Landfills as methane bombs

Mummy: we separate our waste so carefully,

but what happens to it afterwards?

Oleg Kotsyurbenko

Institute of Oil and Gas, Yugra State University, Khanty-Mansyisk, Russia

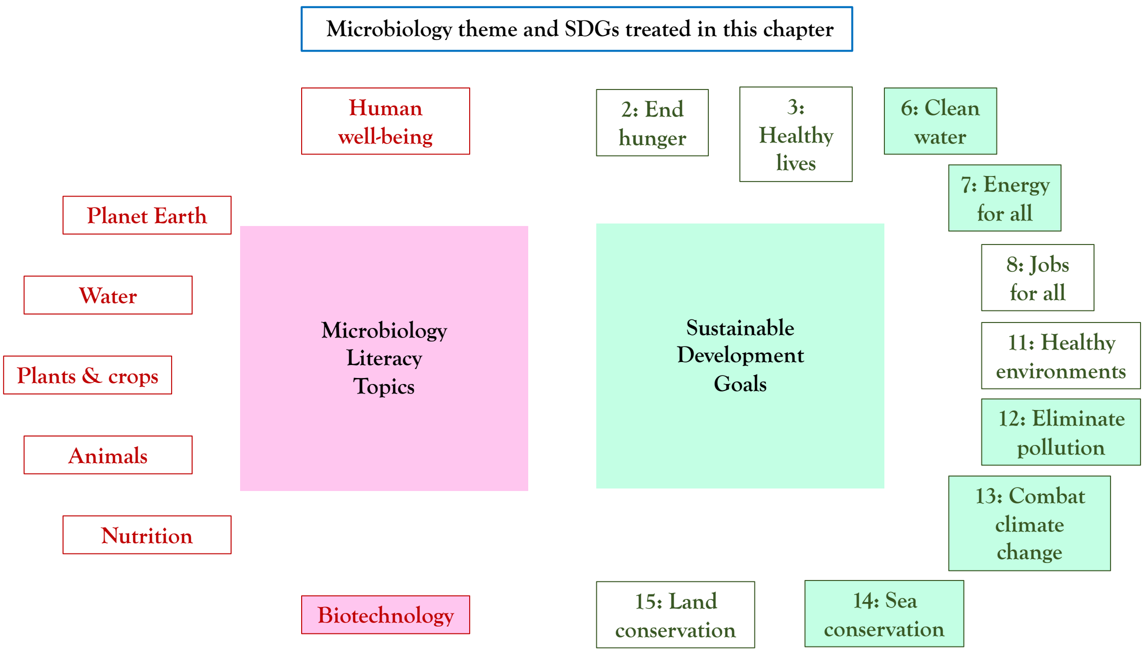
Landfills as methane bombs

Storyline

Currently, disposal of garbage or municipal solid waste is one of the most urgent problems of our civilization. A successful solution to this problem begins at the household level with the participation of people in the sorting of garbage, as well as with an understanding of the need to keep our environment clean. The main method of utilizing the organic fraction of garbage is its microbial decomposition. Microorganisms involved in the decomposition of municipal wastes are closely related to each other and are able to degrade huge amounts of garbage at landfills. Knowing the basics of the living activities of the microbial community, the harmful effects of waste decomposition products on the surrounding environment ecology, as well as the ways of neutralizing and rational use of them, helps the younger generation develop a sense of responsibility for their actions, forms ecological thinking and awareness of the universal interconnection of various phenomena in the world.

The Microbiology and Societal Context

The microbiology: microbial degradation of organic matter; waste treatment, soil microbial communities; aerobic and anaerobic microbial processes; environmental pollution; microbial greenhouse gas production; biogas production; bioremediation. *And, peripherally for completeness of the storyline:* biofuel production; bioremediation business. *Sustainability issues:* health; food and energy; recycling technology; protection of the environment; global warming.



Landfills: The Microbiology

1. ***What are municipal solid wastes?*** Landfills are sites of disposal of municipal solid wastes. MSW are wastes of the economic activity of the population, food residues and household items that have lost their consumer characteristics, and hence their consumer value. Sources of such wastes are household activities, trading enterprises, medical and educational institutions, and municipal services. The composition of the wastes includes defective units, food scraps, all kinds of bags,

packaging, films, construction and street garbage. Organic matter constitutes the bulk of MSW. A high content of organic components (up to 50-70% of the total mass of waste) is especially characteristic of city wastes (Fig. 1), which include chemicals such as cellulose, starch, proteins, fats, lipids and polymer plastics.

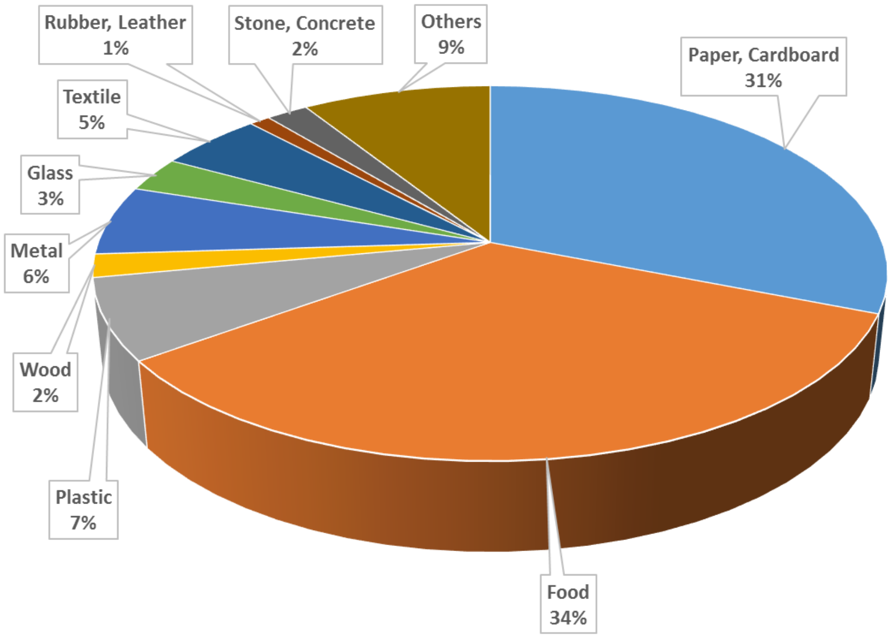


Fig. 1 Composition of Municipal Solid Wastes (MSW). Solid wastes in large cities always have less food wastes and more packaging materials (paper, plastics, non-ferrous metals). The content of non-ferrous metals in MSW is associated with the use of aluminum cans for beer and other drinks. In recent years, active development is in progress to replace conventional plastic used as packaging material with biodegradable plastic, which can be utilized together with other organic matter.

2. ***Wastes need to be separated because they consist of different materials which should be handled differently.*** Since the components of MSW are very different in their chemical nature, the methods for their processing can also be different. To increase the efficiency of waste processing, separate collection of MSW has been put into practice in all progressive countries. If all these components are not separated, but simply stored together, then their decomposition time will be very different (Table 1) and the negative impact on the environment will increase. Each type of garbage should have its own recycling technology.

Table 1. Average decomposition time of various components of MSW.

Type of MSW	Decomposition time
Toilet paper	2-4 days
Newspapers	1-3 months
Apple cores, cardboard boxes	1-5 months
Cotton rope, photos, matches	3-14 months
Boards, butts, milk bags, magazines	1-5 years
Painted wood, packages	15 years
Styrofoam packaging, iron cans	50 years
Batteries, aluminum cans	200 years
Plastic	400-450 years
Fishing line	600 years
Glass	Non-degradable waste

In addition to organizing separate collections of different classes of garbage, there are factories where solid wastes are continuously sorted on special conveyor belts (https://www.youtube.com/watch?v=nUrBBBs7yzQ; https://www.youtube.com/watch?v=c2Tr-U0nALM; https://www.youtube.com/watch?v=kTpRUXS2wmA). First, ferrous metal-containing objects are removed by a massive magnetic plate. Then plastic bags and other plastic items are removed by a strong stream of air, which blows them off the belt. Next, broken glass, glass bottles and ceramics are removed by means of strong vibration supplied to the belt. At the end of this sorting procedure, the garbage has been divided into fractions, which are then further processed. Components such as paper, metal, glass, packaging materials can be burned or prepared for recycling. Disposal methods based on microbiological processes are actively being developed for food waste, the majority of which is currently sent to landfills.

3. ***A modern landfill is a complex industrial enterprise, a bioreactor on a geological scale.*** At present, landfill storage is the most common method of disposing of MSW in the world. Modern landfills are large industrial enterprises designed for the storage, isolation and safe, and often beneficial, disposal of various types of waste.

The main construction site of the landfill is a solid waste storage area, which is a complex environmental engineering structure. Each modern landfill has its own design features, which directly depend on the specifics of local conditions. For the organization of landfills, quarries formed during the extraction of sand and clay, in which there are no valuable wood species, areas in forests, ravines and other territories can be used.

The main factors that are taken into account when choosing such a place are topography, location of roads, localization of settlements, prevailing and dominant winds, and other factors, with the highest preference being given to areas with an underlying water-impermeable matrix, like clay to protect underlying groundwaters from pollution with leachate, the liquid that seeps from landfills. Once a suitable site has been identified, the landfill pit is excavated.

The project for organizing modern landfills provides for the installation of a system for intercepting, discharging and cleaning of leachate, which consists of liquids deposited in a landfill and compounds that dissolve in these liquids and in the rainwater the landfill receives (see below).

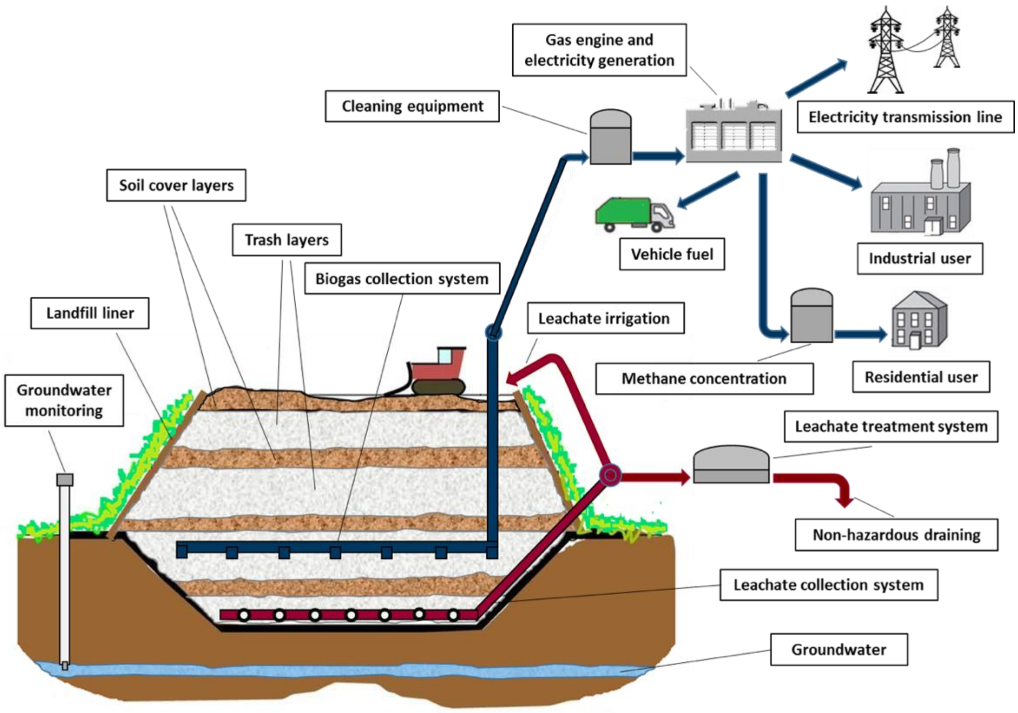


Fig. 2 The structure of the landfill and ways to use biogas.

The preparation of the landfill includes compulsory sealing and waterproofing of the bottom, and the installation of a special impermeable screen laid across the bottom and sides of the landfill and drainage system to minimize contact of the waste and its derivatives with the environment and to protect it from soil and groundwater pollution, as well as a system of observation wells for monitoring groundwater quality, and pipe laying to collect gas generated at the landfill (Fig. 2).

Garbage is compacted using special heavy machines. Waste at the landfill should be deposited in layers, with each two-meter layer of garbage deposit being covered with a half-meter layer of soil. The thickness of the resulting "sandwich (layered) cake" can reach tens of meters. According to European standards, embankments at landfills can be up to 40 meters high.

The completed landfill is covered with a final 1m layer of soil. The average landfill area can be from 50 to 300 hectares. A landfill is divided into multiple sections, which are successively constructed every 3-5 years. The operational lifetime of a landfill must be at least 15-20 years.

The landfill must contain:

1. a waste storage area.
2. an economic zone.
3. engineering facilities that support the landfill, including power lines and access roads.

At a modern landfill, facilities exist for the sorting and further processing of waste, laboratories for analyses, etc. Although, as indicated above, wastes are materials that have lost their consumer characteristics, and hence their consumer value, they still may contain useful components and hence have intrinsic value. Such an infrastructure increases the options to recover value from MSW and simultaneously reduce their negative impacts on the environment.

4. ***Microorganisms can degrade complex organics in different zones of landfill.*** The high content of organic matter in the waste deposited in a landfill, and the porous structure of the waste, even after mechanical compaction, are excellent conditions for the development of the microbial community, which is capable of degrading various organic compounds. In this regard, the landfill can be defined as a huge industrial fermenter of a geological scale.

According to the availability of oxygen, the landfill body can be divided vertically into three zones – aerobic (with unlimiting oxygen), microaerophilic (with limiting oxygen), and anaerobic (without oxygen). In each zone, distinct microbial processes occur. (Fig. 3).

Atmospheric oxygen penetrates into the upper zone (the covering soil and upper waste layer, not more than 1 m thick) where aerobic microorganisms perform oxygen respiration. They actively consume oxygen and, thus, prevent its entry into the lower zones of the landfill. In the aerobic zone, microbial processes of oxidation of organic compounds lead to the formation of CO_2, H_2O, NO_3^-, SO_4^{2-} and a number of other compounds that can partially migrate to the lower zones.

The second relatively narrow transition zone is located below, where the processes of microbial degradation of organic compounds occur under microaerophilic conditions, that is, at a reduced oxygen concentration. In particular, bacteria use nitrates and nitrites, in place of oxygen, and thereby convert these to nitrogen gas.

The third and most extensive segment of the landfill is the anaerobic zone. It is formed quite quickly as a result of oxygen consumption by microorganisms in the upper layers. In this zone, a complex anaerobic microbial community operates, which can develop only in the absence of oxygen.

Since microorganisms obtain significantly less energy under anaerobic conditions, they try to gain it entirely from the available substrates. As a result, complex organic polymers such as cellulose (the base component of paper) or proteins (the main component of food waste) are decomposed to simple gaseous compounds - methane (CH_4) and carbon dioxide (CO_2). In the process, hydrogen sulfide (H_2S) and ammonium (NH_4^+) are also formed.

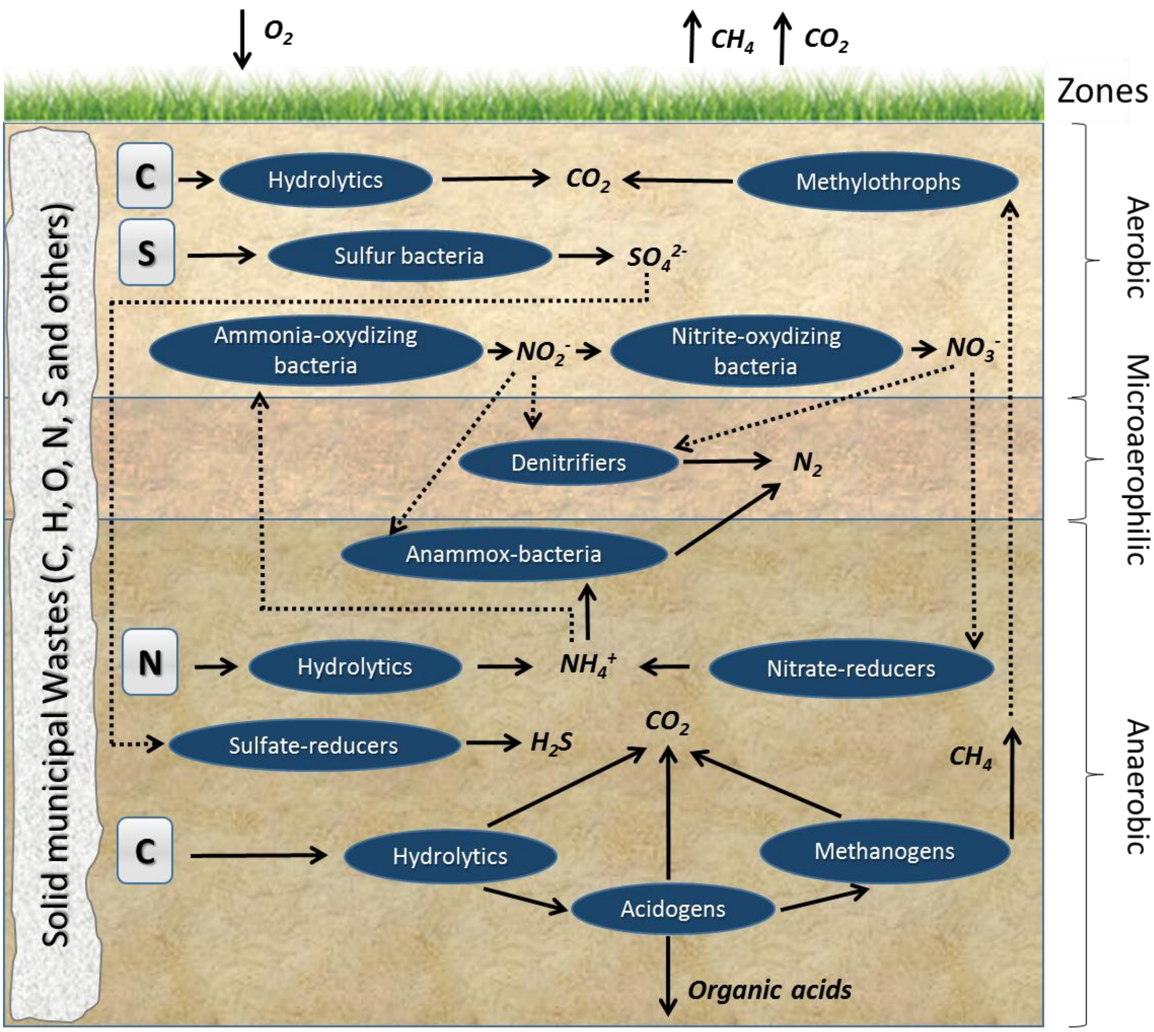


Fig. 3. The zonal distribution of the main microbiological processes of decomposition of the waste organic matter in landfills.

To carry out complete decomposition of organic materials, anaerobic microorganisms organize into communities in which the different members are connected to each other by trophic relationships creating a trophic chain or web. The microorganism that consumes the substrate, forms products that are substrates for other microorganisms of the trophic chain. Thus, hydrolytic bacteria break down polymer organic compounds into monomers, which are mainly sugars and amino acids. These monomers are in turn decomposed into simpler compounds. As a result of these processes, various organic acids are formed, which can be further decomposed by microorganisms or partially enter the wastewater of the landfill. The last microorganisms in the anaerobic trophic chain are methanogens. They use a number of simple organic compounds and form methane, which, together with carbon dioxide, diffuse into the upper zones. In the presence of oxygen, upper zone microorganisms are able to consume methane and form carbon dioxide.

5. Products of microbial degradation processes in landfills are dangerous for environment.
In the process of decomposition in landfills, various MSW become sources of a wide range of harmful substances that affect the environment, polluting groundwater, poisoning the atmosphere, and impacting soil and local fauna and human health. The main end product of microbial processes at the landfill is the biogas consisting of all gaseous products formed.

The second important component is the leachate, which is formed from atmospheric precipitation passing through the bulk of the wastes, groundwater affecting the landfill, and the initial moisture from the wastes themselves or moisture generated during their decomposition.

6. ***Negative influence of biogas on the environment and human health is caused by its complex composition.*** The main components of biogas are methane (40–60%) and carbon dioxide (30–45%). In addition to these compounds, it may contain various micro-impurities, some of which are toxic substances such as hydrogen sulfide (H_2S), carbon monoxide (CO), hydrogen (H_2)), chlorinated and aromatic hydrocarbons, etc. The main component of biogas, methane, can cause large-scale fires and explosions, which themselves create even more toxic gases. This means that landfills can be considered to represent areas of significant environmental risk, and even as "chemical time-delay bombs".

Despite the fact that some methane is oxidized by aerobic methanotrophic bacteria in the upper layers of the landfill, a significant part of it can pass through all layers of the landfill and enter the atmosphere, where it contributes to the greenhouse effect - CH_4 is a very potent greenhouse gas. Landfills are considered to be one of the most important anthropogenic sources of methane, with contributions to global emissions reaching 10-15%. For this reason, it is very important to record the amounts of CH_4 emitted from landfills and relate them to the specific characteristics of individual landfills. Even if the landfill is already closed and does not accept garbage, it can be a significant source of biogas for several decades.

7. ***Biogas can be beneficially used for many purposes.*** Since the methane content in biogas (landfill gas) is quite high, it can in principle be used to generate energy (Fig. 2). From 1 cubic meter of biogas, it is possible to get about 2 kW of electricity. At landfills, biogas is extracted by a system of wells and air-blowing, flare or vacuum facilities. The continuous waste delivery to landfills ensures continuous gas production. It cannot, however, be used directly due to toxic impurities. After a series of purification steps, which may include mechanical, chemical, and biological removal of impurities, biogas can be used for various purposes. For example, next to the landfills, you can build factories that will use the energy of landfill gas to burn bricks and tiles. Heat from gas burning can be used to heat buildings, maintain greenhouses and livestock in rural areas, to power refrigerators in the enterprise, etc. Biogas can be used as fuel for turbines and engines or as a fuel for vehicles. Biogas energy can be directed to the needs of the landfill itself. After converting the chemical energy of biogas into electrical energy, it can be used for the needs of a small village. And after methane enrichment and bringing its concentration in biogas to 95-98%, it can be used in residential complexes.

Currently, there is an international Global Methane Initiative (GMI) database for landfills, which contains data on more than 700 landfills from around the world, allowing users to get comprehensive information about landfills, biogas utilization and landfill project implementation opportunities in a particular country (www.globalmethane.org).

8. ***Older landfills may exhibit high methane emissions.*** To reduce methane emissions from a landfill that does not have a system for collection of biogas, it is possible to intensify methane oxidation by aerobic microorganisms in the upper soil layer. This involves the introduction of an active consortium of methanotrophic bacteria grown in the laboratory into the soil of landfills. Together with indigenous methanotrophic bacteria functioning in the upper layer of the landfill, the bacteria grown in the laboratory can form a strong microbial biofilter that intercepts the passage of methane on its way from the lower layers where it forms.

9. ***Leachates need to be detoxified.*** Leachate is a landfill wastewater with a high concentration of chemical elements, mainly various heavy metals such as copper, cadmium, zinc, lead, cobalt, mercury, etc., dissolved salts, intermediate organic decomposition products, nitrogen compounds, and other compounds. The total mass of leachate from the landfill can ultimately amount to up to 50% of the mass of the stored waste. The collection and purification of the leachate is a prerequisite for the operation of any large landfill, to avoid it entering groundwater or natural reservoirs, where it would poison all living things for many kilometers around.

A variety of technologies are used to neutralize landfill wastewaters: mechanical filtration using sand filters, settling, evaporation, biochemical treatment using special additives, biological filtration and even laser treatment. Sometimes part of the leachate is returned to the waste deposits for a second cycle of processing by microorganisms of the landfill. Only after removal of all components that are toxic to the environment can leachates be channeled into soil and water.

One of the promising biological methods for cleaning leachates is the use of fungi. The effectiveness of such purification depends on the type and concentration of organic matter, the selected fungi and the conditions under which the process occurs.

In the process of purification, valuable resources can be extracted from leachates, in particular, various metals that are accumulated in them in rather large quantities. For example, the amount of copper deposited in landfills is comparable to the amount currently used in the technosphere.

Thus, modern technologies based on processes carried out by microorganisms allow us to safely handle huge amounts of solid wastes while assuring environmental safety and, at the same time, recover valuable resources such wastes contain.

10. ***Alternatives to landfills: composting, vermicomposting, bioreactors.*** There are several alternatives to landfills for the handling of solid wastes, based on thermal and biotechnological technologies. For all of these technologies, prior separation of wastes is a prerequisite. Thermal methods include burning with recovery of energy. Biotechnological methods include composting, vermicomposting and methane digestion in anaerobic bioreactors.

Composting is a biological oxidation process in which organic substrates are degraded by aerobic microorganisms under conditions of elevated temperature and humidity to form more stable products, known as compost, which is used as fertilizer. Composting takes place with the release of heat and therefore is often a traditional method of processing and neutralizing organic wastes of a limited volume, especially agricultural ones, in countries with cold and temperate climates.

Vermicomposting is the process of degrading the organic fraction by earthworms using organic matter as a source of nutrition and, at the same time, their habitat. As a result of vermicomposting, fertilizer is produced, wastes are neutralized and biomass of earthworms is obtained, which can serve as a feed additive in agriculture and animal husbandry.

During anaerobic digestion of food wastes in bioreactors, disinfection of raw materials, production of biofertilizers and the formation of biogas occur, which can be used as described above. There are also advanced technologies for obtaining various valuable chemical and biological compounds from MSW. This is the safest way to dispose of organic wastes, as the content of the bioreactor is completely isolated from the environment. In bioreactors, the organic solid waste fraction is often fermented along with sewage sludge.

11. ***Landfills can be recultivated.*** Each landfill has an area limit; once this area has been used up, the landfill must be closed. In order to make the territory of the closed landfill site safe for people and the environment, and even useful for economic activities, it is necessary to carry out its recultivation (remediation).

After the closure of the landfill, the activity of microorganisms that decompose wastes decreases gradually, but the release of biogas and leachates occurs for decades, approximately 50-60 years, until the organic substrates are depleted. Once landfill processes have practically stopped, the territory can be recultivated.

To improve the land, various rehabilitation and phytoremediation measures are carried out, such as fertilizing the soil, preparing the soil and the subsequent planting of trees, plants and sowing herbs. Plant cover restoration (phytocapping) is practiced at landfills to create a certain barrier and prevent the harmful effects of landfill components on the environment. Phytocapping also contributes to the accumulation and preservation of a certain amount of water in the soil and the initiation of its transport through plants with subsequent evaporation. The mobility of pollutants is greatly reduced due to their retention by the root system of plants and immobilization in the rhizosphere (phytostabilization). This greatly limits distribution of pollutants outside the landfill sites. Plants with high biomass yields, which can be used to produce fuel and energy, are commonly used.

Together with an obvious positive environmental and economic effect, this technology contributes to a better aesthetic perception of landfill areas, which are mainly adjacent to human settlements. At the end of the biological stage of landfill remediation, a picturesque forest park may appear in its place and even agricultural activities can be carried out if soil samples taken at this place will consistently show its satisfactory condition. However, until this time, years and sometimes decades should pass from the time of the initial recultivation.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 6. Ensure availability and sustainable management of water and sanitation for all**; *improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials.* Landfills are the source of various hazardous compounds, including products of microbial decomposition of organics as well as pathogenic microorganisms. They can pollute natural water basins and be the cause of infectious disease dissemination. Avoiding these hazards requires safe design and operation procedures and their associated costs.

- **Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all.** Methane is one of the main products of decomposition of organic fraction of wastes. It is an energetically effective compound that can be used to produce heat and electrical energy. A special system of methane capture is installed at the landfills, which is connected to systems for distribution to the consumers. The investment costs of these systems are generally more than recuperated by the value of the methane energy source.

- **Goal 12. Ensure sustainable consumption and production patterns;** *sound management of chemicals and all wastes.* Solid municipal wastes and their decomposition products can damage the ecology of the surrounding environment. The proper organization of the landfill with reliable system of environmental protection is necessary to avoid inputs of hazardous compounds in water, air and soil. However, some valuable elements can be also extracted from leachates and reused in the industry.

- **Goal 13. Take urgent action to combat climate change and its impacts.** Microbial processes of organic matter degradation at landfills result in formation of various gaseous products, mostly methane and carbon dioxide. Both of these gases are main contributors to the greenhouse effect. To reduce the emission of biogas to the atmosphere, a collecting system should be installed at landfills.

In addition, biomass of methanotrophic bacteria grown in the laboratory can be applied to the soil of the top layer of the landfill to increase methane consumption activity.

- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development;** *reduce marine pollution of all kinds.* All types of hazardous compounds produced at a landfill can run into a marine system, if the landfill is located on or near the coast and if it fails to operate safely.

Potential Implications for Decisions

1. ***Individual***

a. Understanding the importance of sorting garbage (investment of the personal time and effort vs the environmental considerations?).

b. Understanding the importance of using special rubbish bins on the streets (investment of the personal time and effort vs the general environmental and ethical considerations?)

c. Choice to buy goods in biodegradable packing (decision to reduce environmental risks by spending time for shopping)

d. Practising proper hygiene while dealing with wastes (decision to spend time to reduce health risks)

Non-microbial parameters: financial costs of environmentally-friendly products

2. ***Community policies***

a. Local environmental consequences (pollution of public spaces and local water bodies with wastes).

b. Health costs associated with infection diseases.

c. *Non-microbial parameters: support of local businesses – production of biodegradable packing, organization of garbage separation, transporting garbage to landfills, creating new landfills, measures on remediation of the closed landfills, establishing plants for treatment of different sorts of wastes-.*

3. ***National policies relating to organizing landfills***

d. Healthcare economics of infection diseases

e. Environmental pollution

f. Ensuring safe drinking water supplies

g. Developing the 3 R's technology - reduce, reuse and recycle.

h. Greenhouse gas production and global warming,

i. Sequestration of land otherwise used for agriculture.

j. *Non-microbial parameters: policies relating to landfills: licensing the landfill enterprises, penalties for environmentally–unfriendly measures, preventing environmental pollutions*

Pupil Participation

1. ***Class discussions***

a. Enhancing of systems thinking

Studying the topic helps to understand the close relationships between the various processes and systems in which they occur: the ecosystem of the landfill and its impact on global ecology, the microbial communities of various zones of the landfill and their trophic relationships.

b. Understanding the role of microorganisms in the development of our civilization

The participation of microorganisms in the decomposition of wastes is the important condition for the development of modern civilization and ensuring the environmental conditions of its existence

c. Preservation of a healthy ecology near human settlements

The topic helps to understand the importance of implementing measures to protect the environment from the harmful effects of human products.

d. Contribution to the problem of maintaining health.

Familiarity with this topic should help to understand how carefully you need to approach the organization of any enterprises whose products may be harmful compounds that affect human health.

e. Contribution to the rational use of resources

Studying the topic allows us to formulate the problem of rational use of natural resources. The wasteful use of resources contributes to the increase in waste and the search for technologies for their processing

f. Contribution to learning the 3 R's technology - reduce, reuse and recycle

Mastering the material is important in the context of the study of 3 R technology, in which there are 3 main steps for environmentally oriented waste management.
https://www.youtube.com/watch?time_continue=219&v=OasbYWF4_S8&feature=emb_logo
https://www.conserve-energy-future.com/reduce-reuse-recycle.php
Additionally, you can come to a more advanced 5 R technology.
The 5 R's - refuse, reduce, reuse, repurpose, and then recycle
https://www.roadrunnerwm.com/blog/the-5-rs-of-waste-recycling

2. ***Pupil stakeholder awareness***

   a. Discussion of issues related to garbage in the wrong places. Analysis of situations when a group of friends leaves rubbish on a picnic in the forest.
   b. Discussion of the organization of separate garbage collection.
   c. Discussion of the implementation of biodegradable polymers in practice. The use of biodegradable polymers in the manufacture of packaging.

3. ***Exercise.*** What waste can be created during picnics and hiking, and how to dispose of it. Estimation of the decomposition time of various types of everyday rubbish (apple cores, paper tissues, notebooks, plastic bags from the supermarket, beer cans, Pepsi-cola bottles).

The Evidence Base, Further Reading and Teaching Aids

1. U.S. Environmental Protection Agency (2007) Landfill bioreactor performance: second interim report: outer loop recycling & disposal facility - Louisville, Kentucky, EPA/600/R-07/060. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1008B3R.PDF?Dockey=P1008B3R.PDF
2. "How does landfill and litter affect our wildlife?". *MY ZERO WASTE. January 30, 2009.* https://myzerowaste.com/2009/01/how-does-landfill-and-litter-affect-our-wildlife/
3. "Landfills are Ruining Lives".*www.cdenviro.com.* https://www.cdenviro.com/news/2017/october/landfills-are-ruining-lives
4. https://www.cewep.eu/municipal-waste-treatment-2018/
5. Fighting Mountains Of Garbage: Here Is How Indian Cities Dealt With Landfill Crisis In 2018 | Swachh Year Ender". NDTV-Dettol Banega Swasth Swachh India. December 31, 2018. https://swachhindia.ndtv.com/year-ender-2018-waste-management-landfill-how-indian-cities-dealt-with-landfill-crisis-29247/

6. Casella C. "India's 'Mount Everest' of Trash Is Growing So Fast, It Needs Aircraft Warning Lights" *ScienceAlert*. https://www.sciencealert.com/a-growing-mountain-of-rubbish-in-india-will-soon-require-aircraft-warning-lights
7. Horinko, Marianne, Cathryn Courtin. "Waste Management: A Half Century of Progress." EPA Alumni Association. March 2016. https://www.epaalumni.org/hcp/rcra.pdf
8. "Modern landfills". Archived from the original on February 22, 2015. https://web.archive.org/web/20150222005007/http:/beginwiththebin.org/innovation/modern-landfills
9. EPA, OSWER, ORCR, US. "Basic Information about Landfills". https://www.epa.gov/landfills/basic-information-about-landfills#whattypes. https://www.epa.gov/lmop/basic-information-about-landfill-gas
10. https://postnauka.ru/faq/27798 (in Russian)

Glossary

1. **Municipal solid wastes** (MSW) - solid waste resulting from municipal, community, commercial, institutional, and recreational activities including households, offices, hotels, shops, schools, and other institutions. They contain garbage, rubbish, ashes, street cleanings, dead animals, medical waste, and all other nonindustrial solid waste. The major components of MSW are food waste, paper, plastic, rags, metal, and glass.
2. **Biodegradable** - the ability of things to get disintegrated (decomposed) by the action of micro-organisms such as bacteria or fungi to its basic components while getting assimilated into the natural environment. Ideally, but not always, these substances degrade without leaving any toxins behind.
3. **Recycling technology** - the process of converting waste materials into new materials and objects. Different materials like plastics, glass, metals, paper, and wood are recycled by different specifically developed techniques.
4. **Landfills** - locations where disposable materials are sent, which are then buried underground. It is a low area of land that is built up from deposits of solid refuse in layers covered by soil (see the basic text for more detail).
5. **Leachate** - the liquid that drains or 'leaches' from a landfill and is generated from liquids present in the waste and from outside water, including rainwater, percolating though the waste. Leaching occurs when water percolates through any permeable material. The leachate can contain harmful substances that may then enter the environment.
6. **Biogas** - the mixture of gases, primarily consisting of methane and carbon dioxide, produced during anaerobic degradation of organic matter by anaerobic methanogenic microbial community. Biogas is a renewable energy source and can be used for electricity or fuel production.
7. **Fermenter** - an organism (microorganism) that causes fermentation.
8. **Aerobic** – definition of an organism (microorganism) requiring the presence of air or free oxygen for life.
9. **Microaerophilic** - definition of an organism (microorganism) requiring little free oxygen, or oxygen at a lower partial pressure than that of atmospheric oxygen for life.
10. **Anaerobic** - definition of an organism (microorganism) living in the absence of air or free oxygen.
11. **Oxygen respiration** - the biochemical process in which the cells of an organism (microorganism) obtain energy by a set of metabolic reactions with oxygen.

12. **Trophic relationships** - important connections between the organisms (microorganisms) in a food chain within an ecosystem.
13. **Trophic chain** (food chain) - a feeding hierarchy in which organisms (microorganisms) in an ecosystem are grouped into trophic (nutritional) levels and are shown in a succession to represent the flow of food energy and the feeding relationships between them.
14. **Hydrolytic bacteria** - microorganisms forming a variety of reduced end-products from the fermentation of different organic substrates, including various polymers. They hydrolyze polymeric compounds by extracellular enzymes that are excreted into the environment.
15. **Methanogens** - a group of anaerobic microorganisms that are capable of producing methane from a limited number of chemical sources, and are situated at the end of the trophic chain of the anaerobic microbial community.
16. **Methanotrophic bacteria** - a group of microorganisms that utilize methane as their source of carbon and energy.
17. **Greenhouse effect** - the process of the planet's surface warming caused by the presence of gases absorbing and emitting radiant energy in the atmosphere.
18. **Technosphere** - part of the environment that is made or modified by humans.
19. **Composting** - the biological degradation process of heterogeneous solid organic materials under controlled moist, self-heating, and aerobic conditions to obtain a stable material that can be used as organic fertilizer.
20. **Vermicomposting** - the process by which worms are used to convert organic waste into a nutrient-rich fertilizer.
21. **Methane digestion** - a sequence of processes by which anaerobic microorganisms break down biodegradable material with production of methane.
22. **Remediation** - the process by which land resources are restored to their former state so that the site no longer poses any significant threat to human health or the environment.
23. **Recultivation** - the reintegration of the area into the landscape, the final remediation phase.
24. **Phytocapping** - a capping technique that utilizes vegetation as a natural pumping system to reduce water being stored in the soil and hence to reduce the amount of water reacting with the buried waste and being released as leachate.
25. **Phytostabilization** - the establishment of a plant cover on the surface of the contaminated sites with the aim of reducing the mobility of contaminants through their accumulation by roots or immobilization within the rhizosphere, thereby reducing off-site contamination.