadvantages of the earlier-described aerated systems are eliminated by the semi-permeable membrane as there is a slight overpressure in the windrow due to the membrane which obstructs the development of anaerobic zones. The cover allows gas exchange while it retains unpleasant odours, moisture and heat. Its great advantage is that it does not need gas treatment, and in most cases its efficiency is greater than that of biofilters.

III.3.2.2. Closed reactor spaces

Composting takes place in a closed unit in the case of intensive composting procedures with the following possible variants:

- drum composting
- box composting
- tunnel composting
- container composting

These methods differ from each other according to the length of their intensive period and the maturity of the final compost. In certain cases, mature compost (at a maturity level of IV, V) is created by the end of an intensive phase with a maturation phase phase integrated into it, while in the case of other technological processes intensive maturation is stopped when a hygienic raw compost is obtained (maturity level of I, II).

There is no difference in the methodology for maturation phase within technologies - the compost is stacked into windrows and turned or aerated in all cases.

Closed composting processes are difficult and sophisticated technological processes so they usually have a high investment and operational cost.

However, they are frequently used in inhabited neighbourhoods where a larger amount of organic waste is produced, the available area for waste processing is small, and when odours need to be kept under total control.

III.3.3. Operational phases of composting

A great number of composting technologies are available, the application of which in many cases are different and depend on the local specialities and the supplier of the technology. But if we only look at composting as a biological waste management procedure, then, regardless of the technology applied, the following operational phases can be identified:

- Reception of wastes, temporary storage
- Preparation of wastes
- Intensive phase
- Maturation phase
- Post treatment (preparation for end use)
- Storage of end product

The connection between the above-mentioned six phases is provided by the seventh phase, which is material handling.

III.3.3.1. Material handling at the composting plant

Ensuring proper handling of material between the different operational phases of composting and of the composting plant is very important. The most widely-used material handling machine is the front-end loader. This machine is essential at all composting plants. The telescopic loaders need special attention as they can be used in a multi-functional way and they were developed especially for agricultural plants. Supplied with the proper adapters they can deal with almost every kind of loading task in every agricultural plant. They can be utilized for many different tasks because of their universal structure, but their performance cannot compete with machines developed for dedicated purposes.

As it is mostly loose materials that need to be handled at composting plants, a front-end loader can perform these tasks more efficiently than a telescopic loader.

The handling of materials can also be done partially or totally by conveyors. However, purchasing fixed conveyors is a major technology-related expense for composting plants and does not allow for simple changes in technological steps when needed. If conveyors are out of order, the material flow of the whole plant will stop. In practice, only a few conveyor systems are in use at plants.

Figure III.3.2: Telescopic loader

Figure III.3.3: Conveyor system

III.3.3.2. Reception of wastes and storage

Reception and temporary storage of wastes is the first operational phase of composting. It consists of the following steps:

Weighing of wastes and documentation: all incoming wastes are required to be weighed and registered. A weighbridge (18 m long and with a capacity of 60 tons) for weighing larger trucks should be installed when creating the composting plant.

Inspection of wastes: The first important step in creating compost that complies with quality requirements is the professional inspection of raw materials.

Initially, the wastes need to be identified (by checking if the delivered materials are those described in the accompanying documents, and if the EWC code of the materials is on the permitted materials list of the authorities). A waste can have different EWC codes depending on its origin.

The quality inspection of the raw materials and wastes must cover the following areas:

- Does the waste contain impurities in significant quantities?
- Does the quality of the waste correspond to its specifications (if there are detailed specifications)?
- Does the waste contain pollutants (e.g. toxic elements)? The composting plant is required to develop its own sample-taking system for identifying pollutants. This should include taking into account the risks, sampling within a certain period of time and laboratory testing of samples.

III.3.3.3. Storage of wastes (raw materials)

A properly-sized storage area has to be created as part of the preparatory area, or as an adjacent unit in the composting plant. The storage area needs to be sized so that all the wastes that are delivered can be stored properly by type until their treatment begins. The storage area must have a watertight solid casing and a leachate collection system. Building a concrete wall on at least one side of the storage area makes storage and handling much easier. Rapidly-degrading wastes need to be treated on a daily basis; only biologically stable wastes can be kept for a longer period. In the case of longer storage times (e.g. 3-4 months) it is recommended that a roof be built over the storage area.

Waste	Description	Gravimetric density
Residential biowaste	municipal, mainly kitchen waste; wet	0.85 t/m^3
	municipal; mixed with garden waste	0.65 t/m^3
	city; with high garden waste content	0.45 t/m^3
Green waste	loose; mainly plant stems and branches	0.2 t/m^3
Woodchips / Shredded wood	shredded, dry	0.3-0.4 t/m^3
Cut grass	fresh; loose	0.5 t/m^3
	dry; loose	0.2 t/m^3
Manure from stables	rich in bedding material	0.4-0.5 t/m^3
	poor in bedding material	0.75 t/m^3
Compost	fresh compost 1-4 month old	0.6 t/m^3
	mature compost, more than 4 months old	0.7 t/m^3
	mature compost, more than 12 months old	0.85-1.0 t/m^3
Sewage sludge	20-30% dry substance content	1.0-1.2 t/m^3

Table III.3.1: The gravimetric density of some common materials

III.3.3.4. Preparation

Preparation of the delivered wastes primarily refers to the biological-physical optimisation of the substrate. The aim here is:

- to guarantee the gradual build-up of carbon and nitrogen in the intensive phase of composting;
- to provide the appropriate structure to ensure the necessary porosity, thus enabling the right gas and heat exchange throughout the whole mass of the compost;
- to improve the quality of compost by removing the impurities.

The most important operational preparatory steps are:

- removal of impurities;
- destruction of fibres in the wooden fraction as well as decreasing particle size by shredding;
- mixing of different materials, homogenisation and conditioning, and thus
- control of moisture (50-55%);
- provision of the appropriate C/N ratio (30-35:1);
- creating a pore volume that enables gas exchange (making a homogenous structure) as well as a gravimetric density of 650 kg/m^3;
- feeding with additives to facilitate the maturation processes and create a better quality compost.

Means of preparation:

Removal of impurities and pollutants: The removal of impurities and pollutants is most often necessary in the case of residential biowastes, firstly to create an acceptable end product in terms of visual parameters, secondly to remove individual pollutants, and thirdly to protect processing equipment from damage. The presence of pollutants and their quantity must be checked upon receipt of the waste. Larger impurities and objects need to be removed during the reception process. Sorting of biological wastes on a sorting table is not possible for health and safety reasons.

Possible means of preparation:

- Preliminary sieving of wastes (to a particle size of 50-80 mm) with vibrating or drum screens;
- Isolation of metals that either can or cannot be magnetized (magnetic and eddy current isolators);
- Isolation of plastic pieces by air classifier;
- Classification by gravimetric density (isolation of pebbles, pieces of glass).

Size reduction:

By reducing the size of the waste, better access is guaranteed for microbes to the organic materials in the composting process and the specific surface area is increased while the volume of the waste is decreased and the production of a homogenized mix is facilitated.

The degree of size reduction depends on the composting technology and the future utilization purpose of the compost. Reducing the size too finely (grinding) can be unfavourable as the substrate will not have the optimal structure and stability and anaerobic conditions can develop quite rapidly. In an optimal case there will be an even distribution of rough and smaller chips, and the stability of the structure will be provided by the rough pieces.

The following machines are appropriate for reducing particle size:

- hammer-mill shredders;
- knife cutters;
- roll crushers;
- cylinder chipping machines.

Mixing, creating the appropriate substrate:

Front-end loader: Prior to mixing, the raw materials are stacked on top of each other in layers of the appropriate proportions, then they are turned by a front-end loader to create the most homogenized substrate.

Manure spreader: Before mixing the raw materials an appropriate quantity is layered on a manure spreader and is run on the spot. Guiding panels should be placed on the sides of the manure spreader so the appropriate-sized windrows can be built out of the mixed substrate behind the spreader.

Mixers: There are two main types of mixers. The operating principle of the first one is similar to that of the manure spreader, but composting requirements are taken into account during its production (e.g. it has its own engine, it can make smaller changes in position, an adjustable windrow size). The other group consists of continuous mixers. Two or more pulley-blocks are inserted into a properly-sized container in this piece of equipment. The pulleys turn slowly in opposite directions, thereby mixing the raw materials in the container.

Compost turning machine: A proper quality substrate can be produced by going over the layered wastes once or several times with a compost turning machine.

III.3.3.5. Intensive phase

Intensive phase is the phase of composting when the intensive microbiological degradation of the easily-degradable organic matter in the substrate, as well as of the degradation products generated through the process, takes place. Intensive maturation can be considered complete when the temperature of the compost permanently drops below 40 ^{0}C. Intensive phase lasts between 4-10 weeks depending on the technology that is used, the aeration and the composition of the substrate. It is followed by maturation phase. The equipment used for intensive phase is crucial because the different pollutants (e.g. odour emissions) are emitted to the greatest extent during this phase.

Intensive phase usually takes place in one or two phases:

One-phase intensive composting: A continuous one phase procedure, the objective of which is to create compost of the desired stability (e.g. tuning windrow composting, with or without active aeration).

Two-phase intensive composting: A procedure in which the first phase of intensive maturation which produces the most heat takes place in some kind of a closed space (boxes, compost silos, closed halls), but the compost does not reach the necessary stability for maturation phase (T>40 ˚C) during this closed technological phase, so a second main phase of composting needs to be conducted. This second, main composting phase generally involves some kind of a windrow composting procedure.

Regulation of intensive phase: Certain parameters have to be kept at a nearly optimal level for the proper regulation of the process, and, in case of deviations, adequate measures must be taken to ensure that parameters are returned to optimal. Probably one of the most important parameters is the oxygen content of the substrate, which if it drops below a certain level needs to be increased. The most important features that enable the proper tracking and optimisation of the process are the following:

- moisture content (50-55%);
- oxygen supply (>12 V%);
- temperature (50-65 ˚C, depending on the time frame of the operation).

Composting can be done using a continuous procedure or in phases. In the continuous process the raw materials are continually entered into the technological system, and the end product is also continually removed. With phase composting the raw materials are composted in batches. One batch is always at the same stage of composting and the properties of batches should be identical. Phase composting is most widespread for operational/technological reasons, as the necessary conditions for ensuring optimal maturation can be tracked and guaranteed more easily.

III.3.3.6. Process control in the case of different composting technologies:

Open windrow composting

Regular turning is an important technological component of windrow composting. Due to the turning activity, gas exchange takes place (providing the necessary oxygen), the substrate is mixed repeatedly and its size is reduced mechanically. Before turning, if necessary, the substrate needs to be moistened. The frequency of tuning in the case of windrow composting is determined by the quality and state of the substrate (compaction, moisture) and changes in its temperature. Measuring the oxygen or the CO_2 content of the diverted gases is not typical with these systems.

Turning the compost in an open windrow system can be done using the following technologies:

- loader;
- manure spreader + front-end loader;
- compost turning adapter fixed onto a tractor;
- self-propelled compost turning machine.

If providing an oxygen supply is the objective, turning can only be done well by a loader with an associated greater amount of labour input, so the use of this method is only feasible when turning smaller amounts. Turning using a loader (that is, transporting the compost to another place) is an excellent method for eliminating compaction and for mixing the compost to a smaller extent in the case of systems which employ active aeration.

Turning with a manure spreader and front-end loader is a slow and costly method so it should only be done if there are small amounts of material and if the machines are already at the operator’s disposal.

Self-propelled compost turning machines and adapters are the basic machines used for turning compost. Depending on their size they are able to turn 200-1.500 m^3 of compost in an hour.

The frequency of compost turning is determined by the objective and the quality of the compostable raw materials:

- if the oxygen supply is to be provided by turning, then in the first 2-3 weeks turning should be done 2-3 times weekly; later (in the 4-8th weeks) one or two turnings per week is sufficient;
- if turning is only a complementary element alongside an active aeration system, then turning or restacking of the compost needs to be done only every 2-3 weeks.

Windrow composting in closed halls

The procedure is very similar to open windrow composting. The compost windrows are placed in closed halls. The windrows are usually larger (5-6 m wide and 3-3.5 m high) than those used in open windrow systems, so they are often supplied with some kind of an active aeration system.

Regulation of closed composting systems

The anaerobic conditions for a closed composting system are maintained through aeration. The frequency of aeration is determined by the gas concentration (oxygen or carbon-dioxide content) of the diverted gases or of the substrate. It is crucial that the oxygen content of the substrate should not decrease below 10 volume/volume percent (V/V %). When using an active aeration system the proper regulation of moisture is especially important as the substrate can easily dry out due to intensive aeration, and the composting process may slow down or even stop. In this case a large amount of moisture will be given off in the form of water vapour because of the initially high production of heat and intensive aeration, so the substrate will become dry to such an extent that the biological activity will be significantly diminished (the temperature decreases and the process stops) before the easily-degradable organic matter can be degraded to the appropriate extent. Although treatment time is seemingly reduced in such a case, this is not considered to be a suitable outcome because if the treated compost receives moisture again (e.g. during storage) biological processes will restart, but not in a controlled environment so they may cause undesired effects (significant odour emission, re-pollution, blocking of plant growth, etc.).

Active aeration

Active aeration is the technical process by which external fresh air enters the pores of a substrate saturated with gases and replaces those gases (mostly carbon dioxide and water vapour). There are two main types of active aeration processes:

Push aeration systems, in which fresh air is injected into aeration pipes most often placed under the substrate, and through which, due to overpressure, gas exchange takes place.

Pull aeration systems, in which the gases are sucked out through aeration pipes that are placed in or under the substrate, and thus fresh air enters the substrate through its surface due to the vacuum generated by suction.

The following activities need to be undertaken with an active aeration system:

- Diversion and treatment of the gases that are generated. If active aeration is in the intensive composting phase, the gases need to be treated in all cases, while this is not always necessary in the maturation phase phase.
- Active aeration can be efficiently applied only in the case that the substrates are well-structured, homogenized and have the appropriate porosity.
- The compost needs to be turned and restacked every 2-5 weeks to regain the right structure (to recreate the appropriate porosity).

Regulation of active aeration can be done based on:

- the concentration of oxygen and/or carbon-dioxide measured in the substrate (minimum 10 V% oxygen);
- the concentration of oxygen and/or carbon-dioxide measured in the exiting gases;
- the dynamics of the temperature changes;
- pre-defined periods of aeration based on previous experience and the estimated oxygen requirements of the substrate.

III.3.3.7. Maturation phase

Maturation phase is the phase that follows the stage of main or intensive maturation, in which the final stabilization of the compost and high level humification of the remaining organic matter take place. The end product of maturation phase is a complete or mature compost. Intensive maturation can be considered finished if the temperature of the compost permanently decreases to below 40°C, while maturation phase lasts until the compost loses its ability to heat up by itself (T<30 °C).

The following changes take place during maturation phase:

- Degradation of organic matter that is not easily biologically degraded (mainly lignin and cellulose);
- The initial material of humus is created from the proteins (ligno-proteins) generated by proliferated fungi and actinomycetes during the degradation of lignin, as well as from the polymerization of other compounds;
- Degradation of plant growth inhibitors that remain from the intensive maturation phase;
- Development of an emission-free end product for post treatment (e.g. sifting).

The procession of maturation phase:

Preliminary sifting may precede maturation phase (30-50 mm particle size) during which the larger, not-yet-degraded parts are separated. Maturation phase takes place in windrows with a cross section of a triangular or trapezoid shape. The shape of the windrow and any further treatment basically depend on the quality of the intensive phase (the quality of the easily-degradable organic matter and the moisture level of the fresh compost). The windrows should be built in a way that natural gas exchange can happen to the greatest extent (2-3 m wide and 1.3-1.5 m high triangular windrows). If this cannot be achieved, the compost should be regularly turned (weekly or fortnightly) during maturation phase. Active aeration should also be done when the height of the windrows exceeds 2.5-3.0 metres.

III.3.3.8. Post treatment – compost screening

Impurities and not-yet-degraded organic matter is selected by sifting so homogenous good quality compost can be produced. The size of the perforations of the sifter depend on the later purpose of utilization of the compost. For mulching, larger than 40 mm compost particles are appropriate, for plough land they should be smaller than 15-20 mm, and in the case of gardens the particle size needs to be smaller than 10 mm.

Generally, the compost is sifted by drum screens, the main features of which are the following:

- The main part of the screen is a rotating perforated cylinder, the active surface of which is continuously cleaned by a rotating brush;
- One screen is able to generate two fractions, but by combining more screens into one or by applying them parallel an optional number of fractions can be separated. In practice, composting plants use two separate types of equipment together. The first one carries out rough sifting (40-50 mm); the second one continues sifting the fine fraction (>80-100 mm) created by the first screen to separate off an even finer particle size (15-20 mm). The sifting capacity of the combined utilization

of the two types of equipment is greater than separate utilisation of the two, both conducting fine sifting.

- The perforations of the cylinders can be of different sizes (5-100 mm) and shapes (square or round);
- The sifting equipment is equipped with a self-propelling mechanism during its production;
- Cylinders can be changed rapidly;
- They can be easily combined with other methods of separation (e.g. magnetic separators, air classifiers). Producers of the most common types all have these kinds of additional equipment which can also be attached to the screens;
- Performance can be efficiently regulated by changing the speed of feeding and the screen;
- They are available in mobile versions, which are most typical of composting plants;
- They require only a small amount of maintenance;
- Their disadvantage is that in the case of wetter materials (with moisture content higher than 55%) the efficiency of sifting decreases, or the larger pieces tend to stick together in the rough fractions.

Beside drum screens, different kinds of horizontal, vibrating and star sieves are also used at composting plants. These sieves can be used in a wider range of ways (e.g. wet materials can also be sifted) than is possible with drum screens, although their widespread utilization is hindered by the following facts:

- they are not produced in mobile forms (e.g. vibrating sieves);
- their maintenance costs are higher (star sieves);
- it is more difficult to change particle size (star sieves, vibrating sieves).

III.3.3.9. Storage of composts

Most of the nitrogen of the complete compost after maturation phase is in a bound state in the humus material. Humification, and also mineralization to a degree, continue during storage if moisture content is appropriate, so provision of a certain level of oxygen needs to be ensured. Even after sifting of mature compost, anaerobic circumstances may occur during storage which can influence the quality of the compost unfavourably.

Composts must be stored on a solid surface. At least one side of the storage place should have a silo wall which enables better utilization of the space and easier loading. The following aspects need to be considered during storage:

- The size of the storage area should be calibrated so that at least 30%, but if possible 50% of the volume of annual compost production can be stored within it. (The size of the storage area depends on the planned utilization of the compost to a great extent.)
- Sifted compost with a fine particle size can only be stored in a heap of larger cross section if the compost is adequately mature. To preserve its quality, compost stored in larger heaps needs to be turned / restacked regularly (every 4-6 weeks). The frequency of turning depends upon the maturity of the compost and the height of the heap (the higher the windrow, the more frequent turning is needed). If the temperature of the heap increases to over 30˚C after turning, the compost is still in the stage of maturation phase and should be treated accordingly.
- Even by taking the previous considerations into account, the compost should not be stored in a heap the height of which exceeds 3 m.
- If the compost has to be stored for a longer time in a heap that is higher than 3 m, fine sifting need not be done after maturation phase but only before immediate utilization. (The compost has more structure this way, so anaerobic circumstances cannot develop as easily during storage.)
- Attention needs to be paid to the separation and labelling of the different compost batches if they are stored together, especially if the quality of the batches is different.
- Planning and maintenance of the storage places need to be done in a way that the hygienic compost should not become contaminated. (E.g. proper separation of storage places for raw materials and complete compost, avoiding the use of contaminated equipment.)

III.4. Regulations concerning the application of composts in the EU member states (László Aleksza)

The countries of the European Union are grouped into three categories from the point of view of the utilization of biowastes:

- **Group 1**: Austria, Belgium (Flanders), Denmark, Germany, Luxemburg and the Netherlands – in these countries selective collection and composting are ongoing in a situation of full legal regulation.
- **Group 2**: Belgium (Wallonia), Finland, France, Italy, Sweden, United Kingdom and Hungary – the legal background for treating biowastes is more or less available, but the practical application of these regulations is still at an initial stage.
- **Group 3**: Greece, Spain, Portugal and the majority of the new member states –regulations are presently under development.

It has become apparent in the EU countries of Group 1 that both the producers as well as the consumers consider the introduction of quality assurance systems for composts to be the most crucial element for expanding the utilization of biowastes.

Marketing research of the past few years has revealed that quality certification trademarks and the control of independent quality assurance bodies on products are sought out by customers.

III.4.1. The operation of quality assurance systems

There are significant differences in the legal environment and organisational frameworks of the quality assurance systems in the individual countries. These disparities are due to the differences in how the systems evolved, structural circumstances, the environmental problems and the national characteristics of public administration in the given countries.

The main tasks of the quality assurance systems in every country are the following:

- fostering the protection of the environment, promoting the reuse of organic wastes;
- fostering the utilization of composts in order to preserve and improve soil fertility;
- minimizing the environmental and public health hazards of composting;
- enabling the operation of a professionally-competent controlling system, independent from composting plants;
- harmonizing the laws and norms regulating the activities and the composting quality assurance systems.

Every step of treating organic waste is covered by composting quality assurance systems:

- selective waste collection;
- management of a composting plant: any failures in the operation of a plant will have an effect on the quality of the compost, and complying with hygiene-related criteria is also important from the plant's employees point of view;
- quality of the compost: quality can only be assured if chemical composition standards are met on an ongoing basis;
- certification of quality: establishment of a certification system is a prerequisite to gaining certification;
- utilization of compost: professional utilization requires analytical inspection of the certification process;

- compost policy: the information gained from evaluations of inspections during system operations is used for reviewing the operation of the system, for development purposes and for preparing new standards and legal regulations;
- marketing: customers seek out trademark labels;
- PR (public relation) activities: creating and developing a positive image about compost.

Elements of quality assurance systems:
- defining raw materials;
- defining and controlling the level of harmful substances;
- inspecting nutrient content;
- controlling compost production;
- conducting external inspections;
- conducting full-scale internal operational inspections (production, material handling, etc.);
- marking composts;
- awarding trademark labels;
- indicating chemical composition, providing recommendations for use;
- offering annual qualifications.

The following tasks need to be covered by quality assurance systems:
- defining the analytical and qualification methods, testing laboratories (round robin process);
- creating a unified sampling process and a methodology for it;
- building a central database;
- determining fines in case a plant does not comply with the requirements;
- developing a means of inspection;
- acquiring regional or national recognition for the system.

The marketing of compost requires the existence of an inspected product with reliable quality for the following reasons:
- an inspected product is a basis for managing public relations, good arguments;
- the presence of a label has a positive influence on customers;
- regular analysis guarantees good quality;
- the creation of a data sheet containing the results of inspection can form the basis for the qualification of the product and recommendations for its utilization.

III.4.2. Selective biowaste collection and compost quality assurance practices in the EU member states

The collection of selective organic waste is regulated on a statutory level in four countries – The Netherlands, Luxemburg, Germany and Austria. In the majority of the EU countries, the selective collection and utilization of biowastes is made compulsory only indirectly in the form of individual national legislation by prohibiting the landfilling of biowastes in landfills or their incineration.

Quality assurance systems are based on the regulations and legislation of individual countries. The quality assurance systems have been created in 2 or 3 steps:
- private criteria systems (associations, professional organisations) – totally based on common law;
- state or state-protected standards and requirements (ÖNORM, RAL), basically on the basis of common law;
- legislative background and public authority contributions based on legislation emerging from professional areas.

Country	Legislations regulating the quality of composts
Austria	Compost Ordinance (2001) → for all kinds of composts
Belgium	In Flanders – annex to the law on Waste Management → BHK/ZHK
Denmark	Decree on agricultural utilisation of products of waste origin (1996) Decree on the use of crop enhancing materials (1996)
Finland	Law on the use of crop enhancing materials (1993)
Germany	Regulation on biowastes (1998)
Greece	Joint Ministerial Decision on the Establishment of a framework of technical specifications and of general plans of solid waste management (1997) → TSZK, SZI, SZIK
Ireland	Licences based on the Waste Management Act
Italy	Law on soil fertility – modified in 1998 BHK/ZHK/SZIK, Technical legislation (1984)→TSZHK Draft decree on BHK
Luxemburg	Licences
Netherlands	BOOM decree on the quality and utilization of organic crop enhancing materials (1991) → BHK/ZHK
Portugal	There is no separate regulation for composts, only for sewage sludge (1991)
Spain	Waste law on crop enhancing products originating from waste management (1998) Draft decree on composting and composts (national); Draft decree on the quality of composts (Catalonia)
Sweden	Private criteria system
Switzerland	Decree on the environmentally hazardous materials (1996) and its draft modification (2002)
United Kingdom	Private criteria system (Compost Association)

Table III.4.1: Legislation and plans regulating the quality of compost

There have been significant differences among the individual countries in the development of their compost quality assurance systems. As Germany was the first to deal with composting, the greatest number of composting plants can also be found in that country and most of the EU member states have developed their own legislation practices based on the German experience.

Beside Germany, individual organisations that deal with compost quality assurance have been created in Austria, Belgium and the Netherlands.

Country	Certifying organization
Austria	KGVÖ (Kompost Gütesicherung Verband Österreich)
Belgium	VLACO – Flemish organization for the quality assurance of bio and green waste composts
Denmark	Presently in the process of formation by the DAKOFA solid waste workgroup
Germany	BGK (Bundesgütegemeinschaft Kompost e.V.)
Netherlands	KIWA – inspection, certification VVAV – waste management organisation (operating plants, etc.)

Table III.4.2: Compost quality assurance organizations in the EU

Netherlands Belgium

Austria Germany

Figure III.4.1: Trademarks of the quality assurance organizations

Country	Norms, standards, legislation
Austria	Compost Ordinance; Standards of ÖNORM 2206-1 and 2206-2, as well as information on the KVGÖ 12 website which includes a description of the full procedure of composting, quality assurance, inspections and the utilization of composts.
Belgium	VLACO Directives on composting bio and green wastes
Germany	Compost Ordinance and BGK (Bundesgütegemeinschaft Kompost e.V.) and based on the RAL-GZ 251 standards – (RAL – German Institute for Quality Assurance and Certification)
Netherlands	based on the KIWA 1993 criteria

Table III.4.3: Norms applied during the quality assurance of composting

III.4.3. External supervision of composting

The quality assurance systems are classified by their supervisory and monitoring systems. Market research has shown that the most important requirements of customers in relation to these systems are the independence of the organisations as well as the presence of external inspections, which include sampling, accredited laboratory analyses and evaluation and independent inspections of production activities.

In Germany, BGK inspection includes only the sampling and analysis phases as the philosophy of RAL puts the emphasis on the quality of the end product. According to the German regulations the plants can comply with legal regulations in two ways. They either only have inspections conducted by independent laboratories and they themselves then report the results to the competent authorities of the province, or they become a member of the BGK, and by complying with its system they also comply with the legal regulations too.

In the Netherlands, sample-taking is done by the plants themselves during the inspection of the composting process. Later these samples are sent to accredited laboratories for checking. Even though the samples are taken by the plants themselves, independence is assured by KIWA's full spectrum inspections (which involve sampling and examinations) 8 times a year.

In Belgium there is a two-step inspection system, according to which in the first year the composting process, and from the second year only the quality of the compost is inspected by VLACO.

The Austrian system of qualification is similar to that of the German one with the difference that the managers of the plants are obliged to take a compulsory course on qualifying and are required to keep a dedicated plant diary. Furthermore, participating in the KGVÖ system cannot substitute for cooperation with certain state authorities.

Categorization of the plants according to their capacity	**Frequency of external inspection (sampling)**	***Comments***
Austria – Compost Ordinance		
Quantity of compost (per year)		
< 50 m^3	Before the first sales	5 m^3
50–300 m^3	Once every 3 years	20 m^3
300–1 000 m^3	Once every 2 years	50 m^3
1 000–2 000 m^3	Annually	100 m^3
2 000–4 000 m^3	Every 2 years	150 m^3
>4000 m^3	One after every new 4 000 m^3, but annually maximum 12	150 m^3
MSW compost	after every new 500 m^3	200 m^3
Belgium - VLACO		
Capacity of plant (per year)		
< 20,000 t	8 /year	
> 20,000 t	12/year	
Denmark – Decree		
Capacity of plant (per year)		
Every type of plant	4 /year after every 2 000 m^3	
Germany – RAL GZ 251 (BGK norm)		
Capacity of plant (per year)	Ordinary inspection	***In the first year (recognition period)***
≤8,000 t	4 / year	≤2000 t 4 / year
> 8,000 t	1 after every 2 000 t input materials	2000- 6000 t 6 / year
	maximum 12 annually	6000- 12000 t 8 / year
		> 12001 t 12 / year
Luxemburg – Interim Standard and RAL GZ 251 (from Germany)		
Capacity of plant (per year)	***Internal inspection***	***External inspection***
> 20 000 t heavy metals	12 / year	4 / year
PAH, PCB	4 / year	4 / year
PCDD/F	2 / year	4 / year
Netherlands – according to the Interim Quality Control system of KIWA		
Capacity of plant (per year)	***Internal inspection***	***External inspection (KIWA)***
Every category	6 - 12 / year (1 / 4 weeks)	8 / year
United Kingdom – Composting Association criteria system		
Capacity of plant – input per year	***Supervision***	***Qualifying period***
< 5 000 t	2 / year	2 / year
5 000 – 10 000 t	2 / year	2 / year
10 000 – 20 000 t	2 / year	3 / year
20 000 – 40 000 t	2 / year	4 / year
> 40 000 t	3 / year	5 / year

Table III.4.4: Frequency of compost inspections in the different countries

Compost inspections are conducted regularly everywhere, although their frequency varies from country to country. The frequency of inspections is determined by the following factors:

- frequency of appearance of polluting material (general state of the environment);
- the range of use possibilities for the raw materials;
- the collection system;
- quantity of waste treated at the composting plant (except for in Austria where the amount of compost produced is taken into consideration);
- relevant quality assurance procedures (if this is a part of the compost certification process).

III.4.4. Comparison of the quality requirements

The classification of composts and their quality requirements differ from each other significantly in terms of the priority of parameters and the quantities of components which are allowed. In Denmark organic pollutants are the greatest problem, and while in Germany heavy metal pollution used to be the greatest challenge, now meeting hygiene-related requirements is top priority.

Basis of classification	Country
Heavy metal content	Austria, Germany, Netherlands, Spain, Sweden
Types of raw materials	Austria, Belgium, Denmark, Germany, Italy, Spain, Sweden
Maturity of compost	Germany, Luxemburg, Spain
Utilization possibilities	Austria, Germany

Table III.4.5: Possible classification system for composts

The classification of composts can be done using numerous parameters. Most countries apply a combination of different classification methods.

Limit values can be determined in two ways: absolute values, where crossing the limit means immediate exclusion and immediate imposition of a sanction, or target values, where the limits may be exceeded, but decisions about individual cases are within the professional competence of the quality assurance organisations. The latter approach has become more widespread because of its more rational nature as the composting plants have no influence on the pollution level of raw materials, and a transgression may affect only one or two parameters for a short time. As a result, in most cases individual assessment is justified.

There are numerous differences in many areas in connection to compost quality requirements in the observed countries. In most of the countries there are no defined minimum values for plant nutrients, but the nutrient content must be indicated on the packaging or the accompanying documentation to assist with its professional utilization.

III.4.5. Pollutants

Two features must be paid attention to with regards to comparing the limit values of the countries: first, whether the values apply to dry matter or to organic matter content; and second, if the values are absolute or only targets.

Country	Regulation	Type of regulation	Cd	Cr_{tot}	CrVI	Cu	Hg	Ni	Pb	Zn	As
Austria	Compost Ordinance: A+ (organic farming)	legislation	0.7	70	-	70	0.4	25	45	200	-
	Compost Ordinance: A (agriculture, hobby gardens)		1	70	-	150	0,7	60	120	500	-
	Compost Ordinance: B (country planning, re-cultivation)		3	250	-	500 (400)*	3	100	200	1800 (1200)*	-
Belgium	Royal Ordinance 07.01.1998.	legislation	1,5	70	-	90	1	20	120	300	-
Denmark	Decree Nr.49; Composts after 01.06.2000.	legislation	0.8	-	-	1000	0.8	30	120/ 60**	4000	25
Finland	Decree of the Ministry of Agriculture and Forestry No. 46/94.	legislation	3	-	-	600	2	100	150	1500	50
France	NF Municipal Compost	standard	3				8	200	800		
Germany	RAL GZ 251 (Bundes Gütegemeinschaft Kompost- BGK)	private criteria system QAS	1.5	100	-	100	1	50	150	400	-
	Biowaste Ordinance 1st class	legislation	1	70	-	70	0.7	35	100	300	-
	2nd class		1.5	100	-	100	1	50	150	400	-
Greece	Special regulations of MSW management and the general programme of waste management	legislation	10	510	10	500	5	200	500	2000	15
Ireland	Licence, convention on plant treatment with EPA	private criteria system	1.5	100	-	100	1	50	150	350	15
	1st class	private criteria system	1	100	-	100	1	50	100	200	
	2nd class	private criteria system	1.5	150	-	150	1	75	150	400	
Italy	Technical regulation, DCI 27/07/84 (MSW)	legislation	10	500	10	600	10	200	500	2500	10
	Draft decree on the utilization of biowastes 1st quality	draft legislation	3	-	3	300	3	100	280	1,000	-
	Law of Nutrient Management (BHK, ZHK, SZIK)	legislation	1.5	-	0.5	150	1.5	50	140	500	
Luxemburg	Licence for plants		1.5	100	-	100	1	50	150	400	-
Netherlands	BOOM Compost	legislation	1	50	-	60	0.3	20	100	200	15
	BOOM Very clean compost		0.7	50	-	25	0.2	10	65	75	5
Portugal	Regulation on Sewage Sludge (the limit values are also applied in the case of TSZHK)	legislation	20	1000		1000	16	300	750	2500	-
Spain	B.O.E.n’m.131.2 ; 02.06.1998.	legislation	10	400	-	450	7	120	300	1100	-
	Draft on Composting (Spanish) AA class	draft legislation	2	250	-	300	2	100	150	400	-
	(Stabilized bio-wastes) A class		5	400	-	450	5	120	300	1100	-
	Catalan draft of composting A class		2	100	0	100	1	60	150	400	-
	(Stabilized bio-wastes) B class		3	250	0	500	3	100	300	1000	-
Sweden	QAS guidelines	private criteria system	1	100	-	100	1	50	100	300	

Country	Regulation	Type of regulation	Cd	Crtot	CrVI	Cu	Hg	Ni	Pb	Zn	As
Switzerland	Decree on environmentally hazardous materials (1996), modified (in 2001)	legislation	1	100	-	100	1	30	120	400	-
United Kingdom	UKROFS allows crop enhancing materials on organic farms – 'composted biowastes'	legislation (2092/91/ EGK decree)	0.7	70	0	70	0.4	25	45	200	_
	Composting Association Quality Label	private criteria system	1.5	100	-	200	1	50	150	400	-
EU Eco Label	Ameliorators and Substrates	private criteria system	1	100	-	100	1	50	100	300	10
889/2008/EC Regulation Appendix I./A	'composts from selective collection system' in connection with permitted ameliorator and crop enhancing materials in organic farming	legislation	0.7	70	-	70	0.4	25	45	200	-
Hungary	36/2006 FVM Decree	legislation	2	100	-	100	1	50	100		10

* Target value: If the value is exceeded, a declaration to this effect must be made.
** In the case of hobby gardens the lower limit value must be taken into account.

Table III.4.6: Heavy metal content limit values for composts - mg/kg DM content

Country	Comments
Austria	The arithmetic average of four samples is taken into consideration and should not exceed the limit values for heavy metals. Individual samples cannot exceed these limits by more than 50%. (The values refer to 30% dry matter content.)
Belgium	There are absolute limit values which are determined based on the target values of the Belgian Ministry of Agriculture.
Denmark	Target values Out of 5 samples, 75% cannot exceed the heavy metal limit values, and individual samples cannot exceed these limits by more than 50%. (The values refer to dry matter.)
Germany	Target values, samples can exceed limits for only one heavy metal by maximum 10%. (The values refer to 30% dry matter content.)
Netherlands	Limit values can by exceeded in one case by a factor of 1,43. (The values refer to dry matter.)

Table III.4.7: Interpretation of limit values

After comparing the results of inspections of composts produced in the different European countries it can be stated that setting limit values for persistent organic pollutants and conducting routine inspections is unnecessary (Amlinger et al. 2004)*. This is why in several countries limit values and inspections are mandated only for hazardous raw materials.

III.4.6. Quality classification of composts

There are different practical methods for the classifying composts on a quality basis. Usually, one or two classes are differentiated between, but market experience clearly indicates that customers only look for the better quality products, so in Belgium - for example - only better quality category compost receives a label. Three categories are used in Austria but certain areas of use may be indicated on the label (e.g. 'suitable for use in organic farming according to 2096/91/EEC Regulation'), or certain raw materials must be referred to in relation to the origin of the final product (e.g. quality sewage sludge compost).

In Germany, the composts must be classified according to their maturity level, particle size and salt content, corresponding to their likely area of utilization.

Country	**Compost categories**
Austria	Three quality categories: A+; A and B
Belgium	1 biowaste and 1 green waste
Germany	Fresh and mature compost, mulch, substrate (aggregate)
Netherlands	2 categories: classified compost and premium classified compost

Table III.4.8: Quality categories in some EU member states

In general, it can be stated that well-functioning quality assurance systems that have functioned for a very long time and have many decades' experience are guaranteeing the quality of composts that appear on the market in Europe. As the quality assurance systems were first initiated on a community base everywhere, the requirements defined by private organisations towards their members are much stricter in many cases than those defined by legislation. It is not by chance that trust is significantly higher and prejudice arising from lack of knowledge lower towards crop-enhancing products that originate from organic wastes and composts in these countries. Naturally, this phenomenon can also be recognised in data about the amount of compost that is purchased and utilized, which is a significant consideration in the economic, perhaps even profitable management of composting plants.

III.4.7. Utilization opportunities for composts

Country	Method of utilization, highest permitted quantity
Austria	Agriculture: 8 t/ha dm content, 5 year average Town planning: 400 - 200 t/ha dm over 10 years, depending on quality Not for food production: 20 – 40 t/ha dm content over 3 years, depending on quality
Belgium	Defined heavy metal load. Rationing is defined by N and P input according to good agricultural practice
Denmark	Food production: 7 t/ha dm content, 10 year average Not for food production: 15 t/ha/year dm content, 10 year average, taking into account that the absolute limit is 210 kg/ha/year nitrogen and 30 kg/ha/year phosphorus.
Finland	Defined heavy metal load. (sewage sludge regulations)

Country	**Method of utilization, highest permitted quantity**
France	Defined heavy metal load. (compost regulations)
Germany	Agriculture: 10 or 6.7 t/ha/year dm content, 3 year average
Greece	No regulations
Ireland	No regulations
Italy	Food production: defined heavy metal load Town planning: 100-300 t/ha/year dm content based on preliminary risk assessment (load calculation)
Luxemburg	No specific regulation; suggested (criteria system): 15 t/ha/year dm
Netherlands	Agriculture: normal compost – plough land 6 t/ha/year, 2 year average Turf, grazing land: 3 t/ha/year, 2 year average Very clean compost max 80 kg/ha/year P205 New strategy: based on scale calculation normal compost – plough land 6 t/ha/year, Very clean compost max 20 kg/ha/year P205
Portugal	Defined heavy metal load. (sewage sludge regulations)
Spain	Defined heavy metal load. (10 year average)
Sweden	Defined heavy metal load. (sewage sludge regulations) Agriculture: maximum amount of nitrogen 150 kg/ha/year and phosphorus 22-35 kg/ha/year
Switzerland	Agriculture 8.3 t/ha/year, 3 year average
United Kingdom	Defined heavy metal load. (sewage sludge regulations) Based on good agricultural practices nitrogen input of 250 kg/ha/year

The uses of composts are very diverse in the EU member states for the following reasons:

– there are significant differences in the pollutant levels in the individual countries;

– soil protection falls under national jurisdiction, thus there are considerable differences in member state policy;

– systems for composting selectively-collected biowaste is under development or is not yet widespread. So, primarily in those countries where quality assurance systems for composting are not yet developed, the procedures for treating sewage sludge are applied;

– in those countries where quality assurance systems that cover the entire process of composting have been developed, there are simple rules for utilizing composts.

III.5. Biogas production from organic wastes

(Imre Kalmár)

III.5.1. Significance of biogas production

Biogas production needs to be considered from at least four important points of view. These are energy, environmental sustainability, climate change and economics. Biogas (which contains methane) is a renewable energy source as well as a "greenhouse gas". Biogas as a renewable energy source has been gaining more and more significance, and due to increasingly extreme and visible climate phenomena the environmental importance of biogas production and utilization is increasing.

The gas created in the largest amounts during the process of organic matter degradation in anaerobic circumstances is methane, which is a high energy gas. Methane is 20 times as potent a greenhouse gas (GHG) as CO_2 so it is of great importance that the biomass that regularly regenerates itself on Earth should be re-circulated into the primary biomass production cycle only after it has been utilized to the largest possible extent.

Treatment of potential environmentally-polluting organic matter by-products and wastes, produced in concentrated form is especially important for saving natural resources. Organic by-products and wastes, degrading only very slowly in natural circumstances, can be transformed into valuable and useful materials in a short period of time in biogas plants. Methane, produced as a result of the degradation of anaerobic organic matter, can be utilized as a renewable energy source, while the fermented organic by-products and waste can be recycled into plant biomass production as soil enhancers.

Organic matter aggregation and degradation is typically in a dynamic equilibrium in a natural ecosystem. In the ecosystems that are influenced by 'artificial' production technology systems, this dynamic equilibrium can be maintained only if the materials that originate from the use of renewable natural resources are consciously recycled during production cycles. Nutrients, extracted from the soil during plant biomass production, are returned to the soil by recycling the degraded, mineralized organic materials that remain at the end of biogas production and utilization. By burning the methane content of the biogas, the only CO_2 that returns to the atmosphere is that which is built into the organism of the plant during the process of photosynthesis during the production phase.

Thus, by-products and wastes that are generated in agriculture and the food industry should be seen as the value-bearing raw materials of biogas production and not as disposable materials which will generate further costs.

Biogas production and utilization facilitates renewable energy production, waste and by-product utilization, more conscious management of our natural resources, climate protection and the safeguarding of soils.

III.5.2. Technological principles of biogas production

Biogas production involves creating the very same anaerobic organic matter degradation processes in artificial circumstances that take place in the natural environment. In nature, organic matter is degraded into minerals (which plants can later take up) by microorganisms under anaerobic circumstances. The methane and carbon-dioxide produced in the degradation process are the metabolic products of the bacterial strain that conduct the degradation.

During biogas production, biomass of human origin is degraded in artificially anaerobic circumstances using biotechnological methods and is transformed into inorganic materials which cultivated plant organisms are able to take up. The naturally slow and time-consuming process is accelerated by regulating the parameters which influence degradation. During natural anaerobic degradation the gases which are generated exit into the environment, while the artificially (in a closed space) produced biogas is captured and collected for the purposes of utilization.

So biogas production is a technological system that incorporates a biotechnological procedure to produce methane for energetic utilisation and $CO_{2,}$ as well as materials with mineralized components suitable for use by plants from biomass, and also by-products and wastes.

A biogas production system and its operations are determined collectively by its individual subsystems, their elements and their relationships, the technology that is used and its operating parameters, as well as the material inputs.

Biogas production is thus an energy transformation system, the inputs of which are biomass and biomass-based technological wastes and by-products. Heat energy and human resources are also necessary for sustaining the technological process. The information necessary for successful operations includes the input and output characteristics, as well as the operational parameters which must be followed to meet regulations. The main end product of biogas production is biogas with a high methane content, and its by-product is fermented material that can be utilized in crop production to supply nutrients. From the components of biogas CO_2 can be absorbed by plants after it returns to the atmosphere; the other components and gas pollutants need to be removed based on their proportions and the method of biogas utilization. On the output side, from the human resources point of view, creation of health hazards must be avoided.

It is also a defining prerequisite that harmful effects of the system on the external environment must be prevented. Instructions related to the storage of the fermented liquid manure, the creation of the related storage area and the extraction of the product are all oriented to prevent soil-damaging effects because of the concentrated load of biogas. Odour emissions in the area of biogas plants and their surroundings are due to the presence of hydrogen sulphides and ammonia in the input materials. The gaseous-odour-emitting components are separated out from the biogas before utilization, and the well-fermented manure that leaves the fermentors cannot contain hydrogen sulphides or ammonia at a high concentration that is dissimilar to that of the input materials. Odour emissions can be reduced by storing and transporting the input materials in a closed system.

III.5.3. Wastes suitable for biogas production

In theory, in an anaerobic, humid environment biogas with methane content can be extracted from all kinds of biomass. However, in practice the degradation of biomass with low moisture content and poorly-degradable solid structural material (lignin, cellulose) is done aerobically, by composting. Anaerobic degradation in biogas plants is typically applied to organic by-products and wastes with high moisture content.

In Hungary there are three areas of agricultural production and product processing in which enough by-products and wastes with the right components are produced to make them potentially suitable for industrial sized biogas utilization. Taking into consideration the present circumstances, these are the three areas:

- large scale stock breeding,
- sugar production,
- alcohol production.

While a great number of biogas production facilities have been built in Western European countries to utilize the biomass by-products that originate from family-sized farms, in Hungary the biogas plants that have been established to utilize biomass of agricultural origin rely almost solely on different types of manure that come from large-scale pig, cattle and poultry farms.

The dry matter content of the liquid manure to be utilized as raw material should not exceed the permitted 10-12%, as defined in the technological regulations for wet fermentation biogas digesters. To increase the amount of extractable biogas and methane in a given-sized biogas producing facility, other biomass by-products and wastes are also used at almost all biomass plants.

The quantity and quality of the biogas that is produced in the plants is determined collectively by the quality and quantity characteristics of the input materials, the technology that is used and its parameters.

The input material features that determine the production of biogas and its methane content are the following:

- the composition of the base materials and the aggregates,
- the quantity of the specific extracted biogas and methane,
- the organic and dry matter content,
- the C/N ratio,
- pH,
- the physical features of the material,
- the presence of inhibitors.

III.5.3.1. Composition of base materials and aggregates

Agricultural and food industry by-products and wastes always contain carbohydrates, proteins and fats, to a variable extent. Those of plant origin mainly contain carbohydrates, while those of animal origin mainly contain proteins and fats. Carbohydrates and fats are built up of carbon, hydrogen and oxygen, while proteins also contain a great amount of nitrogen and some sulphur, beside carbon, hydrogen and oxygen. The anaerobic degradation process of organic matter that has diverse chemical components is also different. The quality and chemical composition of the base materials and aggregates has a defining effect on the speed of degradation, the gas production intensity and the composition of the produced biogas. The cumulative specific biogas yield of different manures under identical degradation conditions is illustrated in Figure III.5.1.

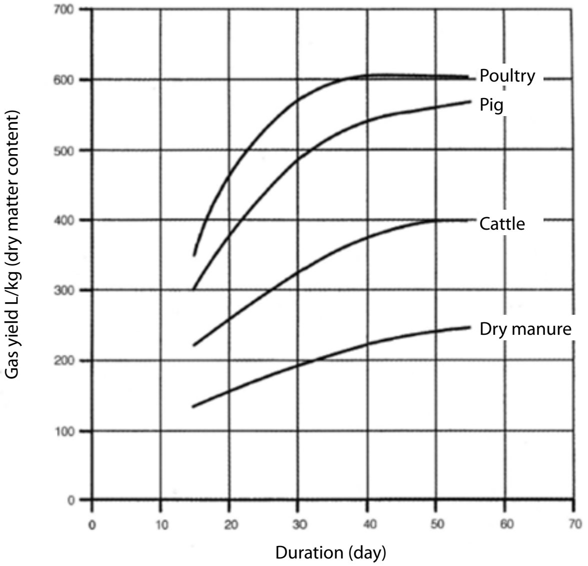


Figure III.5.1: Typical specific biogas yields of different manures over time

The differences in the quantity and the degradation intensity of the biogases produced under identical conditions can be also explained by the different compositions of the manures.

Beside the base material manure types, the parameters of the degradation process and the outputs are influenced by the aggregates which are used. Furthermore, the species, the breed, the age, the feed, the nutritional status and the state of health also have an influence in the case of by-products of animal origin and wastes, while in the case of material of plant origin, the species, the breed, maturity, the part of the plant which is used and the year of vintage are influential.

III.5.3.2. Extractable biogas yield from wastes

Depending on the place of origin, the technology that is used and the technological parameters, a different amount of biogas and methane will be produced from the manure of particular animal species and the different aggregates. Tables III.5.1 and III.5.2 contain specific biomass and methane production data in relation to the particular materials that can be processed. The data is based on different authors, and the table includes the average values derived from these data.

Type of manure	Quantity of extractable biogas		Quantity of extractable methane (calculated data)	
	Min-max	Average	Min-max	Average
	m³/t organic dry matter		m³/t organic dry matter	
Pig liquid manure	340-550	455	187-385	286
Poultry manure (chicken)	310-620	465	140-434	287
Poultry manure (turkey, goose)	455-505	480	205-354	279
Farm manure (livestock manure)	175-280	225	84-182	133
Cattle liquid manure	90-310	200	41-217	129

Table III.5.1: The quantity of biogas and methane extractable from liquid manures of different origins
(based on Tóth P. et al; Woperáné S. Á., 2010; Barótfi I, 2003; Czupy I.-Vágvölgyi A., 2011)

Different amounts and compositions of biogas can be extracted from the main components of the different agricultural and food industry by-products and wastes. According to different sources, 1250-1535 m^3/t organic dry matter (odm) can be extracted from fats with an average 63-72% methane content, 587-700 m^3/t odm from proteins with an average 60-84% methane content, and 790-888 m^3/t odm from carbohydrates with an average 50-66% methane content.

Aggregate	Quantity of extractable biogas		Quantity of extractable methane (calculated data)	
	Min-max	Average	Min-max	Average
	m³/t organic dry matter		m³/t organic dry matter	
Corn stalks	380-460	420	171-322	247
Types of straw	170-310	240	77-217	147
Sunflower stalks	279-321	300	126-225	175
Cut sugar beet top	400-500	450	180-350	265
Carrot slices	35-75	55	16-53	35
Grass	280-550	415	126-385	256
Reed-rushes	170-260	215	77-182	129
Alfalfa	430-490	460	194-343	268
Vegetable waste	330-360	345	149-252	200
Leaves	210-290	250	95-203	149
Mixed agricultural waste	310-430	370	140-301	220

Table III.5.2: The quantity of biogas and methane extractable from different aggregates
(Based on Tóth P. et al; Woperáné S. Á., 2010; Barótfi I, 2003; Czupy I.-Vágvölgyi A., 2011)

III.5.3.3. Organic and dry matter content

The organic and dry matter content of base materials and aggregates are very important parameters from the biogas production point of view as biogas is produced from organic dry matter. By increasing the dry matter content of the degradable material that is loaded into the fermenting area to the permitted level, the quantity of biogas and methane that can be produced also increases. The maximum dry matter content in the case of the use of moist continuous technologies is 10-12%. The fermentor load can be determined based on knowledge of the dry matter content (Table III.5.3).

Organic matter	Dry matter (dm)	Organic dry matter (odm)	C/N
	%	%	
Brewer's grains	20-22	87-90	10
Hop grains	97	90	12
Dry bread	90	96-98	42
Potato swill	12-15	90	13-19
Grain swill	6-8	87-90	10-11
Molasses	80	95	14-27
Whey	80	95	14-27
Fruit waste	45	93	50
Oil seed press remnants	92	97	9-12
Extracted rape grist	88	93	8

Table III.5.3: Main characteristics of some food industry by-products and wastes *(Based on Kacz K., 2011)*

III.5.3.4. C/N ratio

Every living being, including the microorganisms that participate in biogas production, needs nitrogen, carbon and phosphorus to build up the important macromolecules (e.g. proteins or nucleic acids) their organisms are composed of. These nutrients are obtained from the degradable organic matters in the amount which is necessary for multiplication. According to Liebig's law of the minimum, for the appropriate growth of microorganisms all nutrients must be present in the optimal ratio, corresponding to the demands of the microorganisms. The rate of multiplication will be determined by the component which is present in the smallest quantities. This is why, from a speed and efficiency of degradation perspective, the C/N and C/P ratios of the base materials and aggregates are extremely important. Research results and practice have proven that the optimal C/N ratio is 30:1, but 25:1 is tolerable, while the optimal C/P ratio is 150:1. (Tamás J. - Blaskó L., 2011). In the case of a larger C/N ratio than is optimal (i.e. there is too little nitrogen compared to carbon) carbon utilization will not be complete, a great amount of non-degraded organic matter will remain in the mature organic manure and less biogas and methane will be produced. If the nitrogen is consumed in the degradable material and there is no further supply, the process may come to a halt due to the decay of the bacteria. If the C/N ratio is less than the acceptable ratio (i.e. there is too much nitrogen compared to carbon) this may lead to the accumulation of ammonia. The optimal C/N ratio can be ensured by using an appropriate mix of base materials and aggregates with different C/N ratios (Tables III.5.3 and III.5.4).

Organic matter	C/N ratio
Cattle manure	17-25
Pig manure	6-13
Poultry manure	5-7
Wood, sawdust	200-500
Kitchen wastes	30-40
Hay, grass, green wastes	10-20
Hay	13-25
Oat straw	50
Slaughterhouse wastes	2-4

Table III.5.4: C/N ratio of different wastes *(Based on Kacz K., 2011; Tóth P. et al.)*

The C/nutrient ratio in relation to other nutrients does not cause a problem in most cases because the degradable organic matter contains them in the appropriate quantities.

III.5.3.5. pH

As a slightly acidic or neutral pH is most appropriate for the organisms participating in anaerobic degradation, the pH of the degradable organic matters should also occur in this range. The pH of pig manure and some aggregates which are base materials for biogas production are acidic or neutral. The main volume of degradable material is liquid manure – even with co-fermentation technologies – which is neutral. Because there are usually only a few percent of co-ferments (aggregates), ensuring the optimal pH for the degrading organisms is not a problem. After initiation of biogas production the buffering effect of the products which are created will prevail and thus the stability of the pH can be guaranteed.

III.5.3.6. Physical characteristics

The most important characteristics of the base and co-fermented materials in relation to biogas production are the shredded size of the loaded solid components and the mass/volume ratio of solid parts. The size of chips is critical in terms of their physical accessibility to the microorganisms that participate in the anaerobic degradation process. Potentially arising co-ferment components may influence biogas production, have an effect on the characteristics that influence gas development, inhibit the departure of the gases that are created, influence the ability to mix the fermentor content and thus the mixing cycle and they may also decrease the degree of degradation and increase maturation time.

III.5.3.7. Inhibitors

Materials may appear in agricultural and food industry origin by-products and wastes that inhibit the multiplication and operation of microorganisms that participate in biogas production. The majority of them are potential inhibitors as they only exert an inhibiting effect at over a certain concentration, which is typical of a specific material (Table III.5.5).

Toxic elements or inhibitors	Unit	Threshold concentration
Na^+	g/dm^3	6-30
K^+		3
Ca^{2+}		2,8
Mg^{2+}		2,4
NH_4^+		2,7-10
NH_3		1,5
H_2S	mg/dm^3	>50
S^{2-}		>100
Na_2S		160
Ni^{2+}		10
Cu^{2+}		40
Cr^{3+}		130
Pb^{2+}		340
Zn^{2+}		400
Branched chain aliphatic acids		iso-butyric acid >50

Table III.5.5: Threshold concentration for the inhibitory effects of inhibitors that potentially exist in base materials and aggregates used in biogas production *(Source: Tamás J. - Blaskó L., 2011)*

The possibly intensifying metabolism of the acid-producing microorganisms of biogas production and volatile acids may have inhibitory effects at a concentration of over 10 g/dm^3. Oxygen and other compounds (e.g. nitrate, sulphate and trivalent ferric ion), as well as light, also have inhibiting effects. During anaerobic degradation the nitrogen and sulphur content of proteins becomes ammonia and hydrogen sulphides. In moist circumstances, maintaining a constant temperature depends on the pH function of NH_3/NH_4+ and the H_2S/S_2 ratio, while the balance shifts towards free ammonia with an inhibiting effect in an alkaline media, and towards free hydrogen sulphides in an acidic media. The threshold concentration levels for the poisonous effects of heavy metals are summarized in Table III.5.1.

III.5.4. Technological system for biogas production

Regardless of the objective of the application of the technology, there are actually two final products of biogas-fermentation processes, both of identical importance. Beside methane-containing biogas, a liquid fermented material also remains which can be recycled in agriculture as a soil enhancer. The amount of biogas that is extractable from a unit organic matter is determined by the degradable material characteristics – which also influence the technology that is employed –, as well as the interrelated technological parameters.

III.5.4.1. Process of biogas production

The most suitable biogas production technology to be used in any given circumstances is determined by the specific possibilities for utilization of the biogas and fermented manure which will be produced, and by the quality and quantity characteristics of the available organic matter. A functional draft of the process of biogas production is presented in Figure III.5.2.

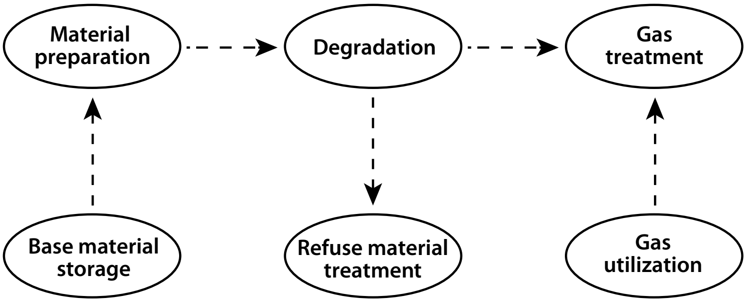


Figure III.5.2: The technological process of biogas production

Several functioning variants of such technological systems are known and are used in practice for biogas production and utilization, but all of them have the main function of biogas production and utilization, as well as correct storage of fertilized manure.

III.5.4.2. Preparatory procedures

Among the input materials, liquid manure is delivered to the biogas plant in the appropriate amount according to the daily scheduling of the degradation process, so it is regularly bought in to the preparatory area. The other co-fermenting materials usually need to be stored. Co-ferments of plant origin need to be stored in some format because of the seasonal nature of their production. Corn and sweet sorghum are stored in silos. Co-ferments of animal origin waste, such as slaughterhouse wastes and animal corpses, need to undergo heat treatment in order that the potentially pathogenic organisms which may found in them are destroyed. Following this they have to be stored until they are needed, as specified by the timing of utilization. Preparatory procedures include the shredding of co-ferments by which the microorganisms participating in the degradation are provided with better physical access to the degradable materials. The co-ferments have to be added to the liquid manure in the amounts defined in formulae and they should be in the form of a homogenous mix prior to being loaded into the degradation area.

III.5.4.3. The breakdown of organic matter

Degradation is the main functional process which occurs during biogas production. Optimal conditions need to be ensured in the degradation area for the degradation of base materials and aggregates. The fermenting area should be closed and be heatable, and the ability to mix the materials must be ensured. In the case of continuous production of biogas the gases are stored partly or completely in the fermenting area. The challenge of loading the input materials and extracting the outputs from the fermenting area must also be dealt with.

Practically, degradation is the last phase of biogas production; all the subsequent procedures are part of utilization.

III.5.4.4. Handling of output materials

The liquid phase, after it exits the fermentor, is either taken to phase separation or to storage depending on the process which was used to produce it. The solid fraction which remains after phase separation is also a valuable by-product which can be composted or recycled into the soil as nutrient supply.

The biogas that is produced always contains components that must be removed from the raw gas before utilization. Regardless of how the gas is utilized, water and hydrogen sulphides must be removed. If the biogas is not to be used for direct burning, the carbon-dioxide must also be removed prior to utilization to increase the efficiency of energy extraction.

III.5.5. Operational methods of biogas plants

According to their operational methods there are two basic types of production that can be distinguished: periodic and continuous biogas production.

It is characteristic of periodic biogas production procedures (BATCH procedure) that the fermentor is totally filled up at one go to a pre-defined level with degradable material (of a certain dry matter content), the fermentation time lasts till the degradable material is fermented, the gas that is produced is stored and utilized, and at the end of the production cycle the fermented material is removed. Numerous variations of this procedure are known, and the process is typical of small scale industry.

In the case of continuously operating biogas production technologies the degradable material is taken from a preparatory-homogenizing container to the fermentors according to a defined loading cycle. From here the fermented material is moved to the fermented matter container according to the tempo of loading. The ongoing operation is only stopped for technological reasons when heavy residue deposits need to be removed. Continuous operation processes are the most widespread of all the operational approaches. This is the only method of biogas production that is used in practice in Hungary. There are many variants on this procedure. It is typical of continuous procedures that the fermenting area is also the biogas storage space. In this case the continually-created biogas must be continuously used or the pace of production must be managed, as without this overpressure may be created and may slow down the production of the biogas. If a separate biogas container is used, depending on the capacity of the container, the pace of biogas utilization may differ from that of its production.

III.5.6. Factors influencing biogas production

Biomass that is found in fermentors can be considered living matter as the operation of microorganisms found within them is exploited to facilitate the anaerobic degradation of organic matter and the production of biogas. Naturally, this is why the ecological demands of microorganisms that participate in biogas production have to be taken into account when selecting the base materials and the technological parameters so that these ecological demands can be optimally fulfilled at every moment. In biogas production the acidifying and methane-producing bacteria that participate in the production of gas perform their activities in parallel, even though their ecological demands are different (Table III.5.6).

Characteristics	Acidifiers	Mesophilic methanogens
Oxygen demand	Mainly facultative anaerobic	Exclusively obligate anaerobes
Temperature optimum (°C)	30	35-37
pH	5.3-6.8	6.8-7.2
Multiplication	Nutrient-dependent, quick (relatively short generation time)	Nutrient and milieu-dependent, very slow (very long generation time)
Mixing (material transport)	Providing the ideal material flow	Less intensive mixing

Table III.5.6: The different characteristics and ecological demands of acidifying and mesophilic methane bacteria *(Source: Tamás J. - Blaskó L., 2011)*

For maximum biogas yield, the applied technology has to optimally meet the ecological demands of the microorganisms that participate in the degradation process at the same time and in the same space. But in practice, these different ecological demands can only be fulfilled through making compromises. The technology that is used is based on an appraisal of typical technological parameters that result in maximum biogas yield.

Technological considerations for the wet, continuous processes:

- anaerobic environment,
- moisture content of the degradable media,
- temperature,
- pH,
- fermentor load (balanced material supply),
- average time spent in fermentor (fermentation time),
- mixing (intensity, duration),
- lighting,
- specific gas production,
- degree of degradation,
- gas yield,
- net gas yield.

III.5.6.1. Anaerobic environment

The necessary anaerobic environment – free from oxygen – is automatically created by the development of a closed fermentation area. In the case of continuously-operating biogas production technologies the oxygen is removed from the fermenting area by the biogas produced during the loading phase. The methanogenic bacteria that participate in biogas production develop strictly in an anaerobic environment. Oxygen kills them as their enzyme system is not capable of neutralizing the harmful free radicals created in its presence. Among the technological parameters, oxygen content should be continuously monitored during fermentation.

III.5.6.2. Moisture content of the degradable media

Microorganisms – naturally, including the bacteria that participate in biogas production, among them also the methanogens – are able to take up nutrients through their cell membranes only if these nutrients are soluble. To take up nutrients the different microorganisms require different moisture contents. Methanogens multiply and work most intensively in a media with a moisture content of at least 50%. Water is needed not only for the nutrient uptake of microorganisms, but also for the hydrolysis which occurs during the first phase of biogas production as water is one of the reaction partners in this biochemical reaction.

III.5.6.3. Temperature

According to the literature, biogas production is possible at a temperature range of between 3 - 90 °C. However, the different methanogen strains function optimally at different temperature ranges within the two extremes (Table III.5.7).

Microorganism group	Temperature (°C)		
	Minimum	Optimum	Maximum
Thermophilic	40	50	80
Mesophilic	5	30	45
Psychrophilic	-10	15	20

Table III.5.7: Optimal operational temperature ranges of microorganisms *(Source: Mocsáriné F. CS)*

In the practice of biogas production, mesophilic (temperature optimum between 30-37 °C) or thermophilic bacteria (temperature optimum between 50-60 °C) are used, depending on the presence of pathogenic agents and their quantity. Naturally, thermophilic technologies that operate at a higher temperature result in faster degradation and a technologically higher specific gas yield, but the energy demand of these technologies is also higher than that of the mesophilic systems. Bacteria are very sensitive to temperature fluctuations. Daily temperature can fluctuate by no more than 2-3 °C in the mesophilic process and only 1 °C in the thermophilic without causing a decrease or a halt in the biogas production.

III.5.6.4. pH

In the anaerobic degradation processes the optimal pH range for the multiplication of acidifying bacteria is between 5.3-6.8 pH, while for methanogens it is between 6.8-7.2 pH. A neutral pH is acceptable for both acidifiers and methanogens, so this pH should be created and maintained during fermentation. If the methanogens are not able to transform the acids created by the acidifiers into methane at the required pace, this may lead to the acidification of the media. A pH of below 6.0 indicates that methane production has stopped.

The CO_2 produced due to the activities of acidifiers during the process of the anaerobic degradation of different organic matters dissolves in a wet environment during the formation of hydrogen carbonates. Carbon-dioxide, hydrogen carbonates and ammonia, created in a reductive environment, form a buffer system which determines the buffering capacity of the media and thus the pH stability of the system.

A change may occur in the pH of the system if its load suddenly changes, or if the system becomes overloaded. Because the fermentors enable faster degradation than the methanogenic microorganism species allow, acid builds up in the media. Other types of operational problems, such as sudden changes in temperature or the abrupt effects of toxic pathogens may also result in equilibrium disorder, which is indicated by a decrease in pH.

III.5.6.5. Fermentor load (balanced material supply)

Ensuring the balanced loading of fermentors which aligns with the degradation capacity of the microorganisms is a prerequisite for guaranteeing gas production. Due to a balanced material supply the fluctuation in the intensity of gas production and daily fermentation efficiency will be less. The fermentor load also depends on the quality of the aggregates that are loaded into the biogas plant which is using co-fermenting technology. Overloading with aggregates that have many easily-degradable compounds may result in the acidification of the reactor content, which after a while may lead to decreases in the pH that methanogens cannot cope with. If they perish, gas production will stop. If the overload occurs with materials with high protein content, the amount of ammonia that is created will increase. This can lead to an increase in pH to beyond a level that the bacteria participating in the gas production can tolerate. The poisonous effects of ammonia may also be felt.

III.5.6.6. Average time spent in fermentor (fermentation time)

The average fermentation time depends on the chemical composition of the base material and the ratio and temperature of the different-sized solid parts. The planned fermentation time has a significant effect on the quantity of gas that is produced, the intensity of gas creation, the degree of degradation and the gas yield as well. The longer the average time spent in the fermentor, the greater the necessity for large-scale fermentation.

III.5.6.7. Mixing (intensity, duration)

The fermentor content needs to be homogenized in order to increase biogas yield. Fresh materials and materials which have already entered the fermentation process may separate in the fermenting area during material input and the organic material remnants containing gas particles may also float to the top during degradation. The fermentor content needs to be rotationally mixed several times a day to ensure that the technologically-optimal circumstances necessary for the degradation processes exist. The functions of mixing are the following:

- to ensure a balanced temperature in the fermenting area,
- to inoculate fresh input material with the bacterial strains that are participating in the degradation,
- to provide the best possible material flow for quick hydrolysis, the transportation of the products of the acidic phase to the methanogens, as well as the transport of the products of metabolism,
- less intensive mixing because of the tight symbiosis between the acetogens and methanogens.

III.5.6.8. Lighting

Besides anaerobic conditions, low or no light conditions are very typical of the natural habitats of methanogenic bacteria, so light exclusion must also be ensured during biogas production. This can easily be guaranteed by providing an airtight degradation environment. The walls of the fermentors are made of reinforced concrete or metal while their doors are made of non-light-penetrating materials or can be covered with them.

III.5.6.9. Degree of degradation

The degree of degradation can be defined as the percentage ratio of the organic matter of the input and output liquid phases. The degradation of the micro-molecules which are always present in the degradable materials takes place at different rates of efficacy. Among carbohydrates, proteins and fats, the latter can be degraded the most easily in anaerobic conditions, while proteins are degraded least easily. The degree of degradation in the case of fats is about 65% and in the case of carbohydrates 50-52%, while it is only about 40% for proteins. There are significant differences between the degradability of specific carbohydrates too: simple carbohydrates can be degraded easily in an anaerobic environment during biogas production. While among the complex carbohydrates starch can be degraded relatively easily, cellulose, hemi-cellulose and lignin may be broken down with great difficulty or not at all. Non-degraded materials remain unaffected in the fermented organic manure and will mineralize only in an aerobic environment after a longer period of time.

III.5.6.10. Specific gas yield of gas production

The amount of biogas and methane produced by a biogas production facility is the main characteristic of that plant according to the objectives of its operation. The quantity of biogas produced on a daily basis is an absolute indicator which illustrates the size of the plant and the technology that is used, as well as the quantity and composition of the input organic matter. The amount of gas that is produced and the intensity of gas production should be indicated in a specific way as m^3 biogas (and/or methane) / kg dry matter content (or dry organic matter), or m^3 biogas (and/or methane) / fermentor volume / day. By using these specific indices the different biogas producing technologies and recipes may be compared.

III.5.6.11. Net gas yield

Heat energy is needed by biogas producing technologies to heat the fermentors, and electrical energy is needed to operate certain equipment. The net gas yield is the difference between the total amount of methane that is produced and the amount of gas (energy) used for the operation. If the energy gained from the biogas that is produced is used for heating the fermentors, the net gas yield simply equals the amount of gas that remains to be sold or further utilized. In a combined electric and heat energy production operation, the heating of the fermentors is done with the heat energy generated through the operation of the gas engines. In this case, instead of the net gas yield, the net electrical energy can be easily defined as the amount of electric energy that is sold.

III.5.7. Output materials from biogas production

On the output side of the biogas production process are the biogas that is created and the fermented bio manure. Biogas refers to the gaseous components, while fertilized bio manure includes the degraded liquid manure and aggregated components of the anaerobic biological procedures, as well as the liquid biomass remnants.

III.5.7.1. Composition of produced biogas

- methane
- carbon-dioxide
- other gases

The composition of the biogas that is produced is primarily determined by the composition of the initial materials, but it also depends on the technological process that is used. Its methane and carbon-dioxide content can vary across a wide range, while a higher hydrogen sulphide and ammonium content would be expected if input materials of animal origin (or with high protein content) are used (Table III.5.8).

Input materials	CH_4	CO_2	H_2	N_2	H_2S	Other (O_2, CO, H_2O, etc.)
	%					
Organic matter	50-84	50-15	0-0.2	0-0.2	0-0.2	
	45-70	30-55	tr*	tr*	tr*	
	55-70	27-44	0-4	0.1-1	0-2	0-1
	50-70	28-48	1-2			
Cattle manure	65					
Chicken manure	60					
Pig manure	65-70					
Stable manure	50-60					
Straw	59					
Fresh grass	70					
Elephant grass (Michantus)	60					
Agricultural waste	60-70					
Leaves	58					
Sunflower leaf and stem	58					
Algae	63					
Hemp	59					
Flax stem	59					
Sewage sludge	70					
Solid municipal waste	50					
Proteins	60-84		6-8			
Fats	67-72					
Carbohydrates	50					

* In trace amounts.

Table III.5.8: Composition of biogas produced using different base materials and aggregates

(Czupy I. - Vágvölgyi A, 2011; Tóth P. et al.; Woperáné S. Á., 2010; Barótfi I., 2003; Mézes L., 2011; H., Schulz- B., Eder, 2005)

III.5.7.2. Characteristics of fermentation residues (digestate)

The matter that remains after fermentation does not contain any pathogenic microorganisms due to its former preparation and the anaerobic degradation process. Its odour is not as strong as that of the input materials and its texture is homogeneous - similar to compost -, thus it can be easily treated. After administering it to farmlands it is absorbed into the soil and contains easily-accessible nutrients in the right concentration for plants; moreover, its nitrogen content dominates so it can be utilized as manure. The organic matter demand for energy production and soil management can also be ensured by biogas production.

- organic and dry matter content,
- nutrient content (total N, NO_3^-, NH_4^+, K_2O, P_2O_5),
- micro element content,
- toxic elements,
- bulk density
- total amount of water-soluble salt.

III.5.8. Opportunities for utilizing the output materials of biogas production

III.5.8.1. Gas utilization

Basically, there are three different methods of energetic utilization.

- direct sale and utilization of methane gas
  - feeding into a public natural gas utility
  - compressed
- production of heat energy by burning the biogas
- production of electrical energy
  - combined electric and heat energy production
  - direct electric energy production by fuel cells.

III.5.8.2. Direct sale, utilization of methane gas

The biogas, cleaned to the quality defined by strict product delivery regulations, can be fed into public natural gas utilities, as well as used in other opportunities as presented in legislation. There are pilot projects that utilize compressed, tank-based methane gas to power buses in Hungary, but the necessary infrastructure and their high expense mean that they cannot be expected to become widespread in the near future.

III.5.8.3. Heat energy production

In places where there is an opportunity to utilize the heat energy gained from the biogas produced from the processes of using organic wastes and by-products or other technological procedures, this is done by direct burning. In these cases the technological heat demands of fermentors must also be covered from the produced biogas.

III.5.8.4. Production of electrical energy

The energy from the methane content of biogas can also be transformed into 'green' electrical energy and may be fed into a so-called island mode facility, or into a public electric utility network.

III.5.8.5. Combined electric and heat energy production

Electrical energy is typically produced from biogas through several energy transformation procedures. Mechanical energy is generated by burning biogas in engines or turbines which is then transformed into electrical energy with the help of generators. Every energy transformation process involves the loss of some energy too. The majority of waste heat energy can be utilized for heating fermentors, thus increasing significantly the energetic efficiency of biogas production technology. It is important from the perspective of the efficiency of the plant that all waste heat should be utilized.

III.5.8.6. Direct production of electrical energy using fuel cells

The use of fuel cells offers the technological opportunity for the transformation of methane into direct electrical energy, but its widespread utilization is hindered by the high cost of the technical equipment required for this purpose.

III.5.8.7. Utilization of the remnants of fermentation

Fermentation remnants can be utilized in agricultural production as soil fertilizers by spreading them directly, or after further composting.

III.5.9. Technical equipment for biogas production

The physical production of biogas is done using production facilities, the technical equipment within it and its components. The main functional elements of the equipment include:

- base material container, homogenizer,
- fermenting equipment, fermentors,
- gas cleaning equipment,
- possibly compression equipment,
- gas containers,
- material flow and transmission equipment,
- control equipment,
- safety equipment [Barótfi, 1998].

The main function-supporting equipment was in place at the first biogas production facilities, but it has since gone through constant development. The most important features that determine structural establishment are the size of the plant, the operational method that is used and the means of future utilization of the biogas.

In Hungary, biogas plants that use the biomass by-products and wastes of agricultural origin are large, continuously-operating combined heat and electric energy-producing facilities. This is due to the quality and quantity composition of the potentially-available utilizable organic matter and economies of scale, as well as the opportunities available for using the output materials.

III.5.9.1. Base material container, homogenizing equipment

Biogas production as a biotechnological industrial procedure is sensitive towards the homogeneity of the input materials. Aggregates, necessary for making the continually-produced liquid manure, need to be stored to ensure that the ingredients remain homogenous throughout the annual cycle of production. The solid-walled silos that are used in agricultural production are appropriate for storing the biomass base materials of plant origin.

By-products, wastes and dead animal carcasses that originate from animal production need to be homogenized (shredded) and treated with heat, according to specifications. The storage area of the fermentable biomass to be daily used is usually a solid-walled closed area equipped with mixing equipment. Storing and mixing the fermentable material in a closed space, as mentioned above, significantly reduces the odour impact in the surroundings of the biogas plant.

III.5.9.2. Fermenting equipment, the fermentors

Fermentors are the most important structural units of the biogas plant as the biotechnological process of biogas production takes place in them. The necessary conditions for the optimal production of biogas should be created in the fermentors according to prescriptions. Fermentors are the physically largest and most expensive structural units of a biogas plant, so correctly determining their size will directly and indirectly influence investment costs and the period of return on investment.

Figure III.5.3: Fermentors with rigid covers
(Nyírbátor, Bátortrade Kft.)

Figure III.5.4: Heating pipes inside the fermenting area

Figure III.5.5: Fermentor insulation
(Nyírbátor, Bátortrade Kft.)

Preparation of the fermenting area

In practice, horizontal and vertical fermenting areas exist. Horizontal metal fermentors are usually used as small-scale industry fermentors in the farm economy. Biogas plants that operate continuously use rigid, vertically-aligned fermentors with concrete walls, accompanied with rigid or tarpaulin covers (Figure III.5.3).

Sedimentation of solid components of high density cannot be avoided during the work of the continuously-operating fermentors, so the opportunity for the physical removal of periodically sedimented residue must be ensured at planning and implementation stage of the fermentors. Unloading can take place during a technological shutdown when the fermentor is drained. If possible, a number of fermentors should be available to process a given amount of degradable biomass to ensure that gas production and utilization goes on continuously.

Heating the fermenting area

Biogas production is a heat-demanding procedure so the fermenting area needs to be heated. One method of heating the fermenting area is to affix heating pipes to the interior wall of the fermentor (Figure III.5.4).

Heating the fermentors is done by directly burning the biogas that is being produced, or by using the waste heat energy of the equipment to produce combined electrical energy. To increase the energy efficiency of the facility, the fermentor walls need to be insulated and wrapped (Figure III.5.5).

The mixing equipment

Biogas is produced when organic solid materials are degraded as a result of bacterial activities. The bacteria perform their activities by moving inward from the external surface of the degradable material. To avoid floating and to ensure better accessibility for the microorganisms, the gaseous components need to be removed from

Figure III.5.6: Electrically-charged mechanical mixing equipment

the surface of the solid parts. This is done using mixing devices. Mixing devices complete the vertical and horizontal mixing of the total volume of the fermentor. There are both hydraulic and mechanical mixing devices, among which the use of electrically-charged mechanical mixing devices with adjustable height has become widespread in continuously-operating fermentors (Figure III.5.6).

III.5.9.3. Gas cleaning equipment

Besides the energetically-useful methane, biogas may also contain water vapour, hydrogen sulphide, carbon dioxide, oxygen and other gases to a degree that can influence their utility. Condensation water that precipitates at an ambient temperature needs to be redirected into a preparatory container or into a fermentor.

Before further utilization, along with dehydration hydrogen sulphide must also be removed in order to prevent corrosion. A biotechnological procedure is the usual method for desulphurization in present-day industrial practices. The hydrogen sulphide is transformed into sulphur or sulphuric acid by sulphur bacteria in the presence of a small amount of oxygen. The resulting dehydrated and desulphurized biogas is suitable for use in engines.

Removing carbon dioxide is a basic energy efficiency and economic precondition before the biogas can be used in engines. The carbon dioxide content of the biogas cannot be utilized in engines, so the heating capacity of biogas decreases according to the proportion of other components that are present. Carbon dioxide can be separated off in different ways – such as through absorption, or the use of an absorption membrane – and as regards its removal, a method should be chosen which best suits the given circumstances based on meeting the efficiency and environmental load specifications of the investment.

Figure III.5.7: Double-walled foil gas collector container – experimental equipment

III.5.9.4. Gas containers

The amount and composition of the produced biogas can fluctuate even when the same recipe is used for the base materials and aggregates and when the same operational parameters are in force at biogas plants. Accordingly, especially in the case of contractual energy utilization when the energy is fed into the public utility network, there is need for buffer containers to be used. The space above the loading level of the fermentors may be enough for this purpose, but in larger biogas production facilities extra biogas containers are used. There are several types available. The equipment typically has a double wall, wherein the external wall offers protection from weather conditions and the internal wall can be flexibly modified depending on the amount of biogas to be stored (Figure III.5.7).

III.5.9.5. Material flow and transmission

Liquid and gaseous materials are transmitted and stored in a biogas plant. If compression equipment is not available, gaseous biogas components are transported to the storage area by the overpressure created in the fermentors through pipes with the appropriate cross section. The dry matter content of the input materials of continuously operating wet biogas production technologies cannot exceed 12% for technological reasons so it can be transmitted from the preliminary storage area to the fermented matter containers through pipes. The capacity of the installed pumps should be adjusted to the daily hydraulic load of the biogas plant.

III.5.9.6. Measurement and control equipment

The running of continuous operation biogas plants is monitored by a computerized process control system. On the output side it continuously provides information about the quantity and composition of biogas, the quantity of electrical energy fed into the network (in the case of a combined electric energy production system), and the temperature of the fermenting area. Among the technological parameters it regulates the temperature of the fermenting area by controlling heating, regulating mixing and input and output cycles according to the technology that is used.

On the input side it maintains an even hydraulic load in the fermentor. One of the common problems with control systems is that the organic matter load is not accurately managed on the input side. The moisture content of the loaded base materials and aggregates can vary over a wide range so the use of mix 'recipes' which are based on weights does not guarantee that a standardized dry matter load will be delivered to the fermentors. The elements of the control system – flow-meter, gas analyzers, quantity meters, intervention components (intersections, control valves) – are available in different price ranges in great variety.

III.5.9.7. Safety equipment

Methane is explosive when mixed with air in concentrations between 4.4-16.5%. Any equipment that is installed must comply with compulsory "detonation proof" standards. Methane sensors are also operated by the production control system.

III.6. Principles of mechanical-biological treatment (MBT) (László Aleksza, Csaba Gyuricza)

With municipal solid wastes, selective collection does not decrease the amount of disposable waste to a satisfactory degree; the majority of it is landfilled without treatment. However, this municipal solid refuse primarily contains useful components from an agricultural and energetic perspective, and this is true of both the biologically degradable and the non-degradable (or degradable with difficulties) organic parts.

Incineration of untreated municipal solid waste (MSW) is unprofitable from an economic standpoint because the MSW has unfavourable pyrotechnical characteristics (such as a low calorific value and high moisture content).

This led to the production of secondary fuel out of municipal wastes based on mechanical procedures (RDF: Refuse Derived Fuel, in German: BRAM - Brennstoffs aus Müll). Following this, in the 1990s, biological treatment was introduced to reduce the moisture content of the biologically degradable fraction, as well as to increase its stability and to produce a better quality alternative fuel.

Thus the notion of mechanical-biological treatment (MBT) has been known since the beginning of the 1990s when the previously-applied mechanical procedures were supplemented with biological treatment procedures. Today, the treatment of municipal waste refuse involves mechanical, biological or thermal procedures, or, most often, a combination of these.

At the beginning numerous challenges had to be met and various insufficiencies supplemented in practice for the application of mechanical-biological treatment processes to be successful. The following problems were found with traditional mechanical-biological treatment systems:

- None of the equipment complied with emission requirements.
- Sewage sludge (leachate) was not treated properly.
- Separation of the materials of high calorific value, as stipulated in regulations, was only done based on the operator's former experience.
- The quality of the separated high calorific value components was low.
- There was no equipment available to separate out metals with non-iron content.
- Not all plants were equipped with machinery suitable for selecting metals.
- The processing of organic wastes was not undertaken.

Mechanical treatment (preparation) predominantly occurs preceding (and following) the biological or thermal treatment of wastes. Mechanical procedures are also used during waste collection too, as it is advisable to separate different waste types to the greatest extent during this phase. First, metals, fractions with a high calorific value, and fractions of less value but which could cause problems during treatment (e.g. rock pieces, soil and glass) should be separated from the material flow. Mechanical preparation is necessary during every cycle of raw material management as it can produce a defined size range of particles, making further treatment significantly easier.

One of the main objectives of biological treatment is to reduce the amount of different gases, leaking water and leachate; thus to minimize and totally eliminate any environmentally-harmful components. The other objective, closely related to the first one, is to utilize the available microorganisms and to influence their operation in a way that the toxic content of the initial material (waste) can be minimized to the greatest extent. This procedure is called biological stabilization.

III.6.1. Stabilization technologies

Stabilisation procedures prepare refuse for utilization. Solid municipal waste (household waste and waste similar to household waste) can be classified into three groups. These groups differ from each other not only according to general (social) and processing technological objectives, but also in terms of the procedures and equipment which are used for each of them:

- Mechanical-biological treatment
- Mechanical-physical stabilization
- Dry stabilization procedure

III.6.1.1. Mechanical-biological treatment

The general objective of mechanical-biological treatment (MBT) is the production of

- one fraction which is rich in calorific value, and
- one fraction which is poor in calorific value, and the safe landfilling of this product. This disposable product should comply with regulations concerning landfilling, the departing emitted air, water leakage as well as dissolution from the solid phase.

Two treatment objectives can be differentiated in relation to the direct objectives of mechanical-biological treatment:

Treatment (processing technological) objective 1: biological stabilization of the majority of the treatable waste and its related landfilling.

In this case, the intention is to bio stabilise the greatest possible part of the solid municipal waste (paper, cardboard, nappies, etc.). First, the material is treated biologically and then the fraction rich in components with high calorific value is retrieved from the stabilized matter by sifting.

Treatment (processing technological) objective 2: separation of the valuable and high calorific value fraction to the greatest possible extent.

In this case, the goal of technological processing is to separate the valuable high calorific value components before biological treatment, as a certain amount of the valuable components (paper, cardboard, nappies, etc.) are degraded during biological treatment.

III.6.1.2. Mechanical-physical stabilization

The main objective of mechanical-physical stabilization (MPS) is to produce a fuel, the moisture content of which is sufficiently low (< 10%) and which is free (to the required extent) of non-combustible inert and metal materials. Thus the loose alternative fuel fraction that is produced needs to undergo drying and a metal separation procedure, followed by pelleting (or briquetting). A further goal is to minimize the amount of waste that must be landfilled.

Advantages of mechanical-physical stabilization:

- Almost the entire carbon content of the MSW is utilized energetically.
- All the matter is utilized, except for the inert mineral materials.

The moisture content of the fuel fraction can be reduced to around 10% (the level required for pelleting) by thermal drying.

Disadvantages of mechanical-physical stabilization:

- The process will be profitable only following significant preparatory work, especially if other types of wastes (e.g. waste from industry which is similar to that of households, DSD waste) are also mixed into the end product.
- Storage of separated inert and large waste components is still a problem.
- The appropriate drying equipment required to dehydrate the solid municipal waste may not be available (in this case, equipment used in other areas such as rock dryers, nutrient dryers, etc. may be used).
- A large amount of water must be driven off if pelleting is to take place.
- Cleaning of the drying air and the condensation water has to be taken care of.

III.6.1.3. Biological drying - Dry stabilization process

The main objective of the dry stabilization process (DSP) is to produce a fuel which is drier than the raw waste and which is free of inert and metal materials to the required extent. An additional aim is to minimize the amount of waste that will require landfilling, and thus maximize the amount which will become fuel.

To achieve these goals, and (as opposed to mechanical-physical processing) to reduce costs, the solid municipal waste refuse undergoes biological drying, and the stabilized matter is liberated from inert and metal materials. Finally, it is pelleted (or briquetted).

III.6.2. Considerations in relation to mechanical-biological treatment

Mechanical-biological treatment (MBT) is designed to treat unclassified municipal solid waste and refuse waste created through other processes (e.g. selective waste collection). It reduces the amount of municipal solid waste (MSW) and fosters the retrieval of certain useful fractions through the combined application of mechanical (shredding, classification) and biological (aerobic or anaerobic) treatment, and by taking advantage of the different physical and biological characteristics of the waste components.

The mechanical processes rely on the fact that the biologically non-degradable fractions (mainly plastics) are more resistant to certain shredding procedures than biologically degradable ones. Furthermore, the waste can be separated into a biologically highly degradable fraction and a biologically low activity fraction through properly-selected classification processes because of the significant difference in the size of particles created during shredding and the pre-existing differences in the gravimetric density of the materials.

III.6.3. Biological treatments

Two procedures can be differentiated in the case of biological treatment; an aerobic one and an anaerobic one. Aerobic treatment refers to the same technology that is used in the different types of composting. As a result of this type of processing a compost-like product (CLO) is created. In the case of anaerobic treatment (in the absence of oxygen), biogas is produced as a result of the fermentation process. In practice, the use of aerobic processes is more widespread. This is because aerobic biological treatment is a robust and reversible process, is less sensitive to the quality of the organic matter and can be efficiently regulated.

III.6.3.1. Aerobic treatment

Within the scope of MBT biological treatment, two procedures can be differentiated. They use different feed materials and treatment technologies and they have different objectives:

Biological stabilization

This process is used to treat the <80-100 mm fraction of the selectively collected waste refuse that contains biologically-degradable organic wastes to a larger extent (> 25-30%). This multi-step biological treatment takes a longer time (10-12 weeks) and consists primarily of intensive and maturation phase phases. The end product of the treatment is a biologically-stable fraction with low respiratory activity (AT4< 10 mg/g dm content).

This type of biological stabilization must be used in EU countries for waste that is to be disposed of.

Biological drying

This process is applied to treat the large particle sized fraction (>80-100 mm) of the mixed collected MSW that contains biologically-degradable organic wastes to a relatively small extent, or to reduce the moisture content of the secondary fuel with a high calorific value. Stabilization is not an objective of biological drying; only a reduction in the moisture content.

The time required for biological drying – depending on the technology that is used – is usually 20-30 days. In the first 14-18 days of the treatment, the aim is to assist biological degradation, so the waste proceeds through a quick warming phase, and then, when the organic matter is partly degraded and the temperature is at its maximum, the moisture content can be significantly decreased by increasing the intensity of aeration. Biological drying cannot be efficiently applied to wastes with a higher amount of biologically-degradable organic-content as degradation would take place only partially due to the short treatment time. Uncontrollable biological processes could start in treated waste dried this way if its moisture content later increased.

III.6.3.2. Anaerobic treatment

The small particle sized fractions of mixed collected municipal solid waste (MSW) has a greater proportion of biologically-degradable organic-content. In theory, it can be utilized through biogas production for energetic purposes, thereby also decreasing dry matter content and stabilizing the waste as well. However, there are only a few successful examples of the industrial scale application of anaerobic biological treatment in the MBT process. The reasons for this lie in the high investment costs and the need for longer transportation distances (thus it is feasible only in the case of larger capacity), but the main reason for the low prevalence of anaerobic treatment of MSW is that there are always biological process inhibiting materials in heterogeneous composition MSW. Because aerobic biological degradation can be optimized over a robust, wide range, these inhibiting materials do not cause a problem at this stage. On the other hand, much more sensitive processes are involved in the methanogenic phase of biogas production. The proper conditions need to be optimized over a very narrow range for efficient fermentation, which presently and in the case of a substrate which is of variable composition and inhibitor content, are not sufficiently developed.

Based on an analysis of the available technical and economic information related to the biological treatment of MBW, the increasing prevalence of the use of aerobic systems may be expected in Hungary.

III.6.4. Output material flow from MBW:

- Compost-like output (CLO): A stable material is created as a result of aerobic treatment, the quality of which is low based on general experience and not equivalent even to the lowest category of composts. In most cases, biological tests indicate its significant inhibitory effect on plant growth. In some countries it can be utilised on plough lands as a soil enhancer, but such use is not permitted in Hungary and this situation probably will not change. However, it can be utilized as a covering soil for landfills or for recultivation purposes.
  - Biogas: an end product of the anaerobic fermentation which can be used for energetic purposes (direct burning, electricity, heat production, etc.). Presently, its significance is low.
  - Refuse derived fuel (RDF): a high calorific value fraction that is created during mechanical treatment which is burnt or co-burnt in power plants or cement factories.
  - Bio stabilized waste: the remaining solid material which remains after treatment which is suitable for final landfilling and which is not harmful to the environment. In Hungary no regulations exist to specify what its mechanical properties should be (e.g. aeration intensity).
  - Recyclable materials: these are selected out after mechanical treatment (e.g. iron, precious metals, glass and plastic).

III.7. Environmental and environmental health effects of biological treatment (András Béres)

The environmental load and pollution that is primarily associated with the treatment of biowastes is related to the presence of specific base materials, polluting and polluted materials, products and by-products. Pollution of the following may occur:

- water (surface and ground): by leachate, polluted rain water, condensation water, etc.;
- soil: by polluting materials in the products which are produced and distributed and by-products utilized as soil enhancers;
- air: as a result of odour emissions, dust emissions, emissions of microorganisms (germs) from base materials and technological processes – these are sometimes hazardous to human health –; emissions of organic and inorganic air pollutants, noise emissions.

Significant emissions are summarized in Table III.7.1 according to the specific working processes of a composting plant and are classified according to the environmental elements that are affected.

Work process	**Equipment and plant area**	**Emissions 2)**		
		To Water	**To Soil**	**To Air 3)**
Delivery of waste	Delivery and storing areas, bunkers, containers	Leachate	None**	Odour, noise (dust, germs)
Pre-treatment	Preparatory area (shredding, sifting, mixing)	Leachate, condensation water from the treatment of the exiting air	None**	Odour, noise (dust, germs)
Intensive phase*	Composting area, windrows, reactor, compost tunnel	Leachate, condensation water	None**	Odour, noise, germs (dust)
Maturation phase	Composting area, windrows, reactor, compost tunnel	Leachate, condensation water	None**	Germs (odour, dust, noise)
Post treatment	Post treatment area (shredding, sifting, separation of impurities)	None	None**	Dust, germs, noise (odour)
End product	Compost container	None 1)	Heavy metals, other polluting materials	Dust (odour, germs, dust)

1) In the case of covered storage.
2) The emissions in brackets are of limited significance and their impact depends upon the technology that is used.
3) The emission of other air polluting materials typically occurs during the maturation process.
*The main phase of maturation is called the intensive maturation phase if the maturation process, regardless of the spontaneous heating of the base materials, is conducted in a technologically-controlled environment (e.g. with aeration, in a closed space).
**If a leak-proof, solid cover the preparation of which complies with regulations is used.

***Table III.7.1: Emissions during the individual work processes of a composting plant classified according to the affected environmental elements** [1]*

III.7.1. Odour emissions

Even in the case of a professional operation, it is inevitable that odour, dust and microorganisms (germs) will be emitted – and in some cases these will be hazardous to human health. They originate from the base materials and the technological processes used at every biowaste treatment facility. The extent of these emissions (which can be judged by their environmental impact) naturally depends on the equipment that is used and the operational methods employed.

Based on a summary of Table III.7.1, odour emissions are created at biowaste treatment facilities during the manipulation and technological processing of base materials (transportation, storage, preparation, loading, aerobic and anaerobic fermentation, post-treatment, unloading, post-storage). In the following section, the methodology that is used to measure odour emissions, the quantity of typical odour emissions and the opportunities for reducing them are reviewed.

III.7.1.1. Measurement of odour

The measurement of the size and strength of an odour is done according to the MSZ EN 13725:2003 'Air quality - Determination of odour concentration by dynamic olfactometry' standard, which applies to Hungary. Based on this, measurement is conducted through inspections that are done in a controlled environment using an olfactometer. Measuring odour strength in other ways (e.g. using the classic organic method of analysis method) is hindered by the following obstacles:

- classical analytical inspection (sampling and measurement of the organic or inorganic component concentration that is causing the environmental odour) takes a long time;
- analytical inspections are very expensive because of their material and instrument requirements; the cost is increased by the fact that they can only be conducted in laboratories;
- the emission concentrations of the disturbing environmental odours in some cases are too low to be accurately detected in terms of sampling sensitivity. If the sampling time is increased, the factual, objective evaluation of the odour-causing technological process becomes impossible;
- it is impossible to draw conclusions about the type and size of a specific odour from knowing the concentration of individual odour-causing air pollutants (i.e. the synergic effects of air polluting components are unknown).

The science of medicine has been of great assistance to scientists and environmental experts in developing the presently-accepted and applied methodology for odour measurement. Olfactometry (and the instrument it employs; the olfactometer) were developed for medical purposes to facilitate the examination of the sensitivity of smelling (olfaction). These originally-medical processes were adopted by experts who deal with the impacts of odours to objectively measure odours.

The instrument used for odour measurement (the olfactometer; Figure III.7.1) is actually a piece of precision gas mixing equipment; the 'sensor' of which is the human nose. The 'smelly' air to be inspected is diluted with a reference gas (this may be clean, odourless air or oxygen gas) in gradually-decreasing amounts until the individual conducting the inspection can detect the odour using a specially-developed nose mask. The gradually-decreasing dilution eliminates the chance that the examiner's nose will get 'tired'. The odour threshold values, the odour concentrations (odour unit, OU/m^3) of different odours and odour samples can be identified by the equipment. These days, the most modern olfactometers that are used are computer controlled. The individual level of dilution, the monitoring of the answers of the test participants (e.g. by periodically offering the tester an odourless air – a so-called null test – for evaluation) and analysis of the testers' answers are done automatically without the intervention of the expert. A number of people (4-8) - who have gone through a selection process to examine their olfactory ability prior to the measuring task, as defined by standards - typically simultaneously participate in the measuring process. Furthermore, the olfactory abilities of the testers is checked before each individual odour measurement is carried out.

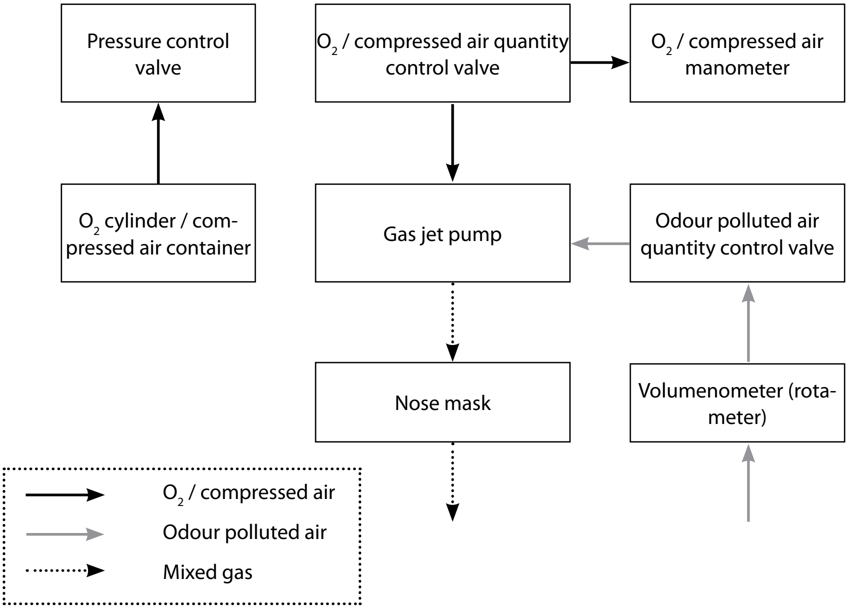


Figure III.7.1: Schematic illustration of an olfactometer *[2]*

The odour emissions (with point source emissions, ou/s; for nonpoint sources, ou/(m^2×s)) of the emission source can be determined by knowing the odour concentration defined in the odour measurement process and the volumetric flow rate of the emitted odour polluted air. When taking samples it is essential to use appropriate sampling equipment and take any specific circumstances into consideration for both point sources as well as nonpoint sources. (Equipment choices include whether to use an odour sampler that operates using the so-called lung principle, a pre-diluted sampler probe, a sampler bell or aerated sampler bell.)

III.7.1.2. Odour emissions from biowaste treatment facilities

The quantity of odour that biowaste treatment facilities emit considerably depends on the following:

- The quantity and quality of the base materials that are used;
- The method of storing the base materials within the facility, their preparation, how they are loaded into the technological equipment and used in the technological processes;
- The type of equipment that is used for treating the biowaste (in the case of anaerobic systems, odour emissions are minimal during the stage of fermentation because of the nature of the closed technology; while in the case of aerobic systems – i.e. composting – the quantity of odour emissions depends directly on whether closed technology (composting in a closed space – chamber, with membrane cover, etc.) or open technology is being used;
- The method of treating the exiting odour-polluted air in the case of closed technologies (if odour-reducing systems are used to treat the exiting odour-polluted air; the odour reducing method that is used and the efficiency of the equipment);
- The method and location of further treatment of the product (with anaerobic systems, the method and circumstances of phase separation – e.g. if it takes place in a closed or an open system; with aerobic systems, if the post-treatment of the product – sifting, shredding, confectioning – takes place in closed or open space);
- The method of storing the product (with anaerobic systems this refers to the method and location

of storage of the liquid and solid phases after phase separation is complete – i.e. open or covered storage);
- and significantly, on the size of contaminated surfaces, and on the frequency and method of pollution that occurs during the manipulation and transport of materials.

When treating green waste with aerobic methods at composting plants, typical odour concentration values (without deodorization [3]) of the exiting odour-polluted air from the specific odour-emitting points, buildings and surface sources are the following:
- base material pre-storing area: 100-300 OU/m^3;
- pre-treatment – selecting – mixing technological area: 50-500 OU/m^3;
- rotating-drum composter: 20,000-80,000 OU/m^3;
- passive windrow composting: 200-1000 OU/m^3;
- aerated composting windrow: 5000-25.000 OU/m^3;
- maturation phase, compost storing: 20-200 OU/m^3;
- transportation area: 20-200 OU/m3.

In the case of windrow composting of biowastes, the odour concentration of the exiting air is the following at the different phases of the composting process [4]:
- at the initially mesophilic phase (15-45 °C) 6,000-25,000 OU/m^3 (a few days, maximum one week);
- at the spontaneous heating up phase (45-65 °C) the highest value can exceed 30,000 OU/m^3 (a few days, maximum one week);
- at the intensive degradation phase (65-70 °C) the highest value can exceed 10,000 OU/m^3 (a few days or maximum a few weeks);
- at the cooling phase (65-45 °C), 150-3000 OU/m^3 (until the 12th week);
- at the maturation phase (< 45 °C) below 500 OU/m^3 (several weeks).

It is apparent from the above odour concentration values that the most significant odour emissions occur at phase of intensive degradation during open windrow composting.

Changes in the specific odour emission values of the windrow composting of biowastes can be seen in Figure III.7.2. The specific odour emissions directly depend on the composition of the treated material, the type of equipment that is used, and naturally, the season [5].

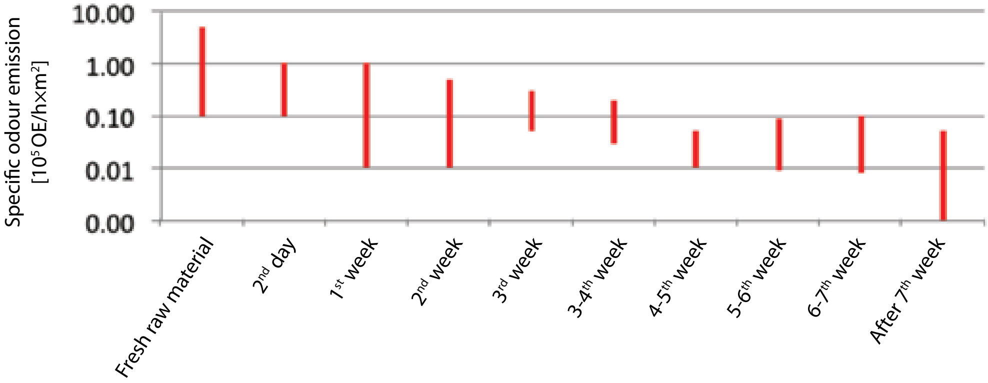


Figure III.7.2: Changes in the specific odour emission values created by the windrow composting of biowastes

Based on the specific odour emission values presented in Figure III.7.2 it can be stated that odour emissions significantly decrease during the composting material's maturation process. If sewage sludge is also among the biowastes of windrow composting the specific odour emission value considerably increases; it can even triple [6]. If a special laminate cover is placed over the windrow in the case of windrow composting a decrease of up to 95% in specific odour emissions can be achieved compared to an open windrow [7].

During biological stabilisation of mixed collection municipal solid wastes, the maximum odour concentration of the exiting odour-polluted air from the aerated windrows can reach 13,000 OU/m^3, while the highest odour concentration in the case of emissions from wastes stabilized in closed systems (e.g. cells) can even reach 35,000 OU/m^3. In the landfilling area after mechanical-biological treatment the highest odour concentration in the vicinity of the landfilled waste is around 6000 OU/m^3, while the same value for the case of untreated landfilled waste is 9000 OU/m^3 [8].

The measurable specific highest odour concentration values at the individual surfaces of the odour sources (i.e. on the surface of stored materials) during anaerobic treatment of biowastes in biogas plants can be seen in Figure III.7.3 [9].

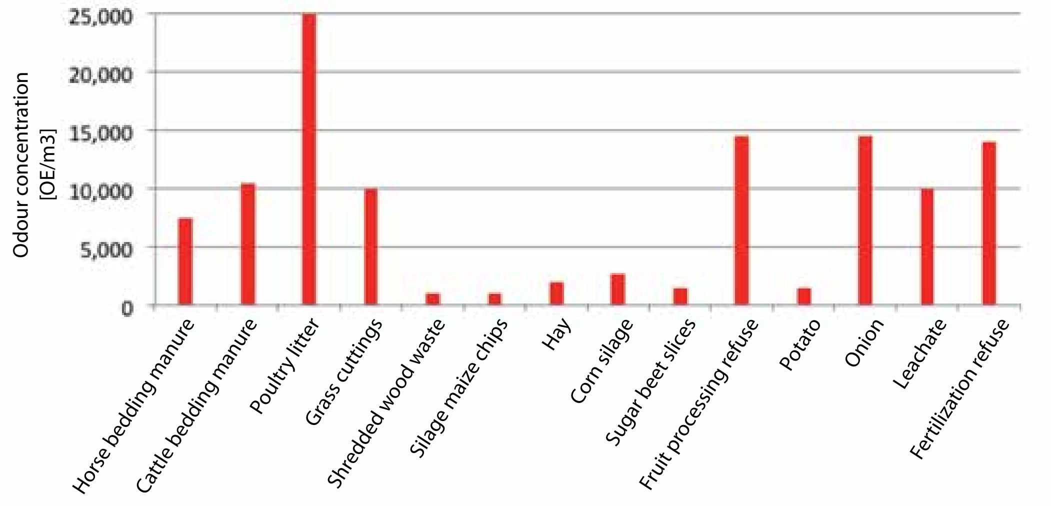


Figure III.7.3: The highest odour concentration values measured at the individual surface of odour sources (i.e. on the surface of stored materials) at biogas plants

Other technology-related rooms (e.g. the separator engine room) in biogas plants can be significant sources of odour emissions too. The air leaving these buildings should also be deodorized to reduce odour emissions. The odour concentration of the emitted air at these sources can be reduced below 200 OU/m^3 if the appropriate deodorization appliances are used [10]. In certain countries limit values are defined for the odour emissions of these technological facilities (e.g. Germany, TA-Luft, 500 OU/m^3).

There is plenty of data available in the literature about the specific odour emissions of the surface sources found in biogas plants. They are illustrated in Figure III.7.4 [10].

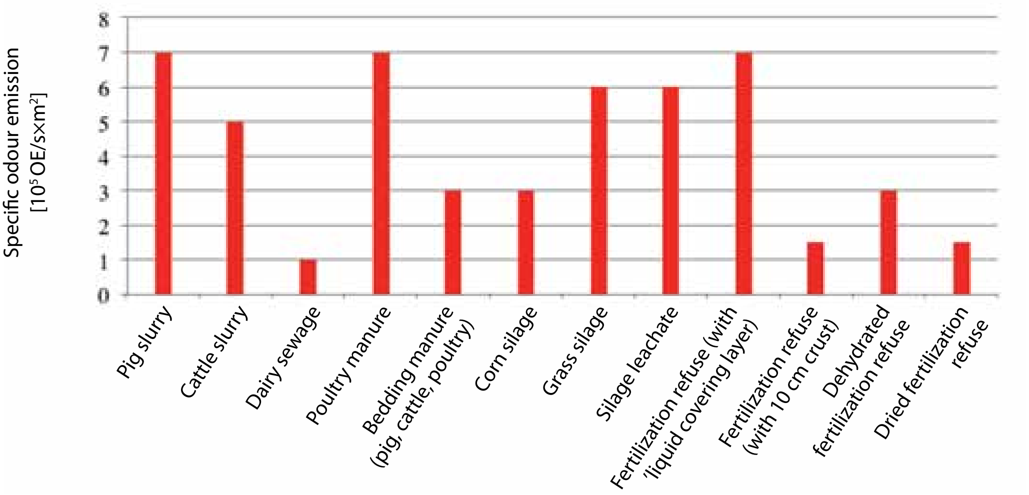


Figure III.7.4: The specific odour emissions of surface sources found at biogas plants

The specific odour emission data presented in Figure III.7.4 confirm that the odour emissions of stabilized fermentation refuse – due to anaerobic treatment – is less than that of the initial, base materials which in certain cases have significant odour emissions.

In the case of open storage of the fermentation refuse, the quality of the base materials and the state of the fermentation refuse (e.g. storage with undisturbed surface or even pumping) determines the extent of specific odour emissions (Figure III.7.5) [11].

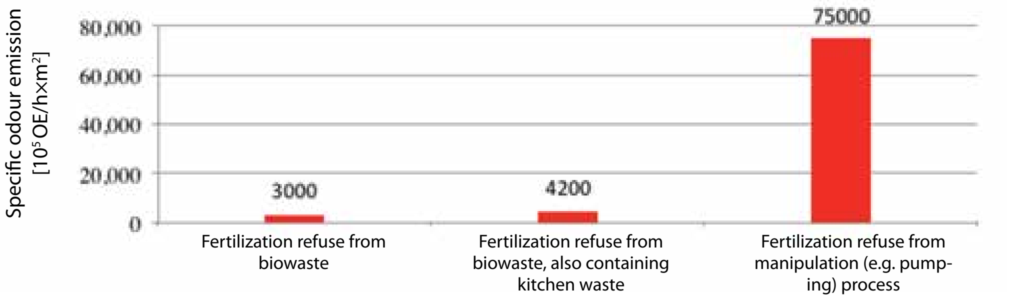


Figure III.7.5: Specific odour emission of fermentation refuse

In biogas plants the typical odour concentration of the emitted smoke gas of gas engines is 3000 OU/m³ in the case of four stroke gas engines and 5000 OU/m³ in the case of injected diesel gas engines [10].

Figure III.7.6 illustrates the efficiency of emission reductions through the use of different covering methods in the case of open storage areas [10]. The data in the figure illustrate that odour emissions can also be reduced in a natural way (e.g. when a skin naturally forms on the liquid surface of liquid manure).

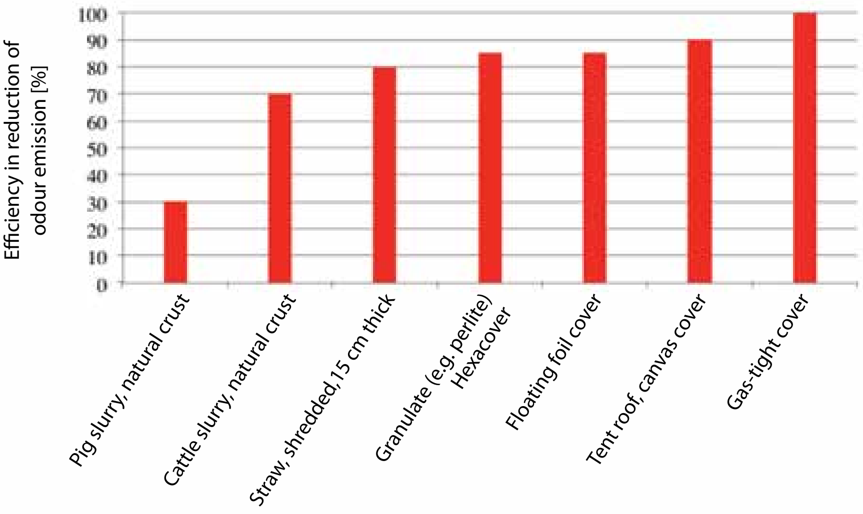


Figure III.7.6: Expected efficiency of reduction of maximum odour using different covering methods (open storage areas)

III.7.1.3. Odour emission reduction

The technological solutions used to reduce odour emission can be classified into main two groups [12]:

- active procedures: when the odour emissions are reduced by preventing the creation of the odours (e.g. in the case of aerobic treatment by preventing the creation of anaerobic zones with the help of proper process control so that very strong odours cannot be produced; in the case of anaerobic treatment, for example, the odour emissions of the product can be reduced by proper degassing of the fermented material into post-storage area); other solutions are also possible and include making sure that open, diffuse odour sources (e.g. material storage) are contained, as well as ensuring that technological processes (e.g. mixing of materials, phase separation of ferments) which generate significant odour emissions are conducted in a closed space;
- passive procedures (so-called end-of-pipe procedures), in which the already created odours are stopped from exiting to air by the use of some kind of filtering system.

In accordance with the above, active protection against odour emissions means reducing the opportunities for creation of odour-polluting materials through the technological process that is chosen (e.g. by using closed technological processes instead of open ones, by choosing the appropriate base materials and optimizing the process-influencing features of the base materials, by making technological changes in the case of composting such as preparing and properly operating an optimal system of aeration). There are numerous other possibilities for actively protecting against odours - from ensuring that the operation is more mindfully conducted (almost cost-free) to changing equipment, requiring total reconstruction. If the issue of active protection against odour emission emerges in relation to a certain production activity or technology, within the given circumstances technological reconstruction and operational changes should be undertaken that have been discussed in the professional literature and which have been tested in practice. With biological waste treatment, the fact that the most significant odour emissions are related to material transport and manipulation (loading, feeding, mixing, turning and separation) must be taken into account. In the case of composting, the highest emissions odour happen to occur during the intensive degradation phase. This is why a considerable amount of attention must be paid to reducing odour emissions in relation to these technological activities and phases by using closed technology and by separating the produced odours, if possible. The following planning and operational practices can be considered for use – this is just an indicative list – to reduce odour emissions when processing biowaste:

- as far as possible, the base materials that have been delivered should be stored in a closed space, and then processed quickly and continuously;
- if it is not possible to store the delivered base materials in a closed space, then they should be stored under a cover. Their emissions will increase as their moisture content increases (e.g. with chicken manure, dehydrated sewage sludge and the solid phase of dehydrated ferment), thus they must be prevented from being exposed to rain;
- in the case of composting, the proper mixing of the base materials and the creation of a composition and structure that promotes an effective maturation process must be ensured;
- with aerobic technologies (composting, mechanical biological waste treatment), odour emissions should be reduced and a membrane cover used to enable proper process control;
- in the case of anaerobic treatment, the solid and liquid base materials should be loaded and mixed in a closed system;
- in the case of aerobic treatment, the proper preparation and control of the aeration system should be ensured to eliminate the development of anaerobic zones;
- with aerobic technologies, the ferments should be degassed and phase separation should be conducted in a closed space,
- fermentation refuse should be stored in a closed space or covered;
- the base material-polluted surfaces (e.g. mixing area, roads, unloaded storage areas) should be kept properly clean;
- odour-spreading meteorological factors (e.g. direction of wind, inversion conditions) must be taken into account when planning the timing of processes which create strong odours (e.g. preliminary mixing, turning, sifting).

Figure III.7.7 illustrates the applicability of the individual odour-reducing procedures according to the flow rate of pollution and total organic carbon content of the air.

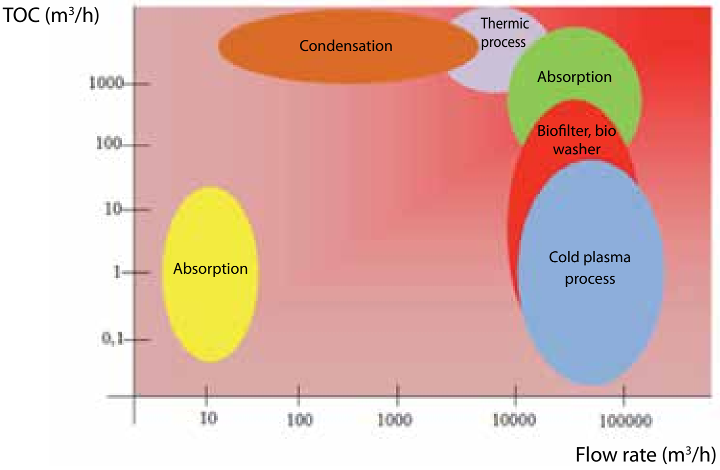


Figure III.7.7: The applicability of odour-reducing procedures according to the flow rate of gas and total organic carbon – TOC – content of air

The objective of passive odour emission reduction is to separate the odour-polluted post-process air from entering the environment through the use of a variety of filtering equipment. The (passive) procedures typically suitable for reducing odour emissions are the following:

- adsorption using a suitable sorbent material (e.g. an active carbon filling);
- adsorption using a washing process or other solvents;
- condensation;
- application of an oxidative process using appropriate oxidising agents (pure oxygen, ozone, hydrogen-peroxide);
- thermal cleaning of tail gas;
- use of bio-washer, biofilter;
- covering and neutralizing with the use of odour-binding or covering materials (e.g. spraying).

III.7.1.4. Biological gas treatment

At biological waste treatment facilities the collected odour-polluted air is most frequently deodorized by biological cleaning of the tail gas. Degradation of gas pollution is done by microorganisms during the process of biological gas cleaning. As water is indispensable for living microorganisms, biologically-degradable pollution which is water-soluble is eliminated this way.

An advantage of this method is that degradation takes place at a lower temperature. The microorganisms that break down the pollution are viable only over a narrow pH range which must be ensured. Bacteria are sensitive to certain pollutants (e.g. heavy metals) which deactivate or destroy them.

Biological cleaning is done by microorganisms that are carried in water suspension or are fixed on solid materials. Fixed microorganisms are used in biofilters, while those in suspension are used in biowashes. The microorganisms used for degradation originate from treated air, the load material, and, less frequently, from the soil. Specific bacteria strains are often used for cleaning tail gas. The bacteria strains multiply in the medium to be treated; the time it takes them to adapt is usually 2-4 weeks. Biological procedures are suitable primarily for removing small concentrations of pollution from large amounts of biologically-degradable gas. These procedures are cheap, trouble-free and most widely-accepted by society. Disposal of their by-products can be done at relatively low cost. The majority of the naturally-occurring organic matter is degradable and utilizable to microorganisms.

Biofilters can be in the form of a so-called open bed, or they may be container biofilters. The schematic structure of an open biofilter is shown in Figure III.7.8; a container biofilter is illustrated in Figure III.7.9. Compost, faggots, straw, peat, tree bark, wood chips, root chips, corn cobs, etc. can be used as screening materials. It is very important for the proper operation of biofilters that the biofilter bed is evenly loaded, the treated air is properly prepared (e.g. dust is removed), and, if necessary, the load to be treated is moistened.

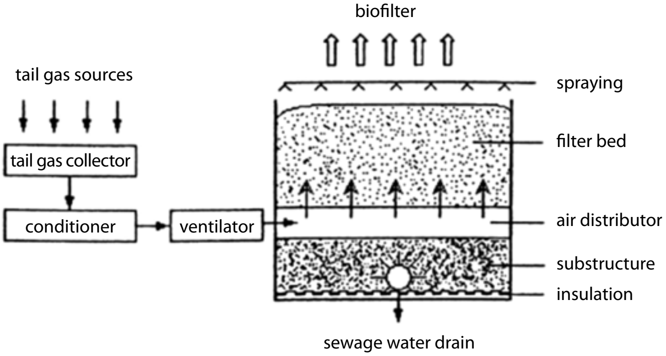


Figure III.7.8: Structure of an open biofilter

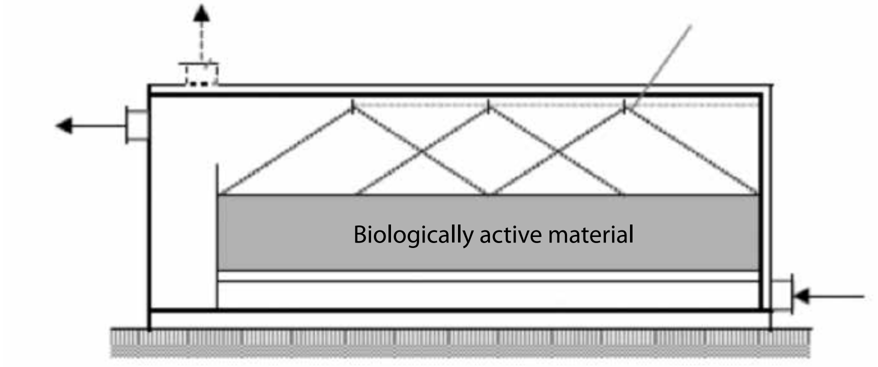


Figure III.7.9: Structure of a container biofilter

A frequently-used odour emission reduction process involves the combined use of biofilters with gas washes. Prior to the treatable gas entering the biofilter, the gas washer appropriately conditions the gas and separates out dust pollution and fats which might hamper the operation of the biofilter. An example of this process is provided in Figure III.7.10.

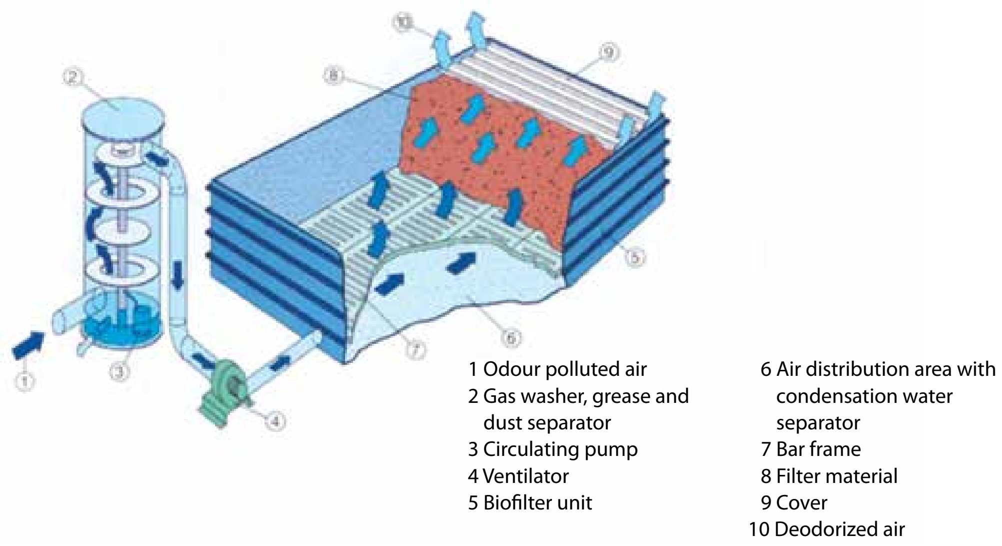


Figure III.7.10: Biofilter combined with gas washer

Bio washers were developed as a result of combining the traditional absorption procedures and sewage sludge treatment. Their two main components are an absorber (gas washer) and an activated sludge container (bio-reactor). In the former, the polluted material is absorbed, while in the latter the absorbed components are degraded biologically. Some kind of a loose filling is placed into the absorption tower to improve the connection interface of the phases and thus increase material exchange. Microorganisms can be found in the washing liquid at concentrations of up to 1-15 g/dm^3. The pollutant content of the polluted gas is absorbed in this washing liquid and degraded in an active sludge container. The pollutant-free solvent is then redirected into the absorber from the sludge container. The oxygen required for the ideal degradation of the polluting materials originates primarily from the gas mixture that is cleaned and deodorized ('technological air').

III.7.1.5. Neutralization of odours

A more frequently used procedure in the case of open, diffuse odour sources is to cover and neutralize emitted odours in the close vicinity of the odour source, or at the property boundaries of the plant. Masking or covering materials are perfumes, the pleasant odour of which obscures undesirable odours. The concentration of the undesired odour is not decreased by their use but the general odour impact is made more bearable to people who are exposed. Instead of a 'stink', a less bothersome odour, the smell of the treatment material will be detected. Some such 'covering' materials (odour-binding materials such as surface active materials and plant oils like pine oil and eucalyptus oil, etc.) do not typically degrade the odours, but by reacting with them they change their characteristics so the detectable odour concentration is reduced by different degrees. This method is generally suitable for the neutralization of odours present in smaller concentrations. The low investment cost and the occasional (and low) operational cost are the advantages of this method, as well as the fact that the environmental odour effect of odour emission sources that cannot be treated in any other way - such as diffuse odour emission sources - can be treated using this method. Figure VII.11 illustrates an example of this method of odour-reduction. A deodorizing spraying system and mobile equipment can be seen at the border of a treatment plant or in the vicinity of the location of the equipment that is creating the significant odour emission.

Figure III.7.11: Deodorant spraying systems

III.7.1.6. Legal regulation of odour emission

Governmental Decree 306/2010 (XII. 23.), entitled 'The protection of air', deals with fundamental issues in connection with odour emissions and the evaluation of disturbing environmental odour effects and their prevention. Strict regulations are defined in the decree about bothersome environmental odours: the decree states that it is forbidden to burden the population with disturbing odours. In connection with this, the decree states that the best available technology should be used for activities that may generate unwanted odours. If use of the best available technology cannot guarantee the protection of the population from disturbing odours, further technological requirements may prescribed; for example the use of odour reduction equipment, or an increase in the filtration efficiency of an appliance. If the burdening of the population by disturbing odours cannot be prevented using technological means, the activities that creates the odour emission may be restricted, suspended or banned. If the operation that leads to the source of odour leads to complaints by citizens, in order to reduce the odour burden of the odour-polluting point source a specific odour concentration limit value in odour unit/m^3 may be enforced. According to the decree, standard MSZ EN 13725:2003 must be used when assessing the concentration of an odour.

The decree also covers issues related to the development of a protection zone around the sources of odour. It declares that the odour emitter must create a protection zone if there are activities or facilities for which odour emission environmental assessments or unified environmental permits must be obtained. The size of the protection zone is defined using maximum capacity utilization and the most unfavourable conditions for odour dissemination (particularly prevailing wind direction and weather conditions), and also takes into account the landscape, the existence of any protective elements and the size of the area to be protected. The operating zone is required to be at least 300, and potentially up to 1000 metres from the odour source boundary. If a new odour-emitting source is planned at an existing premises, the environmental authorities (agencies) may prescribe a shorter distance than the prescribed 300m if all the air protection requirements are fulfilled (that is, no disturbing odours will reach the population outside of the smaller protection zone). There should be no residential, resort-type, educational, pedagogical, health, social or operational buildings within the specified zone, except for those buildings that are connected to the operation of the planned or otherwise already-functioning odour emission sources. The odour emitter must bear all of the costs related to the establishment and maintenance of the protection zone.

III.7.2. Dust emissions

There should be no significant dust emissions during biological waste treatment processes providing the proper operational conditions are assured, typically because of the high moisture content of the waste [7]. However, dust emissions can increase during the storage of base materials with a lower moisture level (e.g. structural materials, chicken manure, silage), during the treatment of materials and material handling (i.e. transport, unloading, shredding, loading of windrows, mixing and sifting), and the extent of the dust emissions become critical if the moisture content drops to below 30%. Dust emissions can be reduced by ensuring that the following guidelines are adhered to in the case of the above-described processing units and technological processes:

- covered vehicles should be used to transport base materials, aggregates and end products (compost);
- storing, shredding and mixing of the base materials and aggregates that are expected to create dust, and the storing and packaging of compost should be done in a covered, windproof space;
- turning machinery and screens should be supplied with a proper dust-protecting cover to reduce dust creation and dust emissions;
- the appropriate moisture content of the materials to be turned should be ensured in the case of composting;
- any specific dust-emitting operations should be done after taking into account wind conditions. If possible they should be done during a windless period;
- open air conveyors should be closed with a suitable cover, and the air under the cover needs to be extracted, while attention should be paid to proper removing the dust from the air which is extracted;
- a small drop in height must be created between loading and material handling stages;
- the dust-polluted air that has been extracted from closed spaces needs should be cleaned of dust prior to its discharge to the environment;
- the ongoing cleanliness and dusting of roads within the premises of the plant, storage areas and operational surfaces must be guaranteed;
- a protective zone should be established around the plant to reduce dust emissions. This will also protect the area outside from other environmental effects such as noise and odour emissions.

III.7.3. Germ emissions

During biological waste treatment special attention should be paid to managing the emissions of germs and viable microorganisms that are emitted to air (such as bacteria, fungi and viruses) – on occasion these may be hazardous to human health, causing infections, allergies or poisoning. Such emissions originate from base materials and technological processes. To avoid and reduce the occupational health and environmental hazards of this type of emission, the selection and operation of the technology that is used, the architectural solutions that are chosen as well as the preparation of the storage/transporting technology need to be done carefully. Data indicates that reducing dust emissions also results in reductions of germs as most pollutants that are hazardous to human health are emitted into occupational areas and environmental air through adhering to dust particles.

The type and quantity of germs emitted by the biowaste treatment facility is determined by the quality of the used base materials, the method of treatment and the treatment method used for the emitted polluted air. The germ quantity and the type of viable microorganisms in the air in the vicinity of the facility and its environment significantly depend on weather conditions, the season and the specifics of the environmental climate (e.g. the temperature of the air in the environment, its humidity, radiation conditions and wind conditions). Emissions of germs typically increase – in relation to odour emissions – during the phase of the manipulation of base materials and the intensive maturation phase. Based on this knowledge, the methods applied to reduce odour emissions can also result in the reduction of germ emission. However, great care needs to be taken that the settled and multiplying microorganisms on the load of the odour emission reducing equipment and the separated materials should not become a secondary source of pollutants. According to Appendix 2 of the KvVM – Ministry of Environment and Water Management – decree (23/2003. (XII. 29.), the treatment of biowaste and the technological requirements for composting, the elimination of microorganisms pathogenic to humans, animals and cultivated plants must be ensured to a degree which complies with hygiene-related requirements.

It is important to highlight that the degree of the occupational and environmental health hazards, as well as the nature of the evolving effects caused by the germs depend on multiple factors. Evolving effects are principally influenced by an individual's basic health status and age. A higher sensitivity will be encountered in the case that individuals have pre-existing illnesses, a poor social environment or other pre-existing health risk factors [15].

III.7.4. Soil and groundwater

In the course of operating biowaste treatment facilities soil hazards as well as surface and groundwater pollution may be caused by leachate, polluted rain water and generated condensation water that is generated during the technological processes. To prevent the above, covering the surfaces with a cover that prevents the leachate from entering geological media and the proper diversion and collection of leachate must be ensured along with compliance with the regulations described in the earlier-mentioned 23/2003. (XII. 29.) KvVM decree.

The generated water can be of the following origins [7]:

- water squeezed out from stored, treated materials;
- endogenous water, generated as a result of biochemical metamorphoses;
- exogenous water from rain that passes through the stored and treated materials or potentially polluted transportation roads;
- rain water from roofs and other covered buildings which does not get in touch with pollutants;
- water generated as a result of cleaning the different buildings used in the treatment process.

Leachate can be polluted to different levels depending on its place of origin and the processes that generate it. Pollutants typically found in leachate include solutes and floating organic matter, solid pollutants, salts, and other types of pollutants related to the base materials or technological processes (e.g. ammonia, oil derivatives and heavy metals). If the shape of the treatment facility and the applied technologies allow, different types of water should be collected separately, and taking into account their pollution characteristics, should be treated separately. With properly-sized storage capacity the collected leachate can be redirected back into the technological processes (thereby moistening the composting mix and/or open windrows, as well as helping define the moisture content of the ferment in the case of anaerobic systems). A solution that is frequently applied is to collect non-polluted waters (e.g. rain water from roofs and other covered buildings which has not become contaminated by pollutants) and store it as fire water.

In biowaste treatment plants the risk of polluting geological media and groundwater is real if the containers that are used are damaged (e.g. loaders, fermentors, storage containers). To prevent this, equipment needs to be supplied with leakage sensors and leakage-proof sections (e.g. latches). A detailed emergency plan must be at the operator's disposal in case the containers fail so the measures defined in the plan can be carried out.

The effects of the biowaste treatment facilities on the soil and groundwater can be tracked by using a groundwater monitoring system and by taking into account the geological and hydrogeological characteristics of the area as well as its morphology. The frequency of sampling and the group of pollutants to be examined in the developed groundwater monitoring wells of the above system are determined by the expected environmental effects of the facility and the basic load of the area.

III.7.5. Leachate treatment technologies

As explained above, the leachate and rainwater that originate from a biowaste treatment facility can be polluted to different levels. Leachate can be redirected into the technological processes - in the case of anaerobic systems into the base materials - or it can supply the moisture content of compostable materials, or it can be the technological water that is used in anaerobic systems. If this is not completely possible, the leachate, depending on how much it is polluted, must be treated after collection just as any other wastewater. If the pollution content permits it, then subsequent to proper pre-treatment (for example, after settling) the leachate can be discharged into receiving waters. If necessary, because of its biologically degradable pollutant content, the treatment-landfilling of leachate can involve any type of biological wastewater treatment, but if possible, an environmentally-friendly process with low operational costs should be used. If the leachate contains biologically non-degradable pollutants then the usual physical-chemical separation methods, physical-chemical or biological stabilization or sifting methods can be used.

III.7.6. Noise pollution, occupational aspects

In biowaste treatment facilities, different mobile (power machines, loaders, shedders, sieves, turning machines, etc.) and stable pieces of machinery (ventilators, pumps, conveyors, mixers, etc.) can generate smaller or greater noise emissions. Transportation within the facility and the vehicles which bring materials in and out of the plant can be a further source of noise [16]. Naturally, the severity of the noise emission primarily depends on the level of mechanization of the treatment process and the plant's processing capacity.

General regulations concerning noise emission measurement and limitations must be adhered to in the case of biowaste treatment facilities. Noise emission reduction can be achieved through using technical, architectural and passive protection methods that are also typically used with other noise-emitting technologies, including:

- paying attention to occupational health and environmental noise emission limits when selecting noise-emitting equipment;
- operating noisy technologies in a closed space and complying with regulations concerning occupational health issues;

- Ensuring that open-air, noisy technological equipment is fitted with a noise protection cover, and if this is not possible, providing appropriate noise shielding;
- paying attention to the level of noise emissions during the operation and maintenance of machinery;
- periodical supervision of the noise protection features of equipment and machinery;
- taking general or local regulations into account when planning noisy working processes, including prevailing wind speed and direction which are very significant in terms of the spread of noise;
- obstructing the spread of emitted noise within or outside the facility boundaries by using a proper noise protection wall or plant zone;
- similarly to with protection against the unpleasant effects of other, already-mentioned emissions that enter the air, it is of great importance to choose the proper site for the treatment process and prepare the necessary protection zone for the object to be shielded.

III.7.6.1. Occupational safety issues

The following sources of danger are typical of biowaste treatment facilities in terms of occupational safety from the perspective of the technological operation to be undertaken, the procedures for doing it and the nature of the base materials and products:

- mechanical and electrical dangers, as well as the danger of the effects of heat, noise-vibrations and dust polluted air;
- biological dangers which arise from the base materials, products and procedures, which can cause allergies, infections or poisoning, as already described;
- combustible, biting, poisonous and/or dangerous materials that are used at the facilities.

It must be emphasized that the majority of the occupational accidents, injuries, infections and poisonings can be avoided by complying with the relevant occupational safety regulations, by enforcing them and by informing and training the personnel conducting the activities at the relevant sources of danger. In the case of biowaste treatment facilities, the following general and specific occupational safety measures can be taken to protect against the above dangers:

- employees must be made aware of occupational safety regulations and must be persuaded of their importance; the objectives of the occupational safety training events are the transfer, maintenance and checking of the acquired knowledge and information;
- preparation and use of action plans that are suitable for professionally dealing with different dangerous situations;
- the safe and secure preparation and operation of technical equipment;
- regularly conducting occupational health fitness checks;
- regular and free-of-charge provision of the necessary medical immunization;
- provision of personal protective equipment (protective clothing, protective shoes, protective gloves, protective glasses, hearing protection, dust protection masks, respiratory masks, etc.) that are appropriate to the activities that are being undertaken along with regular checks of their functioning;
- regular cleaning of protective clothing, and, if necessary, changes of protective clothing or parts of protective equipment;
- proper ventilation of closed spaces that are exposed to dust, germs and odour pollution, the regular checking, cleaning and maintenance of ventilation systems;
- adequate air-conditioning and ventilation of the controlling areas of machinery; provision of properly-screened ventilation air, periodical cleaning and maintenance of screening systems;
- cleaning and disinfection of spaces and equipment that is polluted with dangerous, infectious materials and dust at a suitable frequency;

- adequate control of smoking and eating, monitoring of compliance with these regulations;
- regulation, prohibition and checking for the presence of unauthorized persons in occupational areas.

III.7.6.2. Fire protection issues

In the case of biogas plants, special attention must paid to fire protection issues because of the fire and explosion hazards of the biogas that is produced. Splitting-opening surfaces must be created in the 'A' and 'B' flammability-classified spaces of biogas plants according to regulations, except if the spaces are equipped with fire alarms and fire extinguishers. In addition, they should also be equipped with suitable gas concentration sensors. A fire alarm system should be installed over the whole area of the biogas plant, except for in the open air spaces categorized as 'E' flammability class. The relevant regulations concerning electrical and lightning protection equipment must be complied with during the installation, conversion and operation of the biogas plant. Electrical surge protection must be also installed. If the biogas is stored and/or bottled, a fire protection compliance certificate must be obtained for the installation and use of equipment, machinery and appliances which are fire or explosion hazards during their operation. The gas that exits through the appliances that are used in the equipment or the safety unit must be diverted in such a way that they will not cause a fire or explosion. When 'A' and 'B' flammability-classified equipment is installed within a building, the blowdown should be done outside the building. The premises that host the equipment need to be equipped with a gas concentration sensor which can issue an audible and a visible sign at 20% of the explosive limit value and be able to start emergency ventilation and also initiate the necessary intervention procedures appropriate for the technological process that are prescribed by the operator if the hazardous gas level reaches 40%.

A safety unit should be installed to separate 'A' and 'B' flammability-classified equipment (in front of it or behind) to prevent the spread of a fire or explosion. The automatic control system (process control) of the plant should be planned in a way that in case of malfunction equipment can be controlled manually. Any malfunction should be indicated using auditory and visible signals as well. The contact details for those who need to be informed in the case of a malfunction must be kept in a very visible place in the control room. The gas discharging units must be protected from accidental or unauthorized opening. The maintenance workers must be supplied with portable methane gas sensors during when they undertake maintenance of technological equipment. The employees of the biogas plant must also possess fire protection certificates according to the 57/ 2005 (XI.30.) decree of the Ministry of the Interior. Furthermore, employees of the biogas plant must be (re)trained in fire protection activities every half a year [17].

A protective distance must be created, as prescribed, to prevent the development of a possible fire, explosion or other harmful effects in order to protect the buildings of the biogas plant. Within the specified protective distance the storage of combustible materials, smoking, the growing of woody plants, the installation of electrical overhead wires, pillars or electrical equipment exceeding 400 V, as well as placement of buildings not related to the equipment or public utility is forbidden. Within the protective distance starting open fires or undertaking activities that may cause sparks or other fire hazards can only be done after the obtaining of a valid licence that is specifically issued for the pertinent incendiary activity.

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