PROSPECTS OF ENERGY UTILISATION OF MUNICIPAL SOLID WASTE IN UKRAINE

UABio Position Paper № 22

Yuri Matveev, Georgiy Geletukha

April 2019

Published at www.uabio.org: 22.04.2019
The publication is available at: www.uabio.org/activity/uabio –analytics
Responses and comments: matveev@uabio.org
English version: 18.07.2019

© Bioenergy Association of Ukraine, 2019
Please note that any copying or publication of association materials without reference to the source is prohibited

GRATITUDE

The authors express their sincere gratitude for the detailed acquaintance and valuable comments

Tetyana Omelyanenko

Lyudmila Poltorachenko

Sergei Sokol-Chernilovsky

Sergey Shmarin

CONTENT

Summary

Position Paper No 22 of the Bioenergy Association of Ukraine is devoted to the analysis of the prospects for energy utilization of municipal solid waste (MSW) in Ukraine in connection with adoption of the National Waste Management Strategy in Ukraine until 2030. The situation with management of MSW in Ukraine and the world as a whole is presented, technical and economic indicators of main ways of MSW energy utilization are considered. Criteria and priorities of the choice of technologies for MSW treatment are described, recommendations on elimination of barriers for their development are given.

Introduction

The National Waste Management Strategy in Ukraine until 2030 envisages the transition from simple waste disposal at waste dumps and landfills to the integrated waste management system. Special measures of the Strategy for household waste include the growth of its processing level - commissioning of waste treatment plants, implementation of pilot projects of fuel production from waste based on mechanical and biological treatment facilities, introduction of pilot projects on biological stabilization of mixed household waste.

The choice of MSW treatment technology should be part of the regional waste management plans development. One of the first plan's priorities is a construction of regional landfills for waste disposal created with use of the principles of inter municipal cooperation. Waste treatment facilities will be in most cases geographically tied to regional landfills. The choice of specific processing technology depends on many factors, and currently one of the main factors in Ukraine is the cost of solid waste treatment.

The choice of energy utilization is usually determined by the following considerations:

1. Possibility of increasing of waste processing depth, especially in the case of thermal treatment, in order to minimize disposal and the need for new landfills;
2. Possibility of obtaining an additional source of energy replacing fossil fuels such as natural gas or coal;
3. Possibility of obtaining additional income[1] by sale of electricity and heat, and in some cases a solid fuel substitute.

It means that energy use from MSW is a way to generate income after implementation of possible measures at the upper levels of the waste management hierarchy. Expediency of energy utilization can be determined by reduction the amount of disposed waste and increasing the life duration for new regional landfills. The experience of developed countries shows that separate collection, reuse and recycling is developing simultaneously with solid waste energy use competing to a certain extent in raw materials, but not contradicting each other.

Achieving the goals of the Strategy until 2030 is a challenge for Ukraine. Among the main objectives of the Strategy can be highlighted:

- closing existing old landfills and waste dumps, finding places for new landfills and waste treatment plants;
- preparation of possible and suitable for investment projects;

[1] It should be noted that additional income through electricity and heat sale does not mean automatic achievement of investor-friendly economic parameters of the project

- harmonization of joint efforts of the state and private investment sectors;
- discussion with the public on the need to increase tariffs for MSW management.

Status of municipal solid waste treatment in the world

The main EU's waste regulatory document, which defines the legal framework and the basic principles of waste management is the 2008/98/EU Directive “On waste”. The directive introduces common definitions of "waste", "recycling", etc. Under the term "waste" means any substance or object which the holder discards or intends or is required to discard. The said Directive identifies 16 categories of waste, on the basis of which a single European waste list (Decision 2000/532/EU) has been introduced, which is periodically reviewed and updated.

The modern hierarchy of waste management is shown in Fig. 1. The highest priority have prevention or minimisation of waste generation. Further with the priority reduction is waste reuse and recycling. In the recycling process waste is processed into the products, materials or substances (including processing of organic material). Next priority belongs to the methods of treatment accompanied by energy production. The last in the hierarchy is disposal at the landfills and combustion without energy production. So landfilling is still necessary, but had the last place in this priority chain.

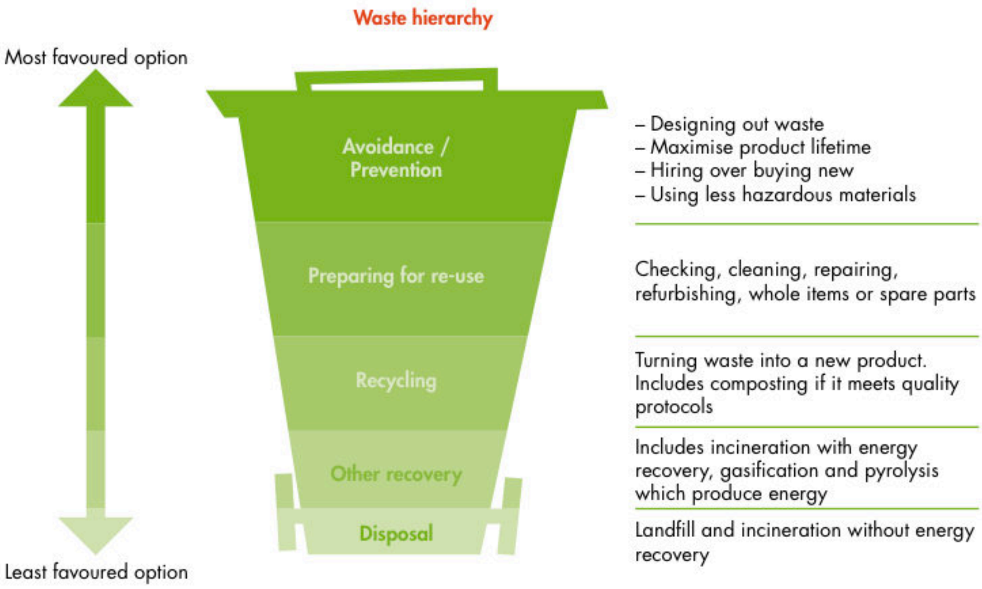

Fig. 01 – Waste management hierarchy

(Source: National Waste Management Strategy in Ukraine until 2030)

It should be noted that landfilling may also be accompanied by energy production by introduction of landfill gas (LFG) recovery and energy use systems. LFG is generated in the process of natural degradation of biogenic wastes.

It is also important to note that separate collection, reuse, recycling and energy use of solid waste competing with each other for raw materials, but do not exclude each other. This thesis can be confirmed by Figure 2, which shows the situation with waste treatment in the member countries of the Organization for Economic Cooperation and Development (OECD) [2].

[2] Organization of economic cooperation and development - international economic organization of developed countries that recognize the principles of representative democracy and free market economy (Wikipedia)

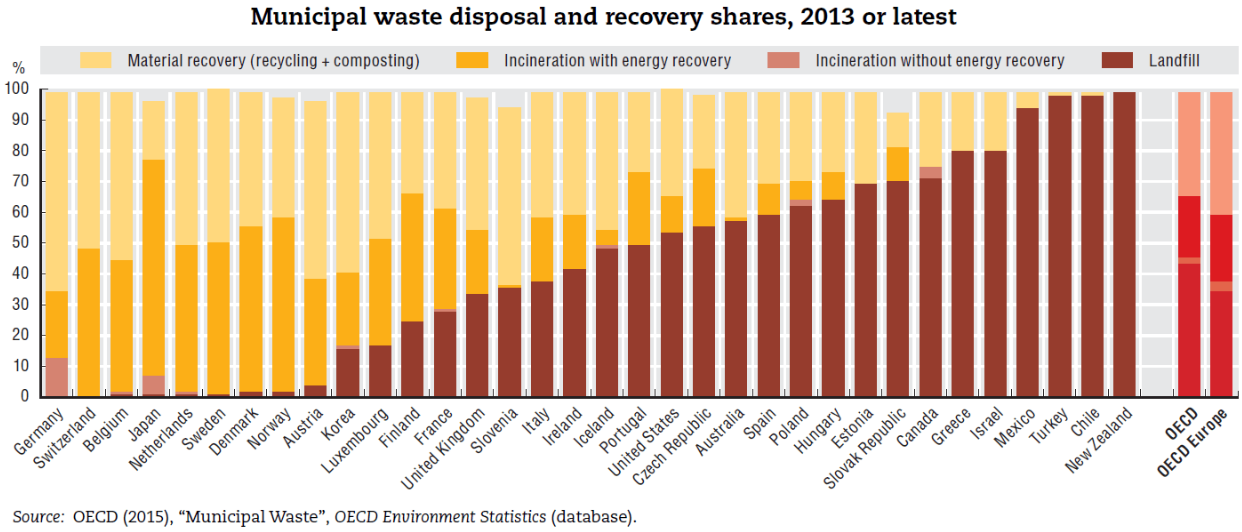

Fig. 02 – Waste management in OECD countries
(Source: OECD 2015)

It is easy to see that countries that have significantly reduced the share of landfilling in recent decades have achieved this result by combining the recycling including composting with thermal treatment - combustion, which in most cases involves the useful energy production. These are at least developed European countries such as Germany, Belgium, Austria, and the Netherlands. It means the countries that have practically abandoned waste disposal use all possible waste recycling methods, both material and energy, without giving preference to any of them.

However, the situation in different developed countries and regions varies. Quantitative indicators of various types of solid waste management in the world are summarized in Table 1 separately for America, Europe and the Pacific region.

Table 1 – Amount and ways of waste management in OECD countries[3]

	North and South America	Europe, Turkey and Israel	Japan, South Korea, Pacific region	Total OECD
Waste amounts, Mt	291,5	263,9	85,3	640,7
Waste amounts, kg/(cap·an)	607	469	421	514
Recycling in %	24%	25%	31%	25%
Composting in %	8%	13%	0,3%	9%
Combustion (without energy use) in %	0,1%	3%	4%	2%
Combustion (with energy use) in %	9%	20%	48%	18%
Landfilling in %	60%	38%	17%	45%

It is evident that the largest amount of waste is generated by Americans, mainly the United States, and most of that waste is still sent to landfills (60%). Recycling and composting are most developed in Europe (38%). Thermal treatment of waste is used in Asia and the Pacific (48%), as well as in Europe, and more than 90% of the waste is used to generate energy.

[3] The Climate Change Mitigation Potential of Waste Management – Dessau –Roßlau, July 2015.

Figure 3 shows the European map of MSW thermal treatment in 2016 according to the Confederation of European Waste-to-Energy Plants (CEWEP). In total, the map represents 522 waste incineration facilities treated about 93.7 million tons of solid waste per year.

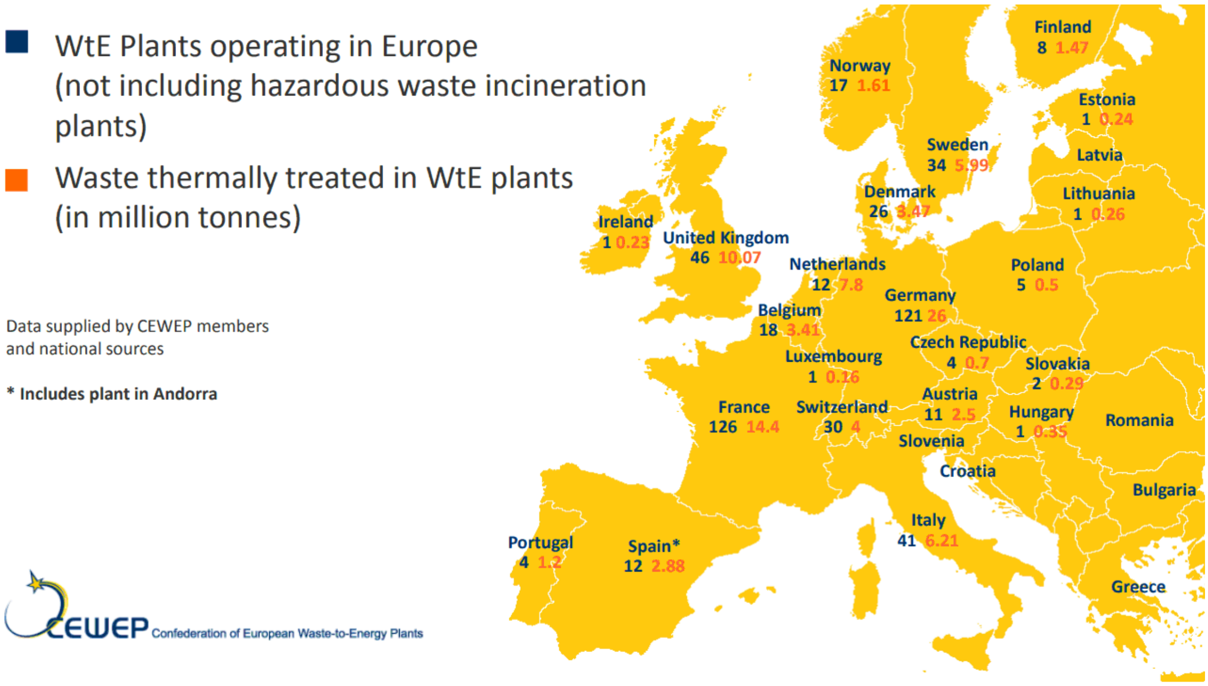

Fig. 03 – Thermal treatment of MSW in Europe (2016)

(Source: www.cewep.eu)

Status of waste management in Ukraine

In 2018 in Ukraine recycled and utilized about 6.2% of MSW due to the introduction of separate collection in 1181 settlements, 26 waste sorting lines, one waste incineration plant and three separate incinerators. Two per cents of MSW were combusted, 4.2% were sent to secondary materials collection points and recycling plants[4]. The rest (about 93%) were landfilled. There were six thousand landfills and waste dumps with a total area of more than 9 thousand hectares in 2017.

Consequently, 9-12 mill tons of solid waste are generated annually in Ukraine. About 93% are sent to landfills and waste dumps. At present, the country has the only one waste incineration plant and several dozen sorting lines, the efficiency of these lines does not exceed 15-20% by weight. Landfill gas is collected at 20 sites for further electricity generation.

The only attempt to start the waste recycling plant with the announced Refuse Derived Fuel (RDF) production proved to be unsuccessful in 2013 mainly due to insufficient technical solutions and the absence that time special tariff for solid waste treatment. Plans for the construction of various waste treatment facilities have been announced periodically over the past twenty years. Currently, there are real plans to introduce mechanical-biological treatment (MBT) technology in L'viv and Khmelnitsky.

Status of legislation in Ukrainian waste management

At present, the Ministry of Regional Development, Construction, Housing, and Communal Services of Ukraine implements state policy in the field of waste management. The Ministry of Ecology and Natural Resources of Ukraine provides normative and legal regulation on issues related to the implementation of waste management operations

National Waste Management Strategy in Ukraine until 2030

New waste management strategy by 2030 was adopted by the Cabinet of Ministers of Ukraine (CMU) in 2017. After that the draft National Waste Management Plan was submitted to the CMU and approved in February 2019. A draft Framework Law "On waste" is currently under consideration for the implementation of the requirements of 2008/98/EU Framework Directive "On waste".

According to the requirements of the National Plan, regional waste management plans should be developed no later than two years after its approval. These plans are the basis for further financing of infrastructure projects on waste management from state and local budgets.

Waste management strategy until 2030 envisages the transition from waste disposal at landfills and waste dumps to the integrated waste management system. At the same time, the strategy foresees construction of sanitary regional landfills network for MSW disposal. Due to relatively high capital and operational costs of landfills meeting the requirements of EU legislation, such facilities should have a minimum capacity of about 50,000 tons per year (optimal capacity –

[4] Status of waste management in Ukraine in 2018 (Стан сфери поводження з побутовими відходами в Україні за 2018 рік), - in Ukrainian.

http://www.minregion.gov.ua/napryamki –diyalnosti/zhkh/terretory/stan –sferi –povodzhennya –z –pobutovimi –vidhodami –v –ukrayini –za –2018 –rik/

100,000 tons/year or more) and cover agglomeration of at least 150,000 persons The optimal coverage (cluster) should cover the territory with at least 400,000 peoples.

Рис. 04 – Development of legislation for municipal waste management
(Source: ProTrach (ProMusor) for Experts (FB)

The special measures of the National Waste Management Strategy include the growth of MSW treatment level taking into account:

- Achievement of 50% recycling rate from the total volume of MSW in 2030 by increasing the coverage of 48% Ukrainian population by separate collection of MSW and commissioning of additional waste sorting lines and waste processing plants.
- Development of pilot projects for RDF/SRF production based on mechanical biological treatment (MBT) facilities under condition of their location in close proximity to cement plants.
- Implementation of pilot projects for biological stabilization of mixed MSW.

The Strategy contains the following target values as long-term perspective (2026-2030):

- Percentage of MSW for re-use – 10%;
- Percentage of MSW for recycling – 20%;
- Percentage of MSW for thermal treatment – 10%;
- Percentage of MSW for landfilling – 30%.

Framework Law of Ukraine "On Waste Management"

According to the draft law of Ukraine "On waste management"[5] municipal solid waste include household wastes, including paper, cardboard, glass, metals, plastics, biological waste, wood, textiles, packaging, electrical and electronic waste, spent batteries and accumulators, bulky waste, as well as waste from other sources similar in composition to waste from households.

In addition, MSW include waste of the settlement infrastructure including green garden and street waste.

[5] https://menr.gov.ua/news/32869.html

According to the draft law state power bodies, local governments, enterprises, institutions and organizations are obliged to support modern hierarchy of waste management in the following sequence:

1) prevention of waste generation;
2) preparing for re-use;
3) recycling;
4) other recovery operations (including energy recovery)/or utilization;
5) landfilling (disposal).

When applying the hierarchy of waste management, the principles of state policy of waste management, environmental and economic feasibility, technical capacity and the best available technologies should be taken into account.

Prevention of waste generation is the highest level of hierarchy that aims at optimizing of design processes from resource utilisation, product manufacturing (eco-design) and waste generation.

The second priority is preparing for re-use actually requiring creation of the industry for testing, cleaning, and processing of waste or items that have not yet become the waste, with the subsequent return of these goods for consumption.

According to the draft law *recovery* is any operation that results in waste material being used as a secondary raw material that is able to replace the primary material necessary for the production of new products or waste prepared to replace the primary material. *Recycling* is a recovery operation when the waste is converted into the products, materials or substances that involve also organic material processing, but does not include energy recovery or recycling into materials that will be used as a fuel.

In general, the waste management system, in particular the municipal, in accordance with the draft Law of Ukraine "On waste management" should look like it is shown in Fig. 5, including various methods of energy utilization, as shown in the last row of the diagram.

Landfilling (disposal) of waste in specially equipped places/objects that meet environmental standards should only be done if it is not possible to involve the highest levels of the hierarchy.

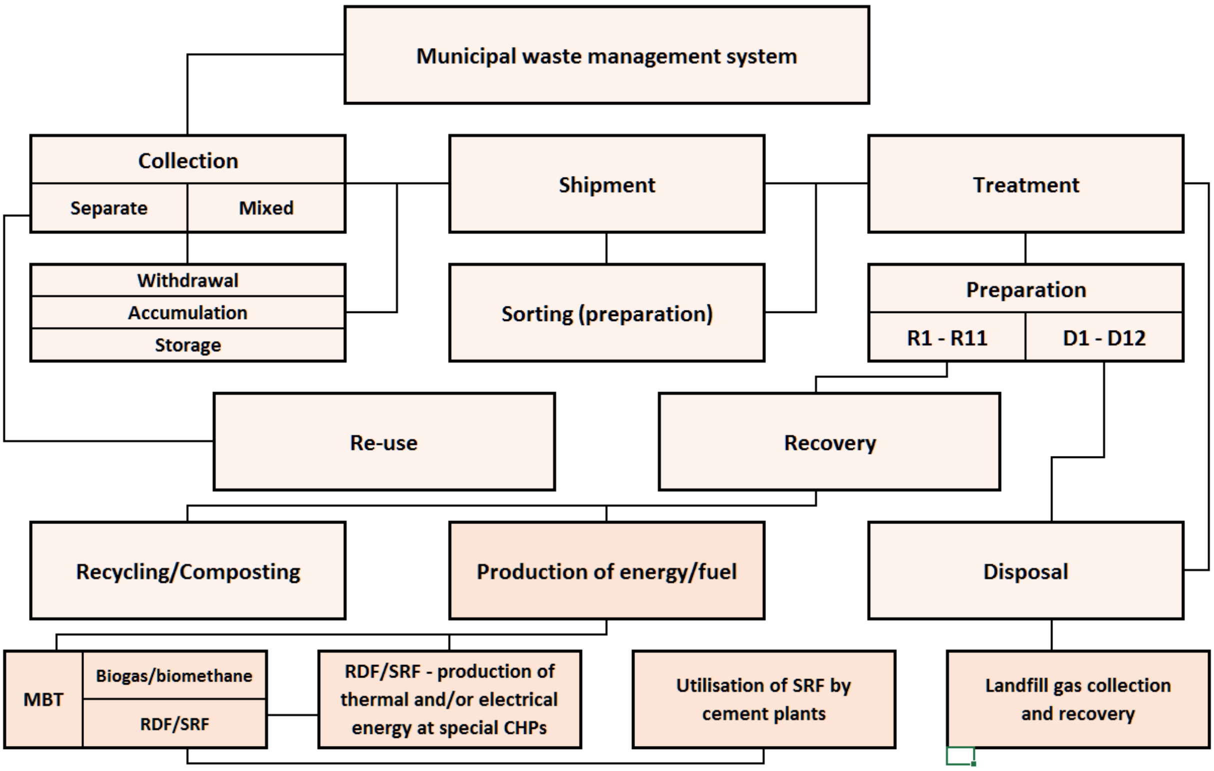

Fig. 05 – Waste management system in Ukraine

D1-D12 – waste disposal operations (Annex 1 of the Law "On waste management"), R1-R11 – waste recovery operations (Annex 2 of the Law)

One of the waste recovery option is the use of the waste as a fuel or another way to generate energy. This also includes installations for thermal treatment of MSW with energy efficiency is not less than:

- 0.60 for plants started before this Law entry into force;
- 0.65 for plants, which operation started after the entry into force of this Law.

To determine the energy efficiency (EE) following equation can be used:

$$EE = \left[\left(E_p - \left(E_f + E_i\right)\right) / \left(0{,}97 \times \left(E_w + E_f\right)\right)\right] \times KKK,$$

where E_p – annual production of electric and thermal energy in GJ/an calculated by the equation:

$$E_p = 2{,}6 \times E_e + 1{,}1 \times E_t$$

де E_e – annual production of electric energy,

E_t – annual production of thermal energy,

E_f – annual amount of energy used for steam production (thermal energy) (GJ/an);

E_i – annual amount of additional energy entering the technological process, except E_w and E_f (GJ/an);

E_w – potential annual amount of energy that can be obtained from the waste (GJ/an), based on its net calorific value);

$0{,}97$ – factor taking into account energy losses caused by slag formation and radiation;

KKK – climate correction factor.

Conception of legislative changes developed by SAEE

The State Agency for Energy Efficiency and Energy Conservation of Ukraine (SAEE or State Energy Efficiency) is the central executive body whose task is to implement state policy in the efficient use of fuel and energy resources, energy saving, renewable energy sources and alternative fuels. The concept of legislative changes developed by the SAEE in relation to the energy use of waste offers:

1. conversion of disposal to the least economically viable alternative of waste management (increasing responsibility for waste disposal in unidentified places, strengthening the powers of controlling authorities, gradually increasing the waste tax charge).
2. Creation of a system of necessary guarantees and incentives for attracting private capital in waste treatment (allowing local governments to conclude long-term contracts for waste treatment (up to 49 years), guarantees by the agreement for waste delivery amounts and waste treatment payments).
3. Creation at the legislative level of a system of environmental requirements for waste treatment industry (mandatory sorting, European requirements for incineration process, flue gas treatment and emission).
4. Introduction of clear rules for tariff setting for waste treatment services (the tariffs for waste treatment can be defined by NRCEU for long-term period, applying the principles of stimulating tariff formation, transparent mechanism for prices indexing, including anchoring to the consumer price index, currency exchange rate, etc.).
5. Setting up a waste administration system at municipal level, expanding the powers of local self-government bodies.

MSW management tariffs

The status of solid waste management is mainly determined by the level of payment for services provided by communal and private companies. In 2018, the average approved tariff for solid waste handling was 102 UAH/m^3 of waste, and the average tariff for disposal was 30.5 UAH/m^3 (approximately 3 UAH per month per person) [6].

Such tariff covers mainly the costs of the shipment (collection and transportation) of waste to the disposal location, but disposal (landfilling) is paid on a residual basis. Moreover, the cost of future waste management facilities construction, both regional controlled landfills and waste treatment plants, substantially exceeds the existing amount of paid services in solid waste management. Therefore, the necessity of the tariffs for waste treatment and disposal in Ukraine exists which would ensure the operation at the necessary technical and ecological level and would include a certain component for the implementation of investment projects.

[6] «Sanitary cleaning» in 2018; reporting form "1 –ТПВ", chapter 1for 2018 year (in Ukrainian)

The new law "On Housing and Communal Services" should come into force on 01.05.19. According to the law, tariffs for MSW management services are set by local self-government bodies (LGB) and are the sum of tariffs for shipment, treatment and disposal services. The procedure for tariffs setting is approved by the CMU decree from July 26, 2006, No. 1010, with alterations made in 2019[7].

In particular, according to these alterations, "planned profit" is defined as the sum of funds added to the sum of the full planned cost, and is directed at the investment program, repayment of the loans and/or investing at the expense of equity in the irreversible tangible and intangible assets for carrying out activities, providing the necessary level of return on owner's equity (dividends), deductions to reserve capital, as well as reimbursement of expenses on income tax".

In this case, "the planning of the profit, which is envisaged for the implementation of the investment program, is carried out in accordance with the investment program of the company approved in accordance with its constituent documents and agreed by the competent authorities in the established manner".

From May 1, 2019, the NRCEU is deprived of the right to set tariffs for MSW management. LGBs will be able to regulate MSW tariffs in accordance with future regional waste management plans and investment programs within available financial resources.

However, the change in utility tariffs may be politically motivated. Despite the fact that the growth of tariffs for MSW management is far behind the dynamics of tariffs for heat and electricity, there is a danger that local governments would prefer to restrain tariffs for the damage to investment projects under regional programs. In these conditions, it might be useful to maintain a system in which the tariffs of MSW management waste are established by the NRCEU over the long-term period.

One of the possibilities for justifying the increase of MSW tariffs is their linking to the average income/resource of the average household in Ukraine. In world practice it is considered that the average household can allocate from 1.0 to 1.5% of its resources for MSW service payments. Table 2 provides an estimate of the tariff, which corresponds to 1% of the household resource using the data of the State Statistics Service of Ukraine on aggregate resources and size of households in Ukraine for 2010-2016.

Table 2 – MSW tariffs estimation depend on the average household income in Ukraine

Parameter	2010	2011	2012	2013	2014	2015	2016	2017
Total resources per month per household, UAH	3481	3854	4145	4471	4563	5232	6239	8165
Average size of household, persons	2,59	2,59	2,58	2,58	2,58	2,59	2,58	2,58
Total average resources per month per person, UAH	1344	1488	1606	1733	1769	2020	2418	3165
Annual MSW generation rate, t/person	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35
Tariff limit (1.0%), UAH/t MSW	461	510	551	594	606	693	829	1085
Annual average exchange rate EUR:UAH	10,5	11,1	10,3	10,6	15,7	24,2	28,3	30,0
Tariff limit (1.0%), EUR/t	43,8	46,0	53,6	56,0	38,6	28,6	29,3	36,2

[7] CMU Decree №318 on 27.03.2019

It is easy to see that at MSW generation rate 350 kg/year per person allocation 1% of average household resource for solid waste service, the tariff corresponds to 1085 UAH/t (or 36.2 EUR/t). ***In turn, this value corresponds to monthly fee of 82 UAH per household or 32 UAH per person.***

In addition to the size of the maximum permissible tariff, the table demonstrates the fact that the possibility of investment projects implementation in Ukraine with the involvement of international financial institutions has deteriorated significantly in 2014...2015 due to the fall of the national currency.

Main types of MSW energy utilization

There are the following main types of MSW energy utilization (Fig. 5):

1. Landfill gas recovery at MSW landfills and waste dumps with following production of electric and/or thermal energy;
2. Mechanical biological treatment of solid waste with the possible production of biogas and/or refuse derived fuel (RDF) or solid recovered fuel (SRF) with subsequent utilization at cement plants or in specialized CHP/boiler houses;
3. Thermal treatment/utilization of mixed (after or without sorting) MSW with subsequent production of electric and/or thermal energy.

Landfill gas recovery at MSW landfills and waste dumps

MSW disposal at the landfills and waste dumps remains the main approach for waste management in Ukraine. The waste management strategy until 2030 envisages the transition from simple disposal to integrated treatment of waste. In particular, the strategy foresees the introduction of separate waste collection and sorting, the gradual increase of the share of reuse and recycling as well as the construction of at least 100...150 modern regional landfills using the principle of interregional cooperation. Thus, the role of landfill will remain significant for at least several decades.

During the waste disposal and accumulation the landfill body is formed, as a result, the bulk of the waste appear in anaerobic (without air) conditions. Lack of oxygen, high humidity and elevated temperature in the range of 30...60 Celsius degrees are necessary and sufficient conditions for the start of the processes of organic fraction decomposition with generation of landfill gas (LFG) – the mixture of methane, carbon dioxide and water with minor addition of nitrogen, hydrogen sulfide and organic volatile compounds.

Ukrainian technical standard DBN V.2.4-2-2005 "Solid waste landfills (polygons)" includes such main provisions as the design "envisages utilization of LFG formed by anaerobic decomposition of the organic component of solid waste. LFG could be used as a fuel for power plants (boiler units, industrial furnaces, stationary generators) or for refueling in fuel tanks. The method of LFG utilization is determined during technical specification development for the design of LFG recovery system. In case of no economical reason to use LFG defined by appropriate feasibility study a special high-temperature flare should be used at landfill site..

LFG recovery system includes usually wells, gas collection points, intermediate and main gas pipelines, gas extraction plant and unit for gas treatment (drainage and purification).

There are following basic possibilities for LFG use:

1. Installation of gas combustion engines (in some cases, gas turbines) at the landfill with electricity supply to the grid without thermal energy utilization;

2. LFG pipeline to the nearest boiler house, sale of heat to district heating system;

3. Combined electricity and heat (for example, installing of CHP module based on an internal combustion engine in a boiler house or supply of thermal energy to domestic or industrial consumers in close proximity to the landfill);

4. Upgrading of LFG to the quality of natural gas, followed by biomethane use as motor fuel or delivery into natural gas distribution/main grids (this option has not been widely used in the world on MSW landfills).

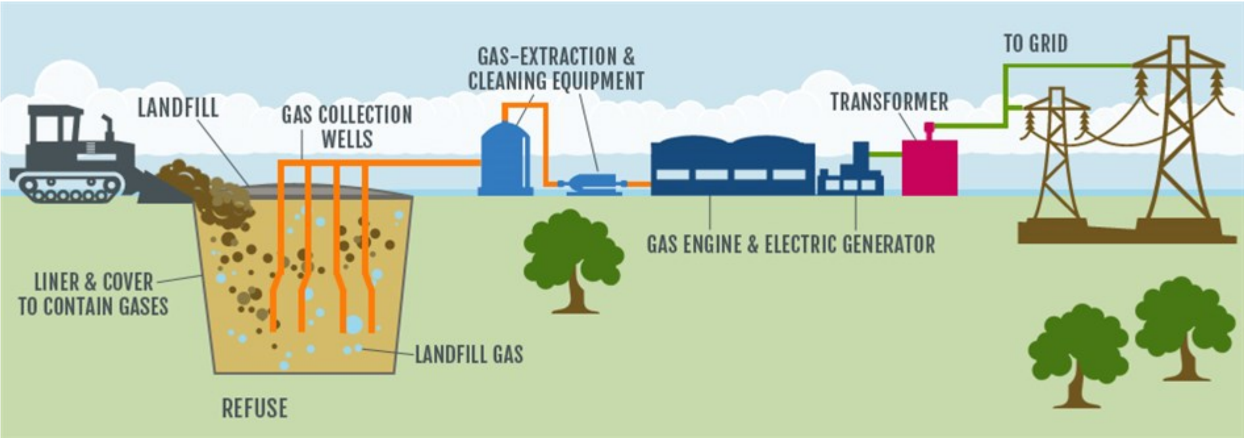

Fig. 06 – Recovery of LFG at MSW landfills

(Source: https://www.advanceddisposal.com/)

It is considered that recovery and energy utilization of LFG makes sense with average thickness of waste layer at least 10 meters and one million tons of accumulated solid waste. The great importance has time of accumulation of required amount of waste. Typically, these conditions are met at the landfills that accept waste from the settlements with total population of 200 thousand inhabitants or more.

Landfill gas volume is determined by MSW content and disposal schedule. In average, methane generation potential of Ukrainian MSW is 60...75 m^3/t.

The rate of decay is also determined by MSW content and physical conditions in the landfill body, mainly water content and temperature. In turn, the internal conditions depend on climate, mainly on the amount of precipitation. The process of decomposition of organic fraction of solid waste is realized according to exponential law, the half-life of decay in Ukrainian conditions (corresponds to 50% of biogas production) is 10...12 years.

The amount of collected LFG is determined by collection efficiency, mainly depends on landfill operation practice. Important factors are the area of the "active" zone of the landfill, the presence/quality of the upper layer with low gas permeability, the degree of waste compaction, the presence of leachate, possible fire events and their category during whole life of the landfill. It is considered that efficiency of LFG collection on the managed landfills is about 50%. For Ukrainian waste disposal sites this value can be considered as upper limit, more suitable values could be 25...30% or even lower.

If we take into account that the share of Ukrainian population living in the settlements with population more than 200 thousand inhabitants is 40%, then the total potential for LFG recovery in Ukraine could be assessed as:

$$10 \text{ Mt/an} \times 60 \text{ nm}^3\text{/t} \times 0.40 \times 0.25 = 60 \text{ Mill nm}^3\text{/an } (CH_4) = 2.1 \text{ TJ} = 580 \text{ GWh}$$

LFG recovery at the landfills and waste dumps is an effective environmental measure. As a result of LFG combustion (in power unit or by flare), GHG emission is reduced, organic volatile compounds responsible for unpleasant odors are destroyed, probability of fire events is reduced or eliminated. In addition, LFG is local and renewable energy source that can substitute any kind of fossil fuel like coal, oil, and natural gas.

Status of LFG recovery at Ukrainian landfills and waste dumps

The first Ukrainian biogas collection attempts were implemented as joint implementation projects in 2008...2012 during the first period of Kyoto Protocol (Yalta/Alushta, Lviv, Mariupol). Almost all recovered LFG was burned on flares.

At present, expediency of LFG recovery in Ukraine is determined by possibility of electricity selling using so called "green" tariff (0.1239 EUR/kWh without VAT). Therefore, after first period of Kyoto Protocol, starting from 2012, the main objective of LFG recovery in Ukraine was not GHG emission reduction, but production of electricity with sales at green tariff. Currently, all active in the country LFG projects are producing electricity by gas engines with an efficiency of 35...42%, but virtually all heat is lost.

The largest landfills and waste dumps of Ukraine are shown in Fig. 7. Disposal sites where LFG is recovered and used for power generation are orange colored. There were 19 cities (20 LFG-to-Energy projects) at 01.01.19 in Ukraine.

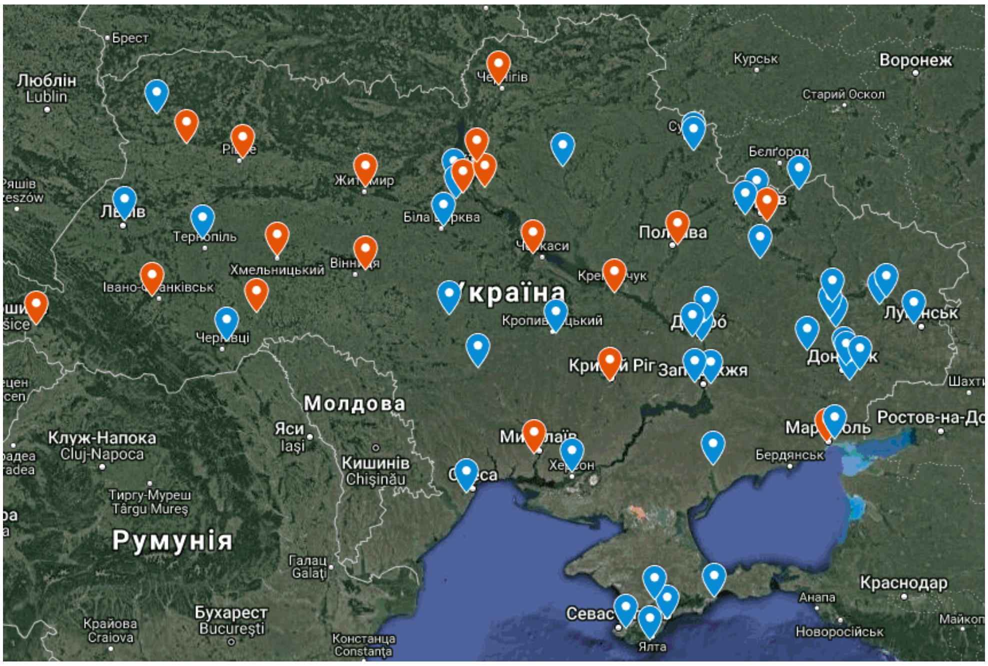

Fig. 07 – The largest MSW landfills and waste dumps of Ukraine

The total installed electric capacity at the landfills and waste dumps is 18.4 MW (01.01.19). Electricity production from LFG for the period 2012...2018 is shown in Fig. 8 and in the table 3. In addition, table 3 shows the total installed electrical capacity and the number of LFG collection systems at the end of the year for the same period.

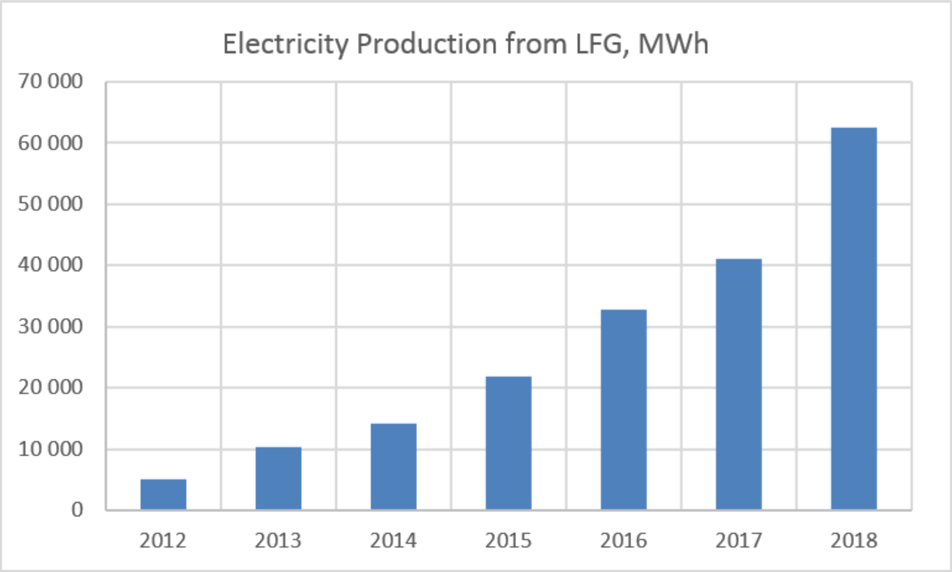

Fig. 08 – Electricity production at MSW landfills and waste dumps in Ukraine
Source: NRCEU (2017-2018), authors' estimation (2012-2016)

Implementation of green tariff led to the fact that a significant part of the energy potential of LFG in Ukraine has already been realized. Distinctive feature is that only Ukrainian companies are present on the local market.

Table 3 – Electricity production, installed electric capacity and number of LFG-to-Energy projects at MSW landfills and waste dumps in Ukraine

Year	Annual electricity generation, MWh	Installed electrical capacity by the end of year, MW	Project number by the end of year, units
2012	4 997	0,9	1
2013	10 299	2,1	3
2014	14 243	4,3	4
2015	21 926	6,4	6
2016	32 792	7,4	7
2017	41 065	12,3	12
2018	62 490	18,4	20

The analysis of operational data for electricity production from LFG in 2017...2018 shows that the utilization rate of installed capacity is only on average 40…60% (70% for the most successful projects), which may be due to excessive expectations regarding gas generation on project preparation stage.

Prospects for the implementation of the next projects may be associated with such cities as Dnipro, Zaporozhe, Odessa, Mariupol, Kherson, Sumy, Kamyanets, and Chernivtsi.

In spite of the fact that in the future the technologies of mechanical biological treatment of waste with biogas production in specialized reactors will probably be developed, a certain part of the potential may be related to the construction of regional sanitary landfills in the framework of waste management strategy by 2030. The concentration of waste resources on large scale and strict compliance with operation rules for sanitary landfills would allow to recover up to 75...85% of the generated landfill gas.

Mechanical biological treatment of MSW

Mechanical and biological treatment of solid waste (MBT) is used for the processing of mixed waste with pre-sorting or without it. The primary concept of technology involves reducing the amount of waste deposited at landfills. Currently this method is also used to produce fuel and for additional extraction of valuable materials. It combines mechanical methods (separation with sieves, drums, magnets, etc.) and biological methods (composting and anaerobic digestion).

MBT is common approach for all concepts that involve treatment of waste with combination of mechanical and biological methods. The main difference between different approaches is the order of the process stages and the purpose of biological treatment. Technological chain is oriented either on the concept of splitting (splitting) or on the idea of stabilization.

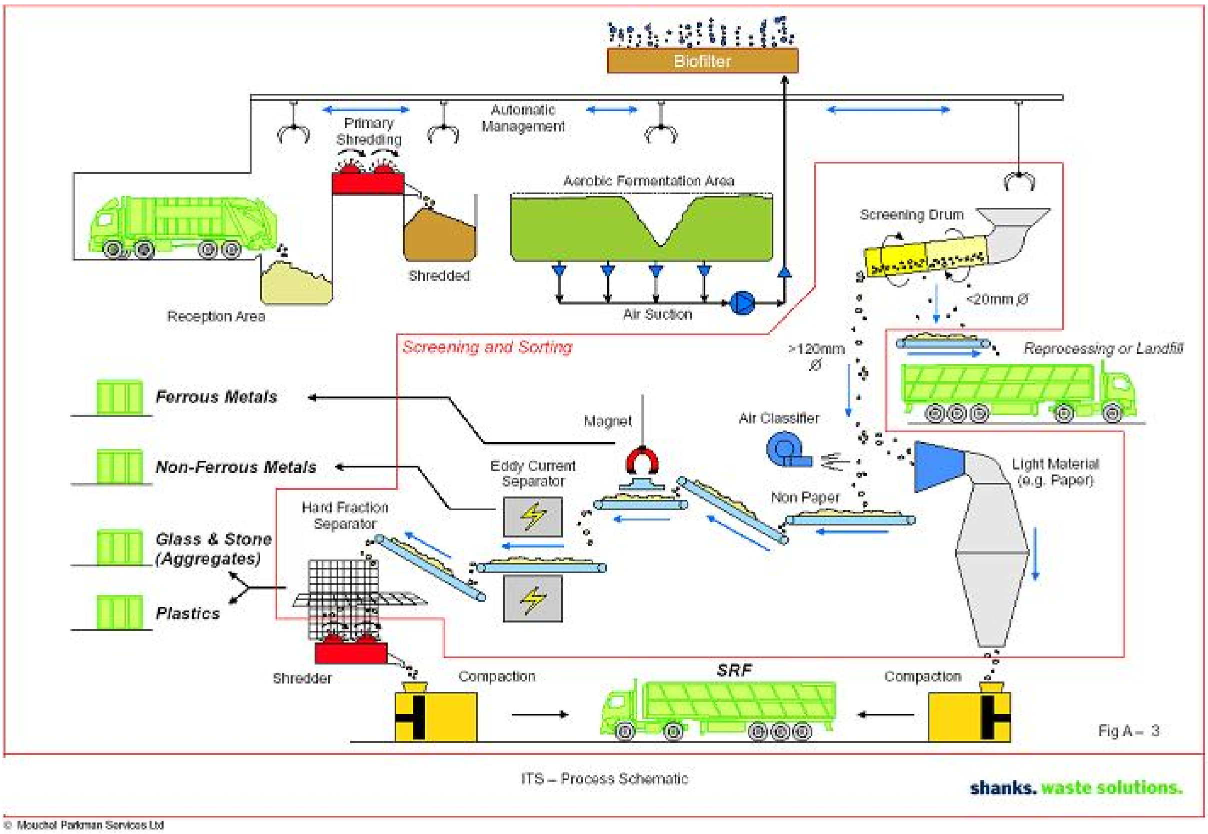

Fig. 09 – One of the MBT options

(Source: https://www.bedford.gov.uk/)

In the first case, the mechanical separation of the total waste flow into the fractions suitable for different types of utilization is carried out for energy production or further biological treatment. Anaerobic digestion or composting, as well as combinations of both methods, can be used for biological treatment. In anaerobic digestion the main attention is paid to optimizing biogas production. When using composting of the mixed residue, the main task is to obtain biologically stabilized material purified from harmful components or material suitable for energy use.

When "stabilization" is the main goal the waste is biologically processed without separation. It is done by convective or diffusion biological drying and maximal hygienisation of waste before the next mechanical separation of non-combustible components. The remaining material can be used as RDF with energy production at appropriate incineration plants.

Green and food waste can be processed biologically by aerobic (composting in the presence of oxygen) or anaerobic methods (digestion in airtight reactors in the absence of oxygen). Final material after aerobic composting of green waste in windrow, aerated static pile, and in-vessel composting can be used in the garden and parks as well as for landscape construction. Composting of food waste requires the use of additional biofilters to reduce atmospheric emissions. Anaerobic methods are associated with high capital cost, but when applied they generate biogas - additional source of energy.

MBT is not a method of final waste abolition as soon as solid residue after MBT must be disposed or incineration.

Thus, there are the following basic possibilities of MBT application:

1. Sorting with separation of valuable and inert components, digestion of the organic fraction of solid waste with biogas production, energy generation from biogas, digestate composting and disposal/utilization of compost;
2. Sorting with separation of valuable and inert components, biological stabilization by composting and disposal/utilization of compost;
3. Production of fuels from solid waste (SRF). In the simplest case, it may consist in preliminary sorting, removal of certain components from mixed waste and shredding the residue for:
    - SRF use in specialized incinerators for the electric and/or thermal energy production;
    - Transfer/sale of SRF to the nearest cement plant.

The use of SRF in the cement industry allows to utilize not only fuel energy but also its mineral part in the process of clinker production.

The total theoretical potential of biogas production in MBT process in Ukraine (in case of treatment of the total amount of organic fraction of MSW generated in Ukraine) is

$$10 \text{ Mt MSW/an x } 60 \text{ nm}^3\text{/t} = 600 \text{ Mill nm}^3\text{/an } (CH_4) = 21 \text{ TJ} = 5800 \text{ GWh}$$

Thus, the potential of biogas production in MBT is much higher compared with LFG recovery by two reasons:

1. in controlled reactors there is possibility to use almost all generated biogas in contrast to landfills where the amount of recovered LFG is limited by recovery efficiency as well as the possible oxidation of methane in the upper layers of landfill;
2. Unlike the disposal of substantial amount of MSW at small and medium-sized waste disposal sites, the MBT technologies involves the concentration of MSW on regional basis with almost complete utilization of biogas potential.

Also, the advantages of biogas production in MBT process are:

1. multiple acceleration of digestion in comparison with natural processes occurring inside the landfills and waste dumps;
2. potential possibility of obtaining conditionally clean compost in the case of separately collected organic waste.

For combustion of fuels from MSW in cement plants or in specialized boiler houses requires fuel classification. The tasks and activities of National Waste Management Plan up to 2030 envisage the development of local Ukrainian standard on the basis of the existing European Standard EN 15359: 2011 "Solid recovered fuels - Specification and classes", as well as recommendations for the use refuse derived fuel (RDF).

However, Ukraine already has a standard for solid recovered fuel[8]. This document was accepted by confirmation method and submitted in the original language (English) only. The document contains the following classification of SRF (Table 4).

Table 4 – Classification system for solid recovered fuels

Classification characteristic	Statistical measure	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV), Q	Mean	MJ/kg	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3
Chlorine (Cl)	Mean	%	≤ 0,2	≤ 0,6	≤ 1,0	≤ 1,5	≤ 3
Mercury (Hg)	Median	mg/MJ	≤ 0,02	≤ 0,03	≤ 0,08	≤ 0,15	≤ 0,50
	80th percentile	mg/MJ	≤ 0,04	≤ 0,06	≤ 0,16	≤ 0,30	≤ 1,00

SRF (class 3) consists predominantly of biological waste. It is homogeneous dry raw material with low content of undesirable impurities, suitable for storage. The calorific value for class 3 is 15 MJ/kg suitable for most cement plants and/or CHP plants working on solid fuels. SRF of this type is characterized by low chlorine content (<1,0%), which is also permissible for cement production.

In Ukraine, there is an interest in implementing demonstration projects for SRF utilization in cement industry as part of the of the waste management strategy[9] implementation. However this possibility requires additional discussion, the Ukrainian Cement Manufacturers Association "Ukrcement"[10] and DAEE may be the partners for discussion.

In most cases, for the use of alternative fuels cement plants need to be modernized. In addition, the feasibility of using SRF is determined by logistics, mainly the distance between SRF producer and cement plant. Ukrainian cement plants are shown in Figure 10. It is easy to see that such plants are located mainly in the west and south-east regions of the country.

[8] ДСТУ EN 15359:2018 (EN 15389 –1:2006, EDN) Solid recovered fuels - Specification and classes

[9] National Waste Management Strategy in Ukraine until 2030

[10] http://www.ukrcement.com.ua

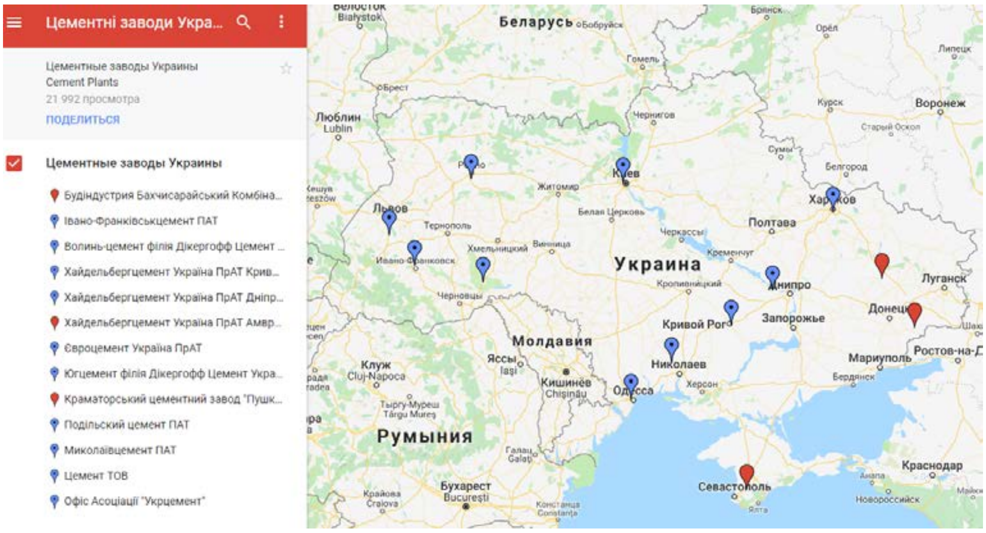

Fig. 10 – Cement plants in Ukraine

(Source: http://www.ukrcement.com.ua/pidpriemstva.html)

From technology point of view SRF production consists of bio boxes for stabilization of the organic fraction of solid waste, mechanical sorting and conditioning, water purification, odour control, dust extraction and filter systems, therefore the operation of such plants is not resulted in additional pressure on environment.

There is considerable discrepancy in the cost of various MBT, because there is no "universal" way for mixed MSW processing. Various solutions can be considered most beneficial for different areas/clusters.

As already mentioned above, the expediency of biogas generation from MSWs with the further production of electricity is determined by the possibility of selling electricity at a fixed green tariff (0.1239 EUR/kWh without VAT). The feasibility of producing RDF/SRF is determined, besides the actual treatment of solid waste, by substitution of fossil fuels, first of all, natural gas.

MBT may be economically sustainable in some cases in Ukraine, for example:

- MBT produces biogas with electricity sale by green tariff, the heat is also sold to the utility or industrial user;
- MBT produces RDF/SRF in the presence of local market (cement industry or district heating system).

Prior to construction of any MBT facility it is first to conduct a thorough feasibility study, which should prove the commercial viability (investment attractiveness) of such project.

Status of mechanical biological treatment of MSW in Ukraine

Currently there are any mechanical biological treatment projects under operation in Ukraine. The only attempt to organize the production of RDF for further combustion at PJSC "Volyncement" in the neighbouring city of Zdolbuniv was made in the city of Rivne. MSW processing plant was built in 2013. The full scale operation was not long due to technological gaps and practical problems with MSW treatment tariffs assignment, as well as the impossibility of certification of RDF quality. Today, the plant is operating irregularly as sorting unit, the residual waste is landfilled.

The large project of the waste treatment facility is implemented in Kharkiv at the Dergachy landfill by 30 million Euros loan of World Bank. However, the project includes only "simple" concepts: rehabilitation of the old landfill, construction of a new sanitary landfill, LFG recovery at old and, in the long term, at new landfill with electricity production, and erection of two sorting lines with capacity of 40 and 80 thousands tons per year.

Another project is at the stage of implementation in L'viv. Within this project it is planned to rehabilitate old closed landfill in Gribovichy and build MSW treatment facility. Technical concept includes MBT approach. The signing of contracts for the allocation of EUR 35 million from the EBRD and the Eastern Partnership Energy Efficiency and Environment (E5P) Fund took place in June 2018.

If tendering procedures are completed on time, construction of waste treatment plant in L'viv can already begin in 2019. The tender participants (short listed) for the construction of waste treatment plant in Lviv are Control Process S.A. (Poland), Eggersmann Anlagenbau GMBH (Germany), Helector S.A. (Greece), consortium MUT (Austria) with Dogusan (Turkey), and consortium WTT (Netherlands) with Axis (Lithuania). In addition to the construction of the plant, an implementation of new separate waste collection system is also planned.

The idea of MBT plant construction with capacity of 80,000 tons/year is actively developing in Khmelnitsky. Local and foreign experts have conducted qualitative and quantitative research on waste streams and feasibility of their use. Khmelnitsky team plans to produce both biogas and RDF/SRF. The project involves EBRD loan (EUR 20 mill) and, in the long run, the loan of International Finance Corporation (World Bank).

The idea of MBT plant construction with capacity of 82,000 tons/year was also announced in Zhytomyr in mid-2018. Production of RDF for cement plant and compost is planned.

Thermal treatment/utilization of MSW

Thermal treatment of MSW is the most effective method for reducing of waste amount and needs for waste disposal. The following types of thermal utilization of municipal waste are possible:

1. production of heat and electricity from RDF/SRF obtained by MBT;
2. standard waste incineration plant (WIP) - combustion of mixed waste streams after removal (separate collection) of valuable components;
3. Experimental technologies: gasification, pyrolysis, plasma.

Incineration

MSW can be incinerated in different types of plants including moving grates, rotary kilns, and fluid bed installations. The main useful product of waste incineration is heat of flue gases, which is used as energy resource for production of steam, electricity, and hot water for industrial and domestic needs.

MSW incineration is normally used for partially sorted waste contained no more than 10...15% of inert material. Only waste with a sufficiently net calorific value (more than 6.0 MJ/kg) can be used for incineration. As a result of incineration of organic waste part carbon dioxide and monoxide, water vapour, nitrogen and sulphur oxides, aerosols are formed. The scope of thermochemical methods is limited by the properties of reaction products. The thermochemical method is undesirable to use for treatment of waste, if it contains phosphorus, halogens, sulphur.

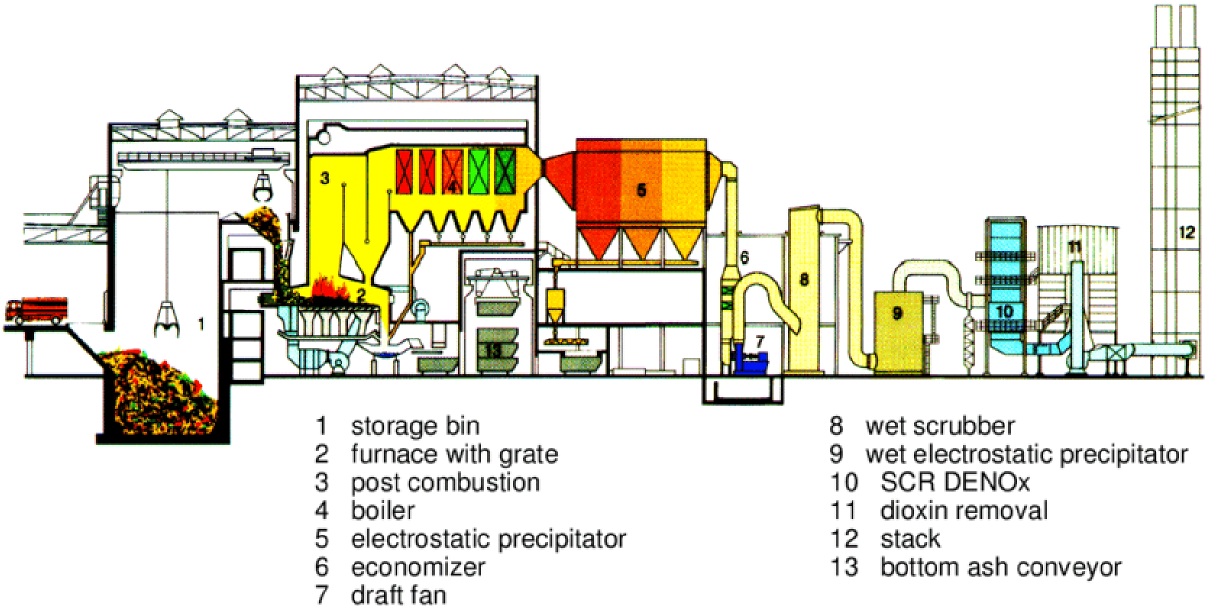

Fig. 11 – Thermal treatment/utilization of MSW

(Source: https://www.researchgate.net/)

Waste is fed into the storage bin directly from the garbage truck (Fig. 11). The bin volume is designed for available waste amount. Further, the waste is fed by the crane to the fuel supply system, for example on the moving grate. The latter can be inclined or horizontal with air or water cooling. Waste moves along the grate by gravity (inclined grate) or as a result of grate parts moving.

The heat of combustion products is used to generate a high-pressure steam, which in turn is fed to turbine with generator. Low-temperature steam after the turbine can be used in centralized heat supply systems.

Flue gas cleaning is a necessary component of the system. For this purpose different processes are used: wet, dry and semi-dry. The choice between them depends on local constraints and certain technological considerations.

In wet process flue gases first pass electrostatic filter or hose filter in which solid particles (dust) are removed. The dust is collected in ash hopper. Then flue gases are passed through wet scrubbers. Usually heavy metals and acids are removed in the first scrubber, sulphur dioxide is removed in the second one. The use of special packaging materials in the scrubbers removes dioxins.

Dry process is based on the injection into a boiler of dry lime powder, which reacts with gasses containing acids. Next dust, salts and other products of chemical reactions are collected in hose filter. Activated carbon is injected for effective capture of dioxins and gaseous heavy metals, such as mercury. In some cases electrostatic filters are used at the beginning of the process.

Another possibility of cleaning is a semi-dry process based on injection into absorber of lime milk instead of dry powder. At the next stage hose filter is used to separate reaction products, heavy metals and dust in flue gases.

In addition to cleaning of flue gases from unwanted components, it is necessary to reduce nitrogen oxides content. One of the possibilities is selective catalytic converter installed after main gas cleaning equipment. Flue gases pass through the porous material and contact with ammonia in the presence of a catalyst, for example, titanium oxide. Nitrogen oxides in presence of catalyst at low temperature are converted to nitrogen. It is selective catalytic process. Another possibility is selective non-catalytic process. For this ammonia water or gaseous ammonia is injected into the furnace at high temperature, which leads to the formation of nitrogen in a non-catalytic manner. Both approaches are widely used in Europe.

It is possible to distinguish at least three levels of flue gas cleaning - basic, medium and advanced[11]. Basic one includes dust removal by electrostatic filters. The medium level can be provided with various combinations of wet and dry scrubbers. At this level additional dust, HCl, HF, SO_2 and heavy metals (As, Cd, Cr, Pb, Mn, Hg, Ni) are removed. Advanced gas cleaning is used in developed countries. It is comprehensive and costly system that further provides purification of nitrogen oxides NOx, dioxins and furans. Transition from medium to advanced gas cleaning option increases the cost of the project by about 15%[8].

Important task for WIPs with purification of flue gases is toxic volatile ash and sludge removal and disposal remaining after combustion (up to 30% of dry mass of solid waste). The concentration of heavy metals oxides in ash is much higher than that in the original waste.

Gasification

Gasification is an option of thermal utilization, in which the first stage of fuel oxidation is accompanied by synthetic gas (syngas) generation, and in the second stage combustible syngas is burned in a secondary heat-generator or gas engines/turbines for electricity generation.

Gasification as industrial technology is commonly used for treatment of solid, liquid and paste-like waste. In particular, it is widely used in metallurgy to produce combustible gases from coal. The essence of gasification is the processing of carbon material (coal) at 600-1100°C with water vapour, oxygen (air) or carbon dioxide. As a result of respectively steam, oxygen, carbon dioxide or combined coal conversion a mixture of newly formed (hydrogen, carbon monoxide) and initial gases is formed.

Syngas (generator gas) obtained by gasification with air or steam blowing has low (3.5-6.0 MJ/nm^3) calorific value due to high nitrogen content. Usually it is used locally in low-temperature technological processes. Syngas of steam and oxygen blowing has higher calorific value (up to 16 $MJnm^3$) and can be used as a fuel for high-temperature furnaces, as well as for transportation at considerable distances. It is also a valuable chemical raw material, in which the content of H_2 and CO reaches 70%.

There are several technology options developed for MSW in Japan, such as the direct melting process JFE, Thermoselect technology, gasification in the vertical column of pelleted RDF, Energos Grate Combustion and Gasification Process (Norway, Germany, Great Britain), Ebara fluidized bed process (Spain), plasma gasification commonly used for treatment of hazardous waste (Japan).

[11] WORLD BANK, “Decision Makers’ Guide to Incineration of Municipal Solid Waste”, 2000

The reason for the prevalence of gasification in Japan is the local legislation, for example, the prohibition of solid waste transportation between municipalities, as a result impossibility accumulate large amount of waste in one place as well as specific requirements for ash quality.

The advantages of gasification in comparison with grid combustion of solid waste are ash melting, reduction of flue gases and NOx emissions. Despite technology development there is still lack of sufficient experience in the world in implementing of gasification projects on mixed waste, there are difficulties with gasification of wet raw materials.

Pyrolysis

Pyrolysis as method of heating of organic substances to relatively high temperatures without air access is accompanied by decomposition of complex molecular compounds on simple substances, liquid, gaseous and solid fractions. It is used in dry distillation of wood waste, processing of rubber and petroleum products, etc.

Depending on the process temperature there are three types of pyrolysis: low-temperature pyrolysis (not more than 450-550 °C); medium-temperature pyrolysis (up to 800 °C) and high-temperature pyrolysis (900-1050°C). At higher temperature the output of liquid is reduced and the output of gaseous products increases. Therefore, low-temperature pyrolysis is usually used to obtain primary tar, a valuable source of liquid fuels and various chemical products. The main task of high-temperature pyrolysis is obtaining of high-quality fuel gas. The solid residue (pyrolysis coke) is used as a substitute for natural and synthetic carbon materials, sorbent when purifying drinking water and sewage.

For mixed MSW pyrolysis experience is not sufficient, the technology is still at experimental stage. The vast majority of thermal waste treatment projects use burning on moving grate. Table 5 shows the prevalence of various types of thermal waste treatment for 22 countries (project started after 2000). It is easy to see that the main methods of MSW thermal treatment is combustion on moving grate and, to some extent, in fluidized bed.

Table 5 – Existing waste-to-energy (WTE) technology in the world[12]

WTE process	Feedstock	Energy product	Annual capacity, Mt	Location
Combustion on moving grate	As received MSW	High pressure steam	< 168	Asia, Europe, America
Rotary kiln combustion	As received MSW	High pressure steam	> 2	Japan, USA, EU
Energy Answers Process (SEMASS)	Shredded MSW	High pressure steam	> 1	USA, EU
RDF to grate combustion	Shredded and sorted MSW	High pressure steam	> 5	США, ЕС
Circulated fluidized bed	Shredded MSW or RDF	High pressure steam	> 11	China, Europe
Ebara fluidized bed	Shredded MSW or RDF	High pressure steam	> 0.8	Japan, Portugal
Bubbling fluidized bed	Shredded MSW or RDF	High pressure steam	> 0.2	USA
Direct smelting process	RDF	High pressure steam	> 0.9	Japan
Thermoselect	As received MSW	Syngas	> 0.8	Japan

[12] WTE Guidebook, EEC/IDB, July 2013

WTE process	Feedstock	Energy product	Annual capacity, Mt	Location
gasification		(CO, H_2, CO_2)		
Plasma-assisted gasification	Shredded MSW	Syngas (CO, H_2, CO_2)	> 0.2	Canada, Japan, France
Mechanical biological treatment	Shredded and bioreacted MSW	RDF to cement kilns and coal power plants	> 5	EU
Global WTE capacity			**< 195**	

Status of MSW thermal treatment in Ukraine

In the period of 80s and 90s, four WIPs were built in Ukraine (in Kyiv, Dnipropetrovsk, Kharkiv and Sevastopol). Recently only two plants were under operation in Kyiv and Dnipropetrovsk. The only one is currently operating in Kyiv. Construction of WIP "Energiya" was started in 1983 and completed in 1987. The capacity of the plant allows incineration about 20% of MSW generated in Kyiv (240,000 t/yr).

Modernization of WIP "Energiya" was done in 2013. Investments for first stage of modernisation amounted to UAH 28 mill. It was dedicated at natural gas consumption reduction and implementation of district heating project. As a result, the residential area of Poznyaki is able to use heat and hot water from MSW incineration process. Consumption of 150,000 Gcal thermal energy sufficient for 200 multi-storage buildings (space heating for 80,000 apartments) in winter time and for 300 buildings in the summer for hot water supply. Natural gas substitution for thermal energy production amounted 30 million nm^3 in 2015.

Fig. 12 – General view and Loading crane of WIP «Energiyaя»

At the second stage of modernization (2015-2018) former owner PJSC "Kyivenergo" was planned to invest UAH 210 mill for retrofitting of all boilers and installation of new electrostatic filters. It was planned to increase MSW combustion capacity by 20% (up to 280,000 t/yr) and thermal energy production by 60% (up to 360,000 Gcal/yr).

The next planned stage of modernization will include an installation of 4 MW turbine and development of flue gas cleaning system. At the moment the main components of flue gas cleaning system plant are electrostatic filters. However, installation of chemical cleaning of flue gases with injection of lime solution and activated carbon is planned for 2022.

Over the past decades, the plans for construction of WIPs in different Ukrainian cities have been announced many times, but these plans have not been implemented.

The potential of energy production by MSW thermal treatment in Ukraine in case of 25% of solid waste is used equals:

Annual electricity production: 10 Mt x 8 GJ/t x 0.22 x 0.25 = 4.4 TJ = 1200 GWh

Annual heat production: 10 Mt x 8 GJ/t x 0,55 x 0,25 = 11.0 TJ = 3000 GWh

The corresponding potential of natural gas substitution by thermal treatment of MSW in Ukraine is more than 0.5 billion nm^3.

MSW composition and its influence at the choice of treatment technology

The method of waste treatment (for example, possibility and expediency of waste incineration) is determined by waste composition, the integral parameters of which can be net calorific value and ash content. It is clear that the higher the calorific value the more effective the technologies of thermal utilization, which involve the use of energy (heat and/or electricity, and industrial steam).

Dependence of net calorific value on moisture for mixed solids as well as for some of the most typical solid waste components is shown in Fig. 13.

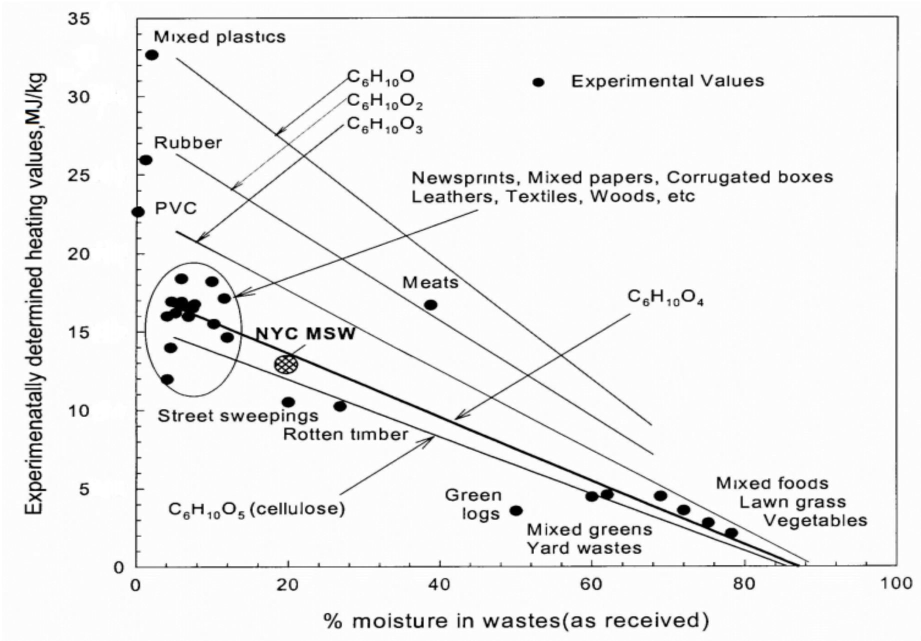

Fig. 13 – Dependence of net calorific value on moisture for most typical MSW components
Source: WTE Guidebook, EEC / IDB, July 2013

It can be seen that calorific value of solid waste components can vary in the range from 3-5 MJ/kg (mainly for food waste) to 15-18 MJ/kg (mainly paper, cardboard, textiles, and wood). Calorific value of mixed MSW can be in the range of 8-12 MJ/kg with moisture 30-50%.

It is considered that the limit value of net calorific value for commercial thermal utilization is 6 MJ/kg. However, thermal utilization is often used for compulsorily treatment of hazardous waste (for example, medical ones). In this case, the net calorific value of the waste does not affect the decision to use the technology.

Calorific value of 10 MJ/kg corresponds to 2.8 MWh of thermal energy per ton of waste. The most effective WIPs (for example, Ramboll, Denmark) obtain from one ton of solid waste 0.67 MWh of electricity and up to 2.0 MWh of thermal energy. The dependencies shown in Figure 13 are confirmed by the data of 97 European WIPs, presented as histograms in Fig. 14[13]. It can be seen that European WIPs incinerated MSW in the range of 7-14 MJ/kg with average value of 10 MJ/kg. Exceeding the value of 14 MJ/kg, which is present in the picture, is typical for mixture with industrial waste.

[13] Waste-to-Energy State-of-the-Art-Report. ISWA 2012

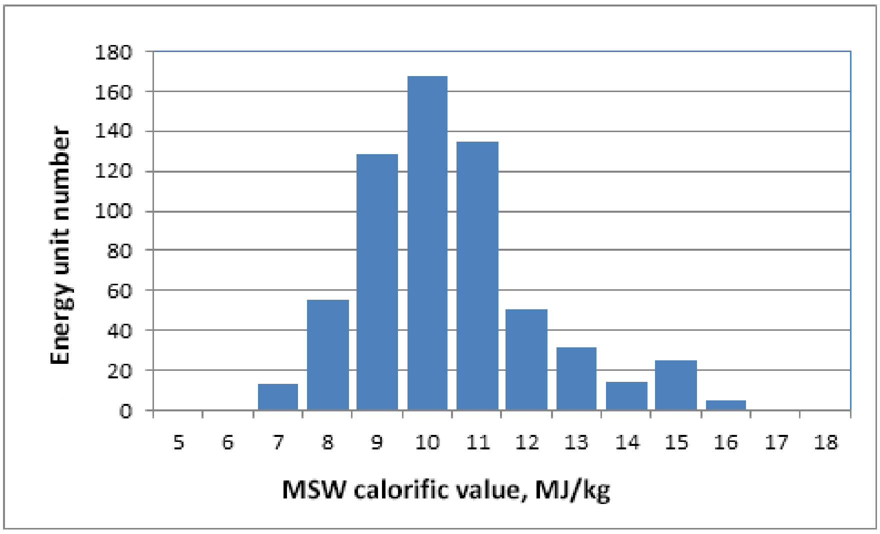

Fig. 14 – The calorific value of MSWs used at 97 European WIPs
Source: Waste-to-Energy State-of-the-Art-Report. ISWA 2012

Figure 14 shows the percentage content (by mass) of different fractions of solid waste in the city of Kyiv according to the data of the State Enterprise "Research, Design and Technology Institute of Urban Economy". It is evident that the main parts of solid waste in Kyiv are food waste, various polymers, paper and cardboard, and glass

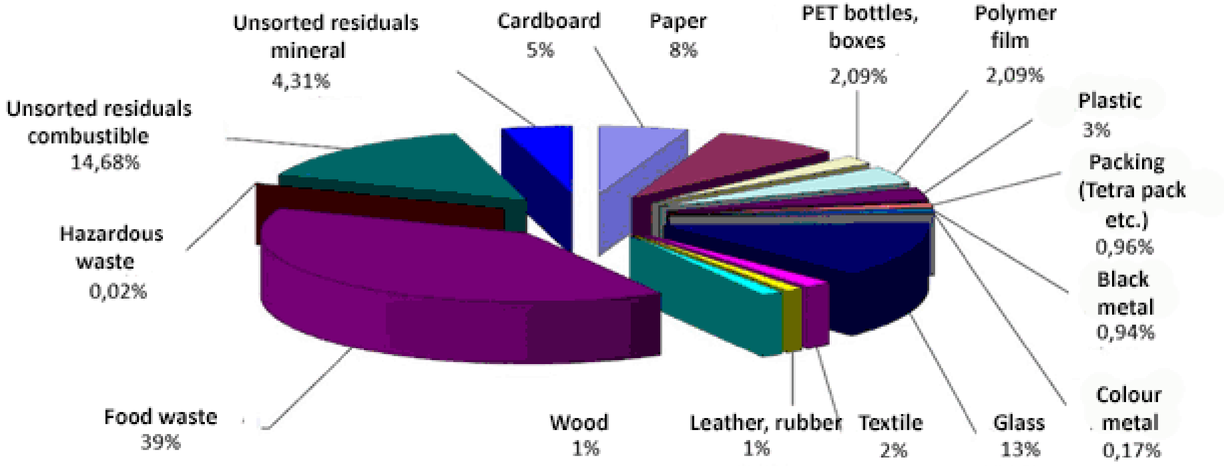

Fig. 15 – Content (by mass) of different fractions in mixed MSW in Kyiv

Composition of solid waste and the corresponding (estimated) value of calorific value are given in the Table 6 for five cities in Ukraine. One can see that MSW and contribution of individual components can vary in a wide range (last column). But despite the widespread view that solid waste in Ukraine is significantly different in composition from European counterparts, the average calorific value of Ukraine's MSW meets the above data for the EU.

Calorific value of solid waste in particular location may vary during the year depending on weather conditions and seasonal consumption patterns. Monitoring of MSW composition change for one of the landfills in Ukraine (Boryspil) for almost two years has shown that the calorific value at certain location can vary from 6.5 to 12.0 MJ/kg.

Table 6 – MSW composition in five Ukrainian cities[14]

Component	1	2	3	4	5	Average	Range
Food waste	30,0	35,5	43,6	45,6	29,4	36,8	30 – 45
Paper and cardboards	5,3	5,9	7,6	8,5	15,6	8,6	5 – 15
Polymers	16,0	8,7	12,3	10,7	16,6	12,9	8 – 17
Glass	13,6	10,9	11,3	9,1	15,2	12,0	9 – 14
Black metal	1,0	0,3	0,6	1,2	2,0	1,0	0 – 2
Colour metals	0,1	0,2	0,3	0,4	0,3	0,3	0 – 0,5
Textile	2,0	3,8	2,2	2,2	5,7	3,2	2 – 5
Wood	1,6	2,5	0,1	1,4	2,0	1,5	0,1 – 2
Hazardous waste	0,3	0,1	0,3	0,3	0,5	0,3	0,1 – 0,5
Bones, leather, rubber	0,5	1,6	0,4	0,9	0,8	0,8	0,5 – 1,5
Combined waste	0,5	0,9	0,4	1,0	–	0,7	0,4 – 1
Residuals, incl.	29,1	29,4	20,9	18,7	11,9	22,0	12 – 30
Small construction	0,3	2,8	3,4	3,2	3,2	2,6	0,3 – 3,5
Street waste	6,1	0,5	0,3	0,0	3,4	2,1	0 – 6
Hygiene products	3,1	3,7	2,6	2,8	3,6	3,2	2,3 – 3,5
Others	19,6	22,4	14,7	12,7	1,8	14,3	2 – 22
Calorific value, MJ/kg	**9,4**	**7,5**	**8,3**	**8,4**	**11,8**	**9,1**	**7,5 – 11,8**

When planning a project, it must be taken into account that MSW composition can change over long periods of time. As an illustration, polymers content for cities of Ukraine and Russia for the period 2000-2012 are given in Figure 16. It is easy to notice the tendency of polymer amount growth.

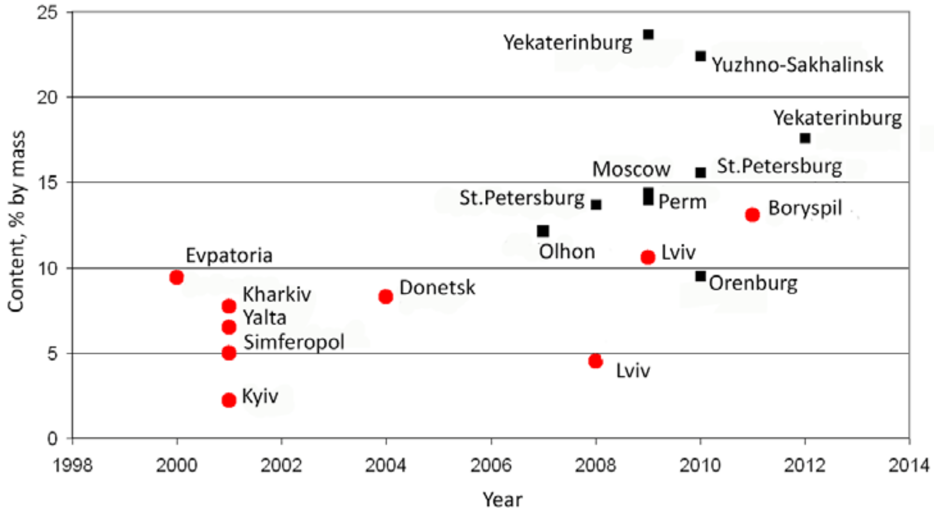

Fig. 16 – Polymer content in MSW growth (Ukraine and Russia)

An attempt to track the change in MSW content in Ukraine from the beginning of the twentieth century was made in the report[15], and subsequently used in the National GHG Inventory for 1990-2016 for biodegradable components of solid waste, contributing to LFG generation at landfills and waste dumps (Fig. 17).

[14] National Project "Clean Cityo"

[15] Report on research "Investigation of gas generation at the largest solid waste landfills and transition to a three-component national model for calculating GHG emissions from landfill in Ukraine / Yuri Matveev [and others.]. UDC 519.87: 628.336.6: 628.4, State registration number 0112U001577. - Kyiv, 2012. - 141 p. (in Ukrainian).

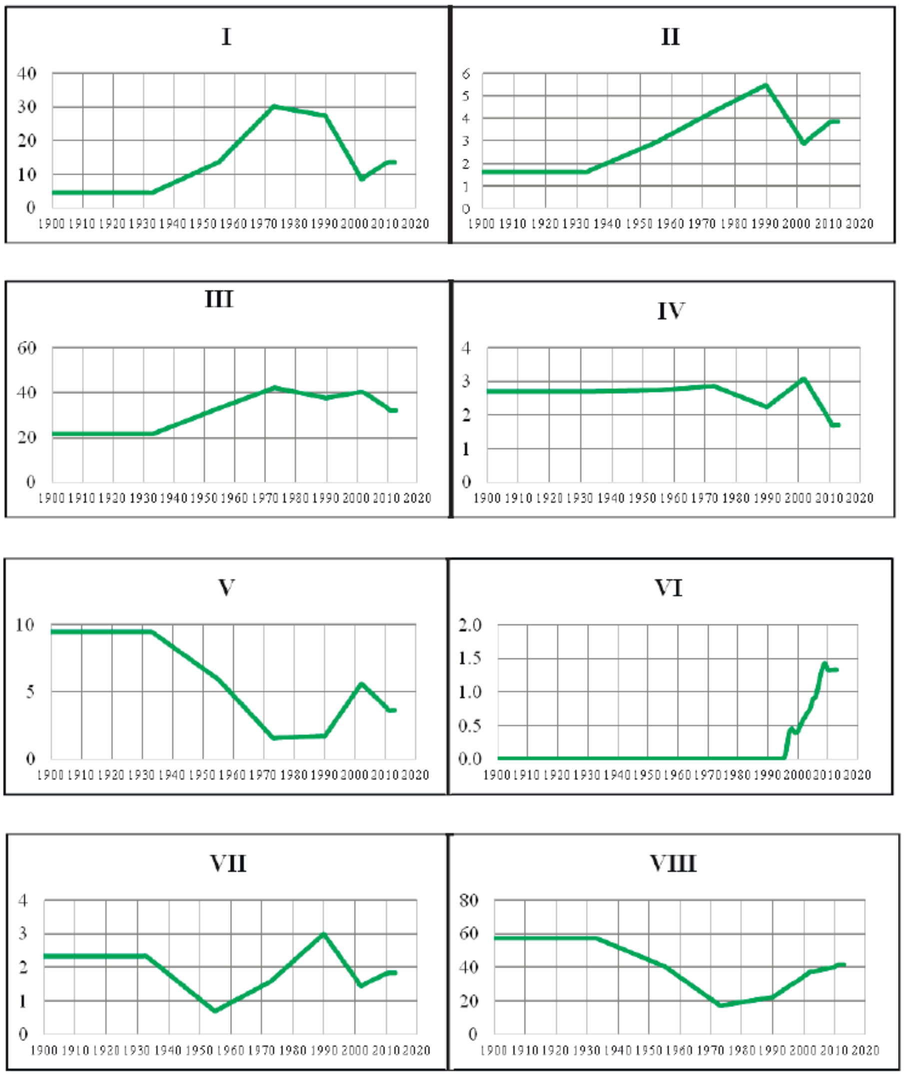

Fig. 17 - Changes in the content of MSW fractions in Ukraine

(I - paper and cardboard, II - textiles, III - food waste, IV - wood, V – green (garden and park waste), VI - hygiene products, VII - leather and rubber, VIII - inorganic waste)

As soon as waste thermal treatment has lower priority in waste management hierarchy compared to reuse and recycling, when choosing a treatment technology, the composition of MSW should be taken into account after sorting if it is implemented.

Sorting can be done in a variety of ways, namely:

- Directly in the place of generation (by population);
- By waste pickers (informal sector of waste economy) in urban containers prior to transportation;
- By specialized sorting lines (manual or automatic);
- As the first stage of MBT technology.

Figure 18 illustrates the effectiveness of manual and automatic sorting of mixed waste according to paper[16]. The figures are given as the benchmark. For each case of project implementation and equipment selection relevant indicators may vary taking into account the actual MSW content.

[16] Slyusar N.N., Ilinykh G.V., Vaisman Ya.I., Pukhnyuk A.Yu., Matveev Yu.B. Managing the methane potential of MSW through their pretreatment // Ecology and Industry of Russia, - November 2013 - p. 38 –42. (in Russian).

The figure shows that sorting residuals are sent to landfills. Thermal utilization with or without prior biological stabilization could be alternative way of waste treatment.

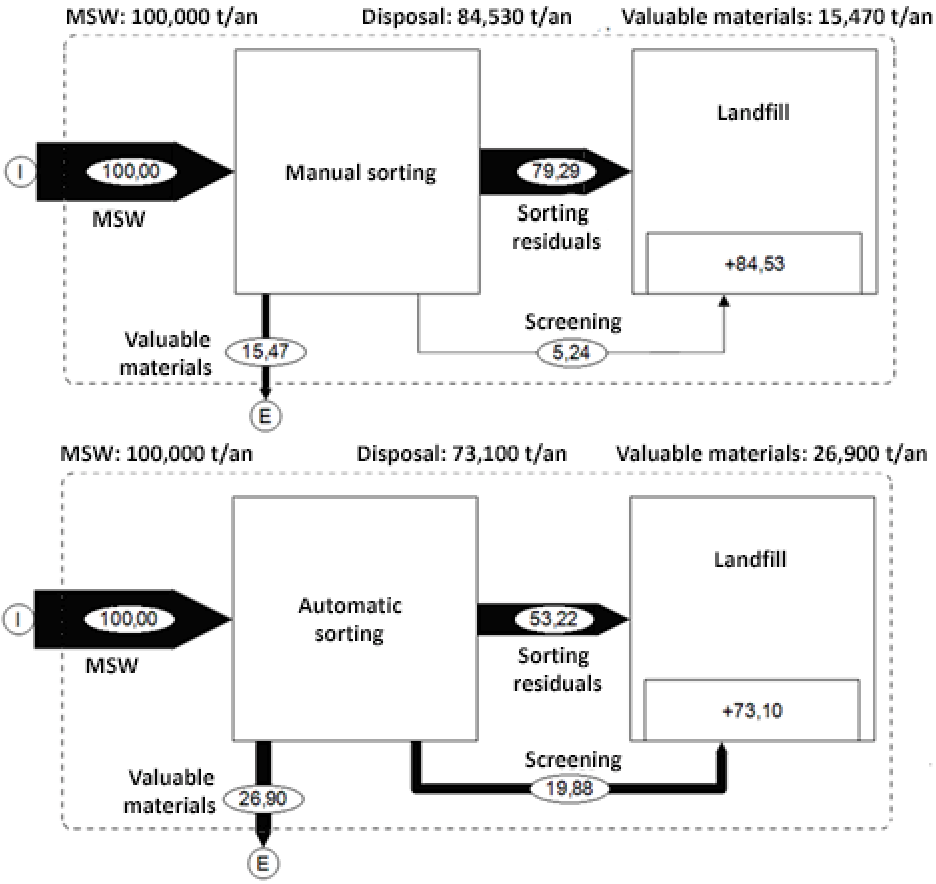

Fig. 18 – Material flows for manual and automatic (optical & mechanical) sorting[19]

The main components that are taken from MSW flow are (in percentage of the initial waste amount) where smaller value associated with manual sorting, bigger value with automatic (optical & mechanical) sorting:

- Paper and cardboard – 17…46%
- polymers – 27…58%
- glass – 38%
- black metal – 39…73%
- colour metal – 52…80%.

The pre-sorting process can have a significant effect on the net calorific value. Since part of the caloric polymers, paper and cardboard are removed from the solid waste stream, the net calorific value may decrease from 9.0 to 8.4 MJ/kg for manual sorting and up to 6.8 MJ/kg for automatic sorting.

On the contrary, the drying and composting of the residue after sorting, for example in MBT process may increase calorific value of potential fuel to 10-15 MJ/kg.

Financial parameters of various methods of MSW treatment

Potential income per ton of MSW

It is interesting to estimate and compare potential income that can be obtained by introducing separate collection and sorting as well as biological and thermal treatment of MSW with energy generation.

Separate collection and sorting

It has already been mentioned that currently there are dozens of sorting lines in the country, however the effectiveness of selection of valuable materials on which does not exceed 15-20%. Sorting of mixed waste is rarely feasible measure due to poor quality of initial waste and, consequently, poor efficiency of sorting. It could be improved by implementation of separate waste collection.

Potential income from sale of valuable materials like polymers (plastics), paper and cardboard, glass per tonne of solid waste can be estimated using percentage of certain fraction of waste, market prices and hypotheses regarding achievable depth of processing. For last parameter it is expedient to use the targets set in the National Waste Management Strategy until 2030. As a selling cost, the average prices for the import and export of secondary polymers, waste paper and glassware for the period 2008-2018 in European market were used. Evaluation results are presented in Table 7.

One can see that income from sale of secondary valuable materials in the event of recycling depth of 60 ... 75% can amount from 24 to 45 EUR/t of waste.

Table 7 – Potential income from valuable materials selling

Material type	Percentage in MSW, %	Amount, kt/an	Price, EUR/t	Depth of processing, %*	Potential income, EUR/t MSW
Polymers	10 –15	1000 –1500	250	60	15.0 – 22.5
Paper and cardboard	5 –15	500 –1500	150	75	5.6 – 16.9
Glass	9 –14	900 –1400	50	75	3.4 – 5.3
Total		2400 – 4400			24.0 – 44.6

* Targets for Ukraine in accordance with the National Waste Management Strategy until 2030

Production and use of biogas (MBT)

Biogas (methane) productivity of one ton of Ukrainian MSW is 60-75 nm^3/t. As conservative estimate a value of 60 nm^3 CH_4/t could be used. The net calorific value of methane is 10 kWh/nm^3. Therefore, the total potential of electric energy generation per ton of mixed solid waste with electric efficiency 40% is

$$60\ (nm^3/t) \times 10\ (kWh/nm^3) \times 0{,}4 = 240\ kWh/t$$

With green tariff of 0.1239 EUR/kWh potential income from electricity sales equals 29.7 EUR/t of mixed solid waste.

Utilization of heat with the efficiency of 45% by the tariff of 1200 UAH/Gcal (37.5 EUR/Gcal) without VAT can bring another 0.240 MWh x 0.45/0,4 x 0.86 x 37.5 = 8.7 EUR/t of mixed waste.

One more source of income for MBT could be compost from digestate after biogas production or without biogas component in the project. However, to make production of commodity compost possible, it is essential to improve separate waste collection.

Potential source of income for MBT could be production of SRF for further use in the cement industry or specialized CHP plants/boiler houses that supply heat to the DH/HWS utility system, and, in case of CHP electricity in the grid or for utilities and industry consumption.

There is an interest in the implementation of demonstration projects of SRF utilization in cement industry in Ukraine. There are barriers for this approach due to the absence of relevant legislation and precedent in Ukraine and, as a result, the uncertainty about the conditions for the transfer/sale of SRF for cement industry.

The use of RDF/SRF as a fuel in power or cement plants is associated with the need to install additional equipment for flue gases cleaning and controlling. Therefore, such enterprises can both buy fuel and charge for the RDF/SRF utilization, considering it as waste, not fuel. It means that RDF/SRF can have both positive and negative market value.

Thermal treatment of MSW

By thermal treatment of MSW with net calorific value of 8 MJ/kg it is possible to obtain from ton of mixed solid waste approximately 0.5 MWh of electric and 1.2 Gcal of thermal energy.

At wholesale electricity tariff of 2 UAH/kWh and heat tariff of 1200 UAH/Gcal, the income from electricity sales may amount to 980 UAH/t (30.6 EUR/t) and from heat sales 1440 UAH/t (45 EUR/t).

Potential income per tonne of solid waste for different utilization ways is shown in Fig. 19. Minimum and maximum values for sorting correspond to minimum and maximum content of certain component in MSW, in case of biogas correspond to output of 60 and 75 cubic meters of biomethane per ton of solid waste, in case of thermal treatment correspond to different net calorific value of solid waste, which is equal 8 and 10 MJ/kg.

It is easy to see that from the point of view of income generation from the sale of material or energy, the most interesting are sale on the secondary market of polymers, production of electricity from biogas with the subsequent sale by green tariff as well as sale of electric and/or thermal energy obtained in the process of thermal treatment. The largest income can be generated by thermal treatment, but the implementation of these technologies is also related to the largest capital (CAPEX) and operating costs (OPEX).

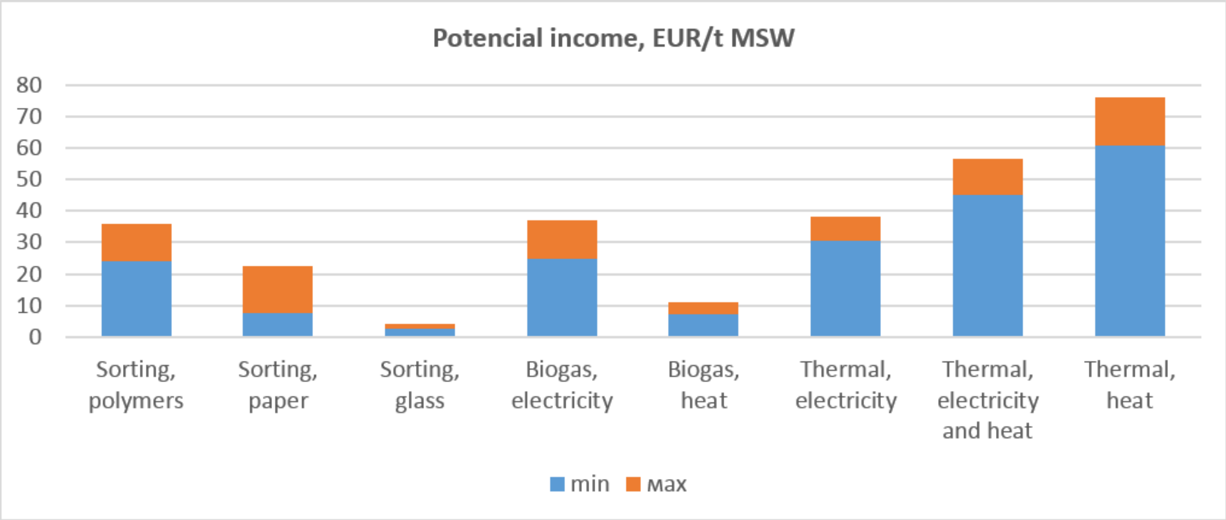

Fig. 19 – Potential income per ton of MSW

Capital and operational expenditures

Landfill gas recovery at MSW landfills and waste dumps

Inputs to estimate required investments for LFG recovery system with production of electric and/or thermal energy can be assessment of LFG generation rate, as a consequence, the potential of installed electric power, as well as landfill area (area of LFG collection system in the event of partial landfill coverage).

Capital expenditures on LFG recovery and utilization system construction at landfills and solid waste dumps depend on physical conditions formed during exploitation process. Specific cost of project, which involves production of electricity from LFG, usually ranges from 1500 to 2500 EUR/kW of installed electrical capacity. The lower value is more associated with controlled landfills, the upper one with waste dumps. There are at least two reasons for that. At waste dumps it is possible to collect less LFG per unit of accumulated waste, in addition, construction of recovery system at uncontrolled waste dumps involves additional costs due to complex geometry of the waste body and the need to form the upper airtight layer covers the waste.

The investor must be aware that, at relatively small capital costs, dumpsite projects are associated with an increased risk because of uncertainty in the baseline conditions and the inability to reliably predict LFG generation rate. The payback period of the project will depend on actual LFG amount and efficiency of its recovery. At current green tariff for electricity sale and achieved efficiency of LFG recovery 50%, projects can pay off in 2-3 years, with possible recovery efficiency of 20% in 6-8 years or even longer.

Mechanical biological treatment of solid waste

Capital expenditures on the implementation of MBT technologies depend on many factors and by this reason cannot be assessed reliably. Specific capital cost will vary depending on:

1. selected treatment priorities, among them RDF/SRF production, depth of secondary materials recovery, biogas production with subsequent energy use, compost or compost-like product production);
2. Initial MSW content (solid waste after separate collection or mixed solid waste);

3. availability and type of sorting process before MBT (manual, automatic);
4. treatment capacity (scale effect).

Since it is not possible to make a reliable assessment of capital and operating costs without reference to the specific project conditions, the following estimates are indicative and should therefore be considered as a benchmark.

The cost of the MBT plant depending on design capacity is shown in Fig. 20 according to two authors published in 2000 and 2006. It is easy to see that in the capacity range of 50,000-150,000 t/yr, the cost of MBT plant can range from 10 to 25 million USD. The cost of similar capacity projects may vary in two or more times probably mainly due to the difference in technological solutions.

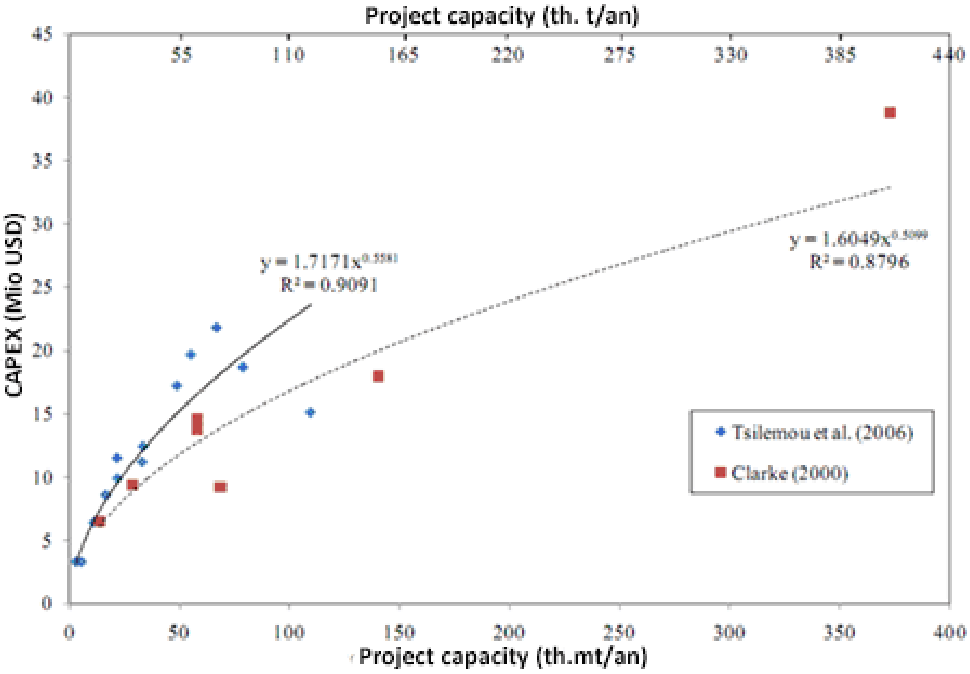

Fig. 20 – MBT projects capital cost

According to the Danish company Ramboll[17], the cost of MBT projects with a capacity of 85,000 to 200,000 t/yr, which were implemented in Germany and the UK from 2001 to 2012, was in the range of 20 to 75 mill EUR (in one case 156 mill EUR) with average CAREX around 250 EUR/t of MSW processed during the year.

The authors' analysis of the MBT projects announced in the period 2017-2018 showed similar result. Typical specific costs for the projects in capacity range of 100,000-200,000 t/yr are from 150 to 400 EUR/t of MSW in countries such as France, Spain, USA, and Australia. There are announcement regarding implementation of similar projects in developing countries such as India and Nepal. In this case, the planned costs are significantly lower in the range of 50-100 EUR/t. However, it should be borne in mind that in this case it is about scheduled costs for unrealized projects.

It is interesting to compare the announced costs for projects in Ukraine. The relevant data is presented in Table 8 for four potential projects in Lviv, Poltava, Khmelnitsky and Zhytomyr. Despite the fact that the given data are only estimation since all considered projects have not yet

[17] Supporting investments in sustainable municipal solid waste management and recycling in Ukraine. Technology workshop – recycling and MBT. – Ramboll – March 20, 2018.

implemented, it can be seen that the planned cost of developing projects in Ukraine is in the range of 120 to 250 EUR/t.

Table 8 - Announced MBT projects in Ukraine

Project	Capacity, kt/yr	CAPEX, mill EUR	Specific cost, EUR/(t/yr)	Project status (January 2019)
Lviv	240	35*	146	Choice of technology provider, tender procedures in progress
Poltava region	130	18 –21**	140 –160	Planning stage, concept development
Khmelnitsky	80	20***	250	Estimation of technical solution, choice of technology provider
Zhitomir	82	10****	122	The project was announced in mid-2018

* - EBRD loan (includes closure of old landfill)

** - assessment of SEC Biomass (lower limit - RDF/SRF production, upper limit - biogas with electricity generation)

*** - GIZ estimation (electricity generation from biogas)

**** - production of RDF/SRF and compost from OFMSW (organic fraction of solid waste)

Operational costs (OPEX) for MBT technology are primarily related to electricity consumption, repairs and maintenance costs, staff remuneration, and cost of residuals disposal. It is typically in the range from 8 to 12% of capital expenditures.

The final cost of MSW processing is determined by CAPEX and OPEX as well as the terms of project financing. If project specific capital cost amounts 150 EUR per ton of MSW processed during the year, the final cost of MSW treatment is 30-40 EUR/t depending on conditions and share of involved bank capital. Here, final cost is evaluated as revenue per tonne of MSW that is needed to ensure zero-value of the project net present value (NPV) for 20 years.

For more costly projects (300 EUR/t, the final cost of MSW treatment can amount 60-80 EUR/t, and in case of involving Ukrainian commercial banks with actual lending terms up to 100 EUR/t. If in the first case (CAPEX= 150 EUR/t) there is a potential possibility to cover project expenses by electricity sale from biogas at green tariff, and in some cases heat sale, then in another case (CAPEX= 300 EUR/t) there is a need for substantial increase of gate fee for MSW treatment.

These considerations did not take into account the hypothetical possibilities of attracting targeted non-repayable financing and the use of budget funds, for example, environmental or development funds

Thermal treatment of MSW

Capital expenditures for waste incineration plant depend on the technological solution, the original properties of solid waste, the type of energy produced, and the depth of flue gas cleaning. Dependence of specific investments versus capacity of the incinerator is shown in Figure 21 according to the World Bank[18]. The authors point out that the curves were relevant in mid-1998 for WIPs with an average level of gas cleaning and electricity generation from waste with net calorific value of 6-9 MJ/kg.

Despite the fact that this data is somewhat outdated, the figure clearly shows the dependence of CAPEX vs. plant capacity as well as differentiation of capital costs for hardware and civil work.

[18] WORLD BANK, 2000

One can see that the total cost of WIP treated mixed waste amounted 60 mill USD for capacity of 100,000 t/yr and 200 mill USD for capacity of 500,000 t/yr. Thus, the specific investments amounted to 600 USD/t in the first case and 400 USD/t for larger projects.

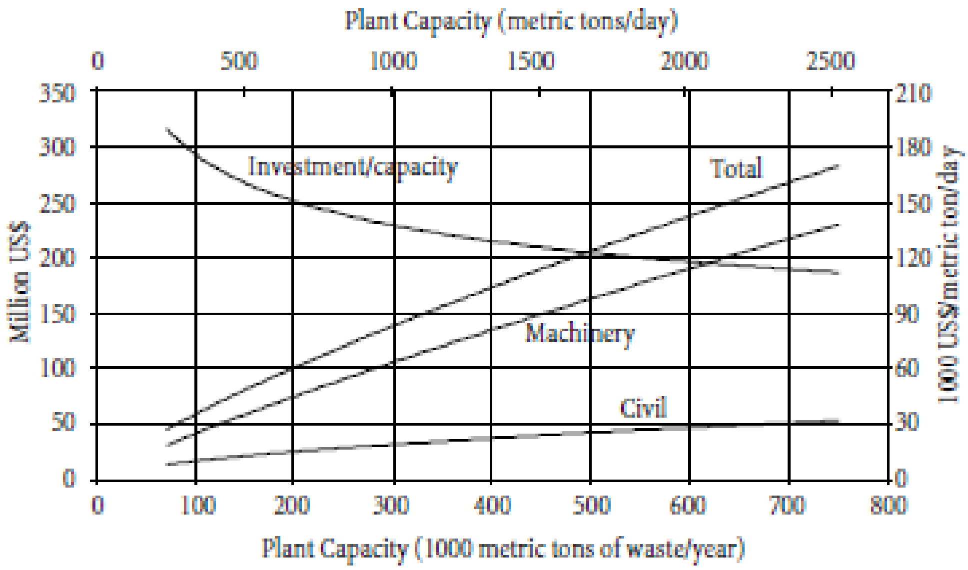

Fig. 21 – Waste Incineration Plants economy (CAPEX)
Source: World Bank

Similar picture can be seen for more modern projects. Figure 22 demonstrates data for capital expenditures of WIP projects, most of which were implemented between 2000 and 2005 in such countries as Denmark, Norway, Germany and China[19].

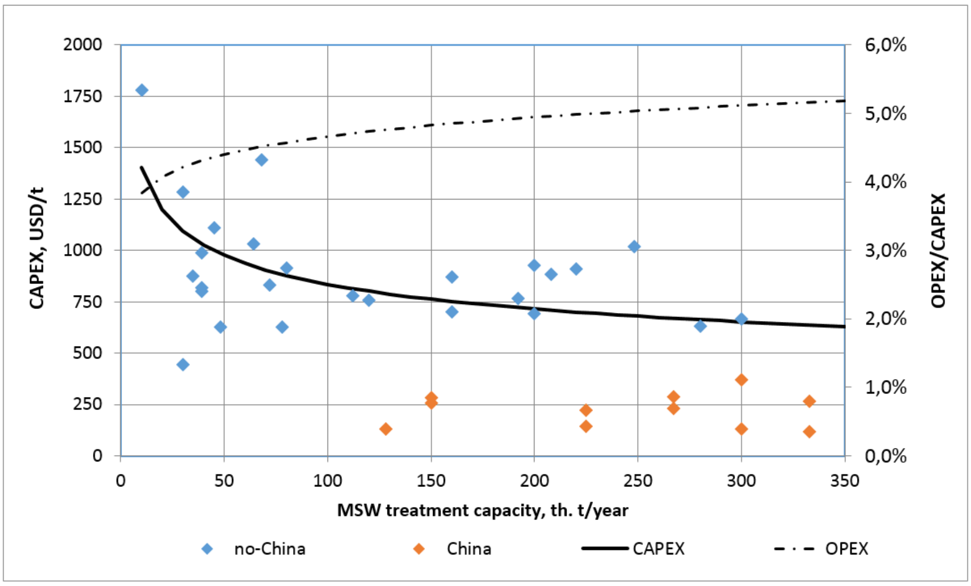

Fig. 22 – Specific cost of implemented WIPs
Source: WTE Guidebook, EEC/IDB, July 2013

Different colours are used for the projects implemented in China and beyond. It is easy to see that specific cost of Chinese projects is much lower than European ones. The cost of WIPs built outside of China amounted an average to 800 USD/t with significant spread especially for relatively small projects (<100,000 t/yr). For small European projects specific cost exceeds 1000

[19] WTE Guidebook, EEC/IDB, July 201

USD/t and can reach up to 1800 USD/t. The cost of Chinese projects is in the range of 150-400 USD/t with an average value 200 USD/t and do not show the scale effect in capacity range of 100,000-350,000 t/yr.

The figure presents also capital and operating costs calculated by following equations: CAPEX = $2.3507 \times X^{0.7753}$ and OPEX = $0.0744 \times X^{0.8594}$, proposed in the paper[20], where X is the project capacity in thousand t/year. It can be seen that the proposed CAPEX dependence describes adequately the average cost of projects outside of China.

In Ukraine, it would be advisable to construct WIPs with treatment capacity from 100,000 t/yr for regional centres with population 250,000-500,000 inhabitants until 300,000 t/yr in the cities with population of one million inhabitants. In Kyiv it is potentially possible to build WIP of 500,000 t/yr. WIP cost can range by using above equations from 75 mill EUR for 100,000 t/yr capacity until 265 mill EUR for 500,000 t/yr capacity (Table 9). For such parameters MSW treatment cost will amount to 100 EUR/t for large project (500,000 t/yr) and up to 150 EUR/t for smaller project (100,000 t/yr).

Table 9 – Basic WIP parameters

Parameter	I	II	III
MSW treatment capacity, t/yearк	100 000	200 000	500 000
CAPEX, mill EUR	75	130	265
OPEX, mill EUR/year	3.5	6.5	14
MSW treatment cost, EUR/t	130…150	110…130	90…100
Installed electrical capacity, MW	5.6	11.2	28
Electricity production, MWh/year	42 000	84 000	210 000
Specific electricity production, MWh/t	0.42		

Sources of revenue for WIPs may be electricity, heat/steam, and metal scrap. Sale of scrap do not exceed a few EUR per ton of waste. The electric power can be estimated based on net calorific value of MSW (8 MJ/kg) and electric efficiency (22%). It is easy to see that specific cost of WIP in terms of installed electric power is very high. It ranges from 10,000 to 15,000 EUR/kW of installed electric capacity. This is clear as soon as WIP is not specialized energy plant, its main function is waste treatment.

Above we have estimated that electricity and heat sale by actual tariffs could form income in the range 30-70 EUR/t.

Another part of the plant's income can be formed by tariff for waste treatment (gate fee). If we assume that current acceptance limit for Ukrainian population for treatment tariff is 30 EUR/t, then for big WIPs the revenue from energy sales should be at least 60-70 EUR/t. Above we have shown that under certain conditions this is possible for combined heat and electricity production and sale or production and sale of heat only.

However, in general, it can be concluded that European approaches and costs of thermal waste treatment are too expensive for current Ukrainian conditions. At the moment Ukraine still needs more economical technological solutions.

[20] Farzad Bazdidi Tehrani, Ehsan Haghi. Techno-economic assessment of municipal solid waste incineration plant – case study of Tehran, Iran. Sharif University of Technology. – 2015.

Criteria for selection of MSW treatment technology

The choice of waste treatment technology should be a part of regional waste management plans development. One of the first plan's priorities is to decide location of new regional landfill using the principles of interregional cooperation. In most cases MSW treatment facilities will be geographically bound to regional landfills. The choice of specific treatment technology depends on many factors, some of which are presented below in Table 10. One of the most important factors at the moment is the cost of treatment for one ton of solid waste.

The choice of waste-to-energy utilization is usually determined by the following considerations:

1. Possibility of increasing of waste processing depth, especially in the case of thermal treatment, in order to minimize disposal and the need for new landfills;
2. Possibility of obtaining an additional source of energy replacing fossil fuels such as natural gas or coal;
3. Possibility of obtaining additional income by sale of electricity and heat, and in some cases a solid fuel substitute.

It should be noted that obtaining of additional income due to the sale of electricity and heat from MSW in most cases does not mean the achievement of investor-friendly economic parameters. In most cases, a substantial increase in the tariff for waste management is essential for projects implementation, especially for thermal treatment methods. Exceptions to this rule are LFG recovery projects.

From the technological point of view, LFG recovery and utilization projects are the simplest, followed by manual and automatic sorting lines, MSW conditioning, aerobic and anaerobic treatment methods, and thermal treatment of prepared (RDF/SRF) or mixed solid waste.

Specific capital expenditures go up with increasing of technology complexity. At the current level of Ukraine's economy only relatively simple projects can be developed, in most cases the choice of technology will be determined by the principle of "reasonable sufficiency". According to this principle there are already implemented projects for LFG recovery and manual sorting lines, planned first MBT projects with capacity at least 80,000 t/yr. Such projects supported by Ukrainian legislation providing stimulating green tariff for electricity from LFG or biogas obtained by MBT.

For implementation of thermal treatment projects using equipment of European suppliers, economic conditions in Ukraine are not yet available. Such projects could be realized only in case of substantial reduction of CAPEX preferably without loss of flue gas cleaning quality. An exception is potential combustion of RDF/SRF by cement plants.

Solid fuel from MSW can be used in specialized CHP/boiler supplying heat in DH/HWS system, and in case of CHP electricity in the grid or directly to utilities. Implementation of such project is possible in two ways as CHP with a turbine operating in heating and condensing modes or boiler houses (without turbine). The first option (CHP) provides a relatively constant load on fuel, in summer time excess heat can be utilized in cooling towers (up to 30% of fuel energy). The second option (boiler house) allows to reduce capital expenditures, increase efficiency of fuel use, but does not provide constant load on fuel during the year. In summer time fuel should be accumulated and used in the autumn-winter period. For thermal treatment projects the distance to DH network is very important factor.

The use of a stimulating green tariff for electricity generated by MSW thermal treatment is not foreseen in Ukraine. Moreover, even hypothetical use of electricity tariffs at green tariff level for biomass and biogas does not generate the necessary cash flows to enhance enough economic attractiveness of thermal treatment project required for investor. When the costs of MSW incineration is at the level of 100-150 EUR/t potential profit from electricity sale by green tariff does not exceed 60 EUR/t for MSW with calorific value 8.0 MJ/kg and 75 EUR/t for 10 MJ/kg.

For incineration of MSW electrical efficiency is fairly low, in cogeneration schemes additional energy can be obtained in the form of heat. Therefore, the main income can be related to heat sale. For example, in the EU waste incineration is mostly developed in countries practicing centralized district heating (Denmark, Sweden). Despite the fact that there are negative trends in the development of the DH in Ukraine, the potential for using heat from solid waste in the DH/HWS systems is quite large.

In the absence of CHP/boiler plants for RDF/SRF utilization the distance to the nearest cement plant that is interested in the use of alternative fuels and has complete clinker firing cycle is important.

Project risks are associated with dependence on waste/raw materials supplies, dependence on energy consumers, the need to allocate additional land plot in the vicinity of the DH systems, and law heat consumption in summer time. Risk reduction can be achieved by increasing the amount of waste/raw materials and guarantees for its delivery, clarification of conditions for transfer/sale of fuel for cement plants, creating conditions for total heat use. Table 10 provides comparative analysis of different options of waste-to-energy use.

Table 10 – Comparative analysis of different waste-to-energy options

Project type	**LFG recovery with electricity production**	**MBT with biogas**	**MBT for SRF (cement plants)**	**Production of RDF/SRF with energy use**	**MSW incineration with energy use**
Equipment	LFG collection system + CHP at the landfill	Sorting + biogas plant + CHP	Biological stabilization + sorting + conditioning	SRF production + industry CHP/ boiler house for solid fuel	Waste incineration plant (mixed MSW)
Electricity production and use	Green tariff for electricity from LFG	Green tariff for electricity from biogas	n.a.	There is no green tariff for electricity from biogas	
Heat production and use	Usually no heat consumer within 3 km radius	Usually no heat consumer, 30% of heat for the process	No	DH/HWS system, low heat consumption in summer time	
Logistic	Local electricity production	Electricity production from biogas as part of MSW treatment	Production and delivery of SRF to closest cement plant (up to 200 km)	Optimization of the distance to DH/HWS system, MSW delivery and storage in summer time (without CHP)	
Need for disposal after treatment	100%	30 –35% (+ digestate)	20 –25%	25 –30%	20 –25%

<table>
<tr><th>Project type</th><th>LFG recovery with electricity production</th><th>MBT with biogas</th><th>MBT for SRF (cement plants)</th><th>Production of RDF/SRF with energy use</th><th>MSW incineration with energy use</th></tr>
<tr><td>Risks</td><td>Low efficiency of LFG recovery</td><td>Amount and quality of raw material for biogas production</td><td>Dependence from SRF consumer</td><td colspan="2">Need for land plot next to DH/HWS system, low heat consumption in summer time</td></tr>
<tr><td>Risk reduction possibilities</td><td>Landfill covering (recultivation), creation of heat consumer next to landfill</td><td>Expansion of raw material base (multi-regional approach)</td><td>Clear condition of SRF transfer/ sale to cement plants</td><td colspan="2">Combining of DH systems into single clusters, presence of industrial heat consumer of heat, priority of heat production</td></tr>
<tr><td>Economy

CAPEX</td><td>Low cost

1,5…2,5 EUR/MW_e</td><td>Mid cost

200…400 EUR/(t/yr)</td><td>Mid cost

150…300 EUR/(t/yr)</td><td>High cost

300…500 EUR/(t/yr)</td><td>Very high cost

500…1000 EUR/(t/yr)</td></tr>
<tr><td>Advantages</td><td>Simple,
not expensive</td><td>Satisfactory economic performance</td><td>Substitution of fossil fuel by cement industry</td><td colspan="2">Substitution of natural gas, diversification of fuel sources</td></tr>
<tr><td>Disadvantages</td><td>Short project life, limited influence at MSW management</td><td>Dependence on raw material, lack of information regarding MSW quality</td><td>Big delivery distance, dependence on SRF consumer</td><td colspan="2">Need for additional land plot next to DH system, unsatisfactory economical parameters, need for substantial increase of gate fee</td></tr>
</table>

Conclusions and recommendations

The new Ukrainian waste management strategy until 2030 envisages the transition from waste landfill disposal to the integrated waste management approach. In practice, this means the construction of new regional landfills, the achievement of 50% recycling of household waste in 2030, the commissioning of additional waste sorting lines and waste treatment facilities, and pilot projects on SRF production based on MBT facilities in case they are approached to cement plants, and introduction of projects for biological stabilization of mixed municipal waste.

The expediency of energy utilization can be determined by reducing the amount of disposed waste and increasing the life of new regional landfills. The experience of developed countries shows that separate collection and reuse are developing simultaneously with the energy use of solid waste, competing to some extent for raw materials, but not contradicting each other.

From technological point of view, LFG recovery and utilization projects are the simplest, followed by manual and automatic sorting lines, MSW conditioning, aerobic and anaerobic stabilization methods, thermal treatment of prepared (RDF/SRF) and mixed solid waste. With increasing of technology complexity specific capital expenditures for their implementation also increase.

Introduction of any processing methods requires the consolidation of MSW management system at the regional level with a capacity of at least 100,000 t/yr or more. At this scale MBT projects with biogas production and electricity sale by present green tariff may demonstrate satisfactory economic performance in Ukraine.

Another perspective is SRF production for further application in the cement industry. The complexity of this approach is due to the lack of relevant legislation in Ukraine and, as a consequence, the current uncertainty about the conditions for transfer/sale of SRF to cement plants.

With the existing level of economy in Ukraine, only relatively simple projects of MSW treatment could be developed, the choice can be determined by the principle of "reasonable sufficiency". In accordance with this principle, LFG recovery and manual sorting lines are being implemented, several MBT projects with capacity over 80,000 t/yr are in the planning stage.

Waste incineration remains the most expensive method of MSW treatment. For implementation of thermal treatment projects using equipment of European suppliers, economic conditions in Ukraine are not yet available. Such projects could be realized only in case of substantial reduction of CAPEX preferably without loss of flue gas cleaning quality or substantial increase of the tariff for processing of solid waste.

Possible options for reducing the cost of thermal treatment:

1. Preferable combustion of RDF/SRF by cement plants and specialized solid fuel boilers/CHP instead of combustion of mixed MSW;
2. Focusing on DH systems of large cities, preferable generation of thermal energy instead of electricity, corresponding savings on the equipment that generates electricity (steam turbine etc.);
3. Reduction of CAPEX by maximal involvement of local equipment suppliers if possible.

The existing tariff for waste management covers mainly the costs of waste transportation to disposal sites, but disposal is paid on a residual basis. The cost of construction potential waste management facilities, both regional controlled landfills and waste treatment plants, substantially exceeds the currently available amount of paid services in Ukrainian solid waste management. Therefore, in Ukraine, there is a need to implement tariffs for treatment and disposal, which would ensure operation at the required technical and environmental level and include a certain component for the implementation of investment projects.

Acronyms

HWS	–	Hot water supply
SAEE	–	State Agency on energy efficiency and energy saving of Ukraine
ICE	–	Internal Combustion Engine
EBRD	–	European Bank for Reconstruction and Development
CUIP	–	Coefficient of Utilization of Installed Capacity
CHP	–	Combined Heat and Power
CMU	–	Cabinet of Ministers of Ukraine
ME	–	Municipal Enterprise
MBT	–	Mechanical Biological Treatment
NRCEU	–	National Regulatory Commission for Energy and Utilities in Ukraine
SEC	–	Scientific Engineering Center
OECD	–	Organization of economic cooperation and development
LGB	–	local governments bodies
VAT	–	Value-added Tax
WTP	–	Waste Treatment Plant
WIP	–	Waste Incineration Plant
CHPI	–	CHP (Industrial scale)
MSW	–	Municipal Solid Waste
DH	–	District Heating
CAPEX	–	Capital Expenses
EUR	–	Euro
GIZ	–	Deutsche Gesellschaft für Internationale Zusammenarbeit (**GIZ**) GmbH
OPEX	–	Operation Expenses
RDF	–	Refuse Derived Fuel
SRF	–	Solid Recovered Fuel
USD	–	US Dollars
LFG	–	Landfill Gas
WTE	–	Waste-to-Energy

Previous publications by UABio

http://www.uabio.org/ua/activity/uabio-analytics

1. Position Paper N 1 (2012) "Position of bioenergy in the draft updated energy strategy of Ukraine till 2030".
2. Position Paper N 2 (2013) "Analysis of the Law of Ukraine "On amending the Law of Ukraine "On Electricity" No5485-VI of 20.11.2012".
3. Position Paper N 3 (2013) "Barriers to the development of bioenergy in Ukraine".
4. Position Paper N 4 (2013) "Prospects of biogas production and use in Ukraine".
5. Position Paper N 5 (2013) "Prospects for the electricity generation from biomass in Ukraine"
6. Position Paper N 6 (2013) "Prospects for heat production from biomass in Ukraine"
7. Position Paper N 7 (2014) "Prospects for the use of agricultural residues for energy production in Ukraine".

8. Position Paper N 8 (2014) “Energy and environmental analysis of bioenergy technologies”
9. Position paper N 9 (2014) “State of the art and prospects for bioenergy development in Ukraine”
10. Position paper N 10 (2014) “Prospects for the growing and use of energy crops in Ukraine”
11. Position paper N 11 (2014) “Prospects of biomethane production and use in Ukraine”
12. Position paper N 12 (2015) “Prospects for the development of bioenergy as an instrument for natural gas replacement in Ukraine”
13. Position paper N 13 (2015) “Analysis of energy strategies of the EU and world countries and the role of renewables in their energy systems”.
14. Position paper N 14 (2016) “Analysis of tariff setting in the district heating sector of EU countries”.
15. Position paper N 15 (2016) “Analysis of additional sources of wood fuel in Ukraine”.
16. Position paper N 16 (2016) “Opportunities for harvesting by-products of grain corn for energy production in Ukraine”.
17. Position paper N 17 (2016) “Analysis of criteria for the sustainable development of bioenergy”.
18. Position paper N 18 (2017) “Creation of the competitive biofuel market in Ukraine”.
19. Position paper N 19 (2018) «Opportunities for wood fuel harvesting in forests of Ukraine».
20. Position paper N 20 (2018) “Analysis of possibilities for the production and use of agribiomass briquettes in Ukraine”
21. Position paper N 21 (2019) “Analysis of barriers for the production of energy from agribiomass in Ukraine”

Civic union "Bioenergy Association of Ukraine" (UABio) was established to create a common platform for cooperation on bioenergy market in Ukraine, as well as to provide the most favorable business environment, accelerated and sustainable development of bioenergy. General constituent assembly of UABio was held on September, 25, 2012 in Kyiv. The Association was officially registered on 8 April 2013. Among UABio members there are over 30 leading companies and over 20 recognized experts working in the field of bioenergy. http://uabio.org/en/

Біоенергетична асоціація України