Report on sustainable SWM solutions

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1. Introduction

The following documents define the European Union 3R policy (see Fig. 1) on waste management:

- **Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives;** http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0098:EN:NOT
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions tackling the challenges in commodity markets and on raw materials (COM (2011) 25 Final) http://ec.europa.eu/prelex/detail_dossier_real.cfm?CL=en&DosId=200119
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (COM(2011) 21 Final**);** http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0021:FIN:EN:PDF
- Commission decision (draft): rules and calculation methods, November 2011. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri= OJ:L:2011:310:0011:0016:EN:PDF
- Guidelines on the interpretation of key provisions of Directive 2008/98/EC on waste, 2012 http://ec.europa.eu/environment/waste/framework/pdf/guidance_doc.pdf
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (COM(2014) 398 final), http://www.ipex.eu/IPEXL-WEB/dossier/files/download/082dbcc54653729e014700ae122f61dc.do
- Directives of the European Parliament and of the Council of 30 May 2018
  2018/850, on the landfill of waste https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0850&rid=3
  2018/851 on waste https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32018L0851
  2018/852, on packaging and packaging waste https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A32018L0852

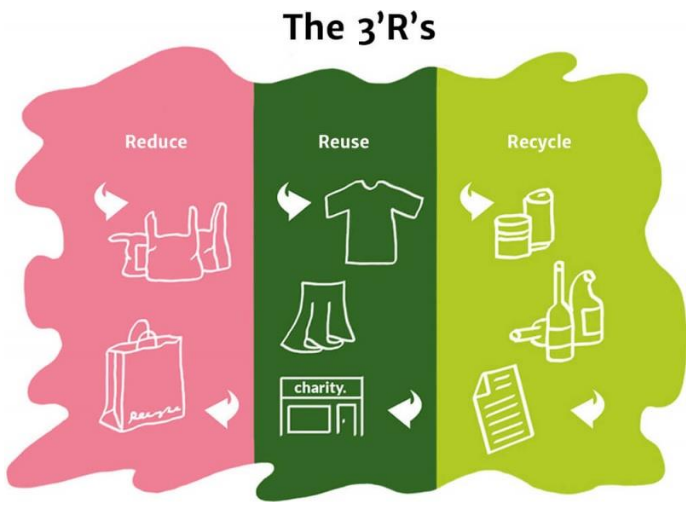

Fig. 1. EU 3R policy on waste management

The WFD setted also the targets that Member States should achieve by the year 2020; i.e

- Art 11 sets a minimum recycling target of 50% (by weight) for waste from households and 70% for construction and demolition waste;
- Art 22 says that 'Member States shall take measures, as appropriate, to encourage the separate collection of bio-waste with a view to the composting and digestion of bio-waste';

The WFD assumed that incineration of waste in facilities dedicated to the processing of municipal solid waste with energy efficiency equal to or higher than 65% (installations permitted after 31 December 2008) can be considered as a recovery operation (not recycling). Article 11 of the WFD states that recycling should include waste streams such as '... paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households'. Some explanations about waste fluxes accounted in recycling and re-use operations as well as methods for the calculation of the target on municipal waste (defined as household waste and similar waste) are given in the Commission Decision (2011/753/EU).

Art.2 (6) of the Decision states that **-** 'Where the target calculation is applied to the aerobic or anaerobic treatment of biodegradable waste, the input to the aerobic or anaerobic treatment may be counted as recycled where that treatment generates compost or digestate which, following any further necessary reprocessing, is used as a recycled product, material or substance for land treatment resulting in benefit to agriculture or ecological improvement'.

It can be concluded from the EU Decision that composting or anaerobic digestion of the organic fraction of municipal waste (OFMW) could help in achieving the 50% recycling target only if the digestate product can be applied to land as a biofertiliser or in combination with other organic materials to improve soil quality.

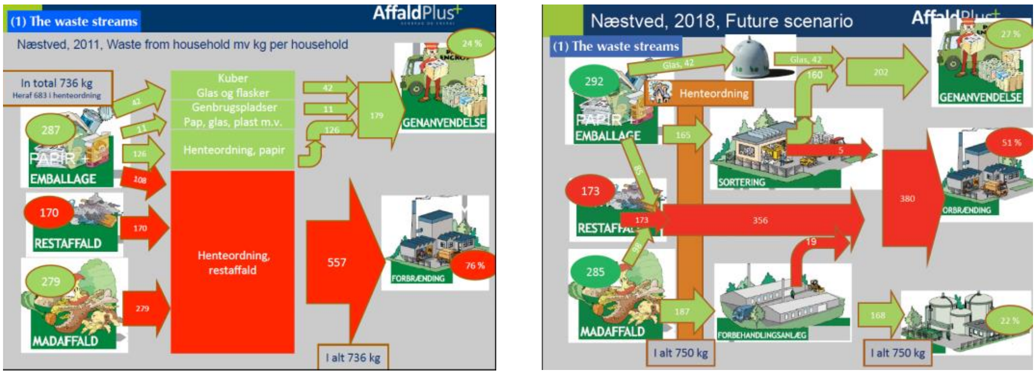

Fig. 2. Example of changes in waste streams by 2018, compared to the year 2011 in Næstved, Denmark [1].

It means also that the use of compost or digestate as a fuel for waste incineration plant precludes classifying the processes of aerobic or anaerobic treatment of biodegradable waste as recycling. In that case, waste treatment is classified as 'other recovery' that is ranked lower in the waste hierarchy than recycling and composting. In view of this fact, countries with advanced technologies of waste incineration have started revising their waste management systems.

An example of planned changes to meet all requirements of the Framework Directive on Waste 2008/98/EC including Commission Decision of November 2011 is the Næstved municipality in Denmark (see Fig. 2). In 2011 the stream of waste from Næstved to incinerators amounted to 76% (or

[1] Source: Presentation of Tyge Kjaer**,** Professor of Roskilde. University, given at the meeting of BP2 project: Roundtable on biowaste/energy solutions in Gdynia, 21.06.2013.

about 557 kg per year, per household). The remaining waste (about 24% and 179kg, respectively) including glass, plastics and paper was recycled. To increase the level of recycling to obligatory 50% by 2018, the organic **fraction of municipal wastes of high moisture content** will be directed to a biogas plant. It is expected that this will result in reducing the waste stream for energy recovery to about 51% (380 kg per year per household). Successful implementation of this plan requires separation **of the organic fraction of household waste at source.** If this is done, the condition of **using** quality **digestate** and compost in agriculture can be easily met.

In 2014, the EU Commission published the Communication "Towards a circular economy: A zero waste programme for Europe" (COM(2014) 398 final) addressed to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions promoting "zero waste" (circular) economy. The idea is based on long term sustainability criteria, i.e. taking into account the generations which will follow us. Among the considered criteria are: source and energy efficiency, greenhouse gas emission, social responsibility (e.g. avoiding conflict with production of food and support for local market).

The Communication postulates increased (up to 70%) material recycling and limitation of landfill disposal to 5% of all collected waste in previous year. The Commission pays special attention toward availability and phosphorus safety, the necessary element for agriculture. Although this issue is already considered in previous legal framework, the Commission is planning more restrictive legislation in the future.

The Polish municipalities elaborating currently their strategies for waste management systems have also to take account of the requirements of the WFD and EU Decision (2011/753/EU) when planning new installations for thermal treatment of municipal solid waste. **The installations for the combustion or gasification of dry combustible fraction of municipal waste, so-called 'pre RDF' should be designed carefully (**especially with regard to the installation size).

EU regulations postulate that separated at source, the o**rganic fraction of municipal wastes of high** moisture content, should be subjected to aerobic or anaerobic processes producing high-quality products that can be used as a fertilizer or soil improver. Then the processes of **the waste thermal treatment** can be considered in the recycling target calculation.

Properly conducted policy on waste management (in accordance with the EU requirements and hierarchy for waste management) creates opportunities to increase the recycling level as well as material and energy recovery from the municipal waste stream**.** As a result of anaerobic digestion taking place in a biogas plant two valuable products: biogas and digestate are produced. Biogas is a source of renewable energy. The digestate can be a valuable biofertiliser or after drying it can be used as a **solid fuel for** energy recovery installation (**waste incineration plant). T**he use of compost or digestate as a fuel for waste incineration plant preclude from classifying the processes (anaerobic digestion or composting) of biodegradable waste utilisation as recycling – it lacks of phosphorus recycling. It can only be classified as 'energy recovery', that is ranked lower in the waste hierarchy than recycling and composting. This is an important conclusion that should be considered by the municipalities when planning new installations for treatment of municipal solid waste. In order to avoid problems with digestate utilisation (as biofertiliser) the **fraction of municipal wastes of high moisture content** should be separated at source and directed strait to the biogas plant. This will result in a reduced waste stream for energy recovery installation.

2. Innovative methods of waste transformation

The innovative technologies of waste transformations are discussed here in relation to EU legal framework. The technologies include: mechanical – heat treatment (in large autoclave), biodrying, depolymeriztion, extrusion of mixed waste, extrusion of mixed polymers, methane fermentation, hydroseparation, gasification and pyrolysis (biocoal production). Some of these technologies represent a full waste treatment process (from substrate to product); others can be considered as a partial method or solution. Among full innovative processes are: depolymerization, extrusion of mixed polymers, methane fermentation or gasification and pyrolysis (biocoal production) - we do not consider combustion as this process is already well developed and not fully in line with new EU regulations. Other technologies can be regarded as partial solutions and will be discussed first.

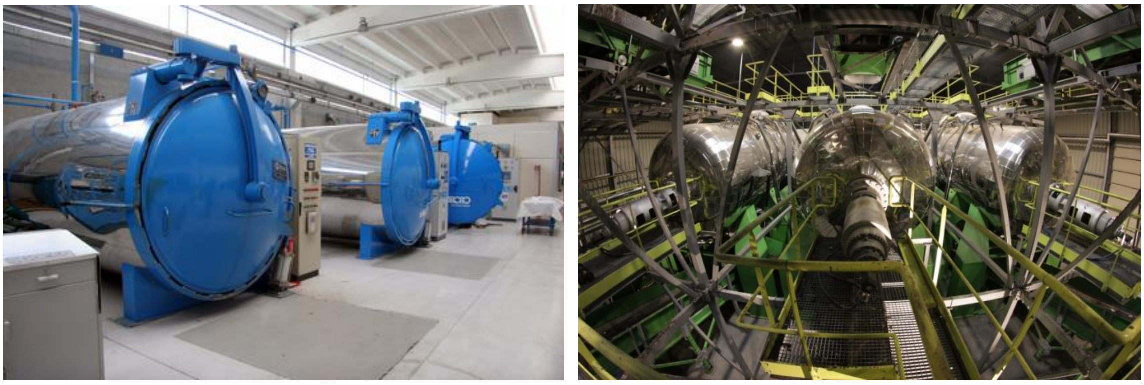

Fig. 3. Autoclaves Envipa and Bioelectra Group

(i) Mechanical – thermal treatment (in autoclave)

This solution has been known for many years but lately applied for municipal waste treatment. The process based on mechanical-heat treatment of mixed waste under temperature around 160^{o}C and pressure of a few bars results in odor and pathogen elimination - see Fig. 3. The process should later be continued in order to separate materials to be recycled.

Fig. 4. Pulper firmy BTA

(ii) Biodrying

This process is related to composting i.e. intensive self-heating of the organic fraction under influence with oxygen (from air) but without addition of water. The temperature in collected prisms reaches a level of 70 - 80˚C leading to fast drying (taking about 2 weeks) of the biomass. The resulted decrease in mass and volume make for easier transportation to e.g. combustion facility or fermentation in a Periodical Anaerobic Bioreactor. Biodrying is a partial process which leads to waste treatment hardly complying with EU regulations.

(iii) Hydroseparation

The process is based on mechanical separation of mixed waste using a water stream. Separation is achieved through the different mass density of various materials. Light fraction e.g. plastics may stay near the surface while minerals and metals settle at the bottom. The organic fraction is located in between (in the water).

Plastics, metals and glass (recovered up to 90%) will be recycled, organic matter can be supplied to a local fermentation facility. The treatment can be a very useful partial process in the technological cycle in line with EU regulation.

(iv) Extrusion of mixed communal waste

VMPRESS Ltd (Italy) proposed separation technology for mixed communal waste. The process uses a high pressure chamber (600 - 1000 bar) with holes in the wall – Fig. 5. The organic fraction of the mixed wastes is pressed through the holes and can be used later as a substrate in a biogas installation. The dry fraction which stays inside the chamber can be combusted or gasified. The energy efficiency of the process is about 40 %. There is some doubt about the possibility of achieving the recycling levels stipulated in the EU regulations. There is not any information about paper, plastics, glass and metal separation.

Fig. 5. Extruder VMPRESS company

(v) Depolimerization

Depolimerization is a process which transforms sorted fractions (biodegradable organic fraction or polyolefin). It is used in order to transform the biopolymers into easy transportable fuels. The hydrothermal depolimerization (sometimes described as HTDP or TDP) enables conversion of organic materials into products, which are presently produced using fossil based materials from petroleum refinery[2]. The process imitates the natural geological processes leading to creation of fossil fuels under high pressure and temperature conditions.

In the process of thermal depolymerisation the feedstock material is first ground into small chunks, and mixed with water if it is especially dry. It is then fed into a reactor vessel where it is heated to around 500K and subjected to 4 MPa for approximately 15 minutes, after which the pressure is rapidly released to boil off most of the water and some gases. The result is a mix of crude hydrocarbons and solid minerals, which are separated out. The hydrocarbons are sent to a second-stage reactor where they are heated to ~750K, further breaking down the longer chains.

[2] *A. Demirbas, "Thermochemical Conversion of Biomass to Liquid Products in the Aqueous Medium", Energy Sources 27 (13) (2005) 1235-1243 oraz* Biomass Program. Agricultural mixed waste biorefinery using Thermal Conversion Process (TCP). U.S. Department of Energy (2006-08).

The various feedstock material has been subject of TDP process, including: biomass (remnants of food and paper industry, of agriculture, of forestry), plastics, heavy products of refinery (heavy fuel oils, tars, …) medical waste or sewage sludge.

Among the products of this process are gases (mainly methane, propane, butane) 6 –16%, liquids (light fuel components: methylbenzene, methyl-ethyl-benzene, cyclohexane, cyclopropane, etc.) 26–70% and solids (coal, minerals) 5 – 8%. Although elements on the inlet and outlet of the process are conserved the chemical composition of the products depends strongly on thermodynamic parameters and of the duration of this particular part of processing. Quality of products, specially their heating value is a function of carbon and hydrogen fraction in the overall mass of a charge.

The volume of liquid products grows with an increase of biomass oils including animal fats, fish and poultry oils, plant oils, and recycled cooking greases. In contrast a greater proportion of carbohydrates in the feedstock results in a growing amount of gases and carbon in the products.

It is known that most biomass oils contain about 95% triglycerides with small amounts of phosphatides, sterols, antioxidants, and other minor compounds. Triglycerides are composed of three long hydrocarbon chains called fatty acids (containing 6 to 24 carbons) with carboxyl ends attached to a glycerol molecule.

There are three processes leading to biodiesel formation: hydrolysis, decarboxylation and product degradation. The first one called hydrolysis leads to disconnection of the fatty acids (e.g. palmitic acid - one of the most common saturated fatty acids found in animals and plants) from the glycerol backbone. The second process of decarboxylation proceeds according to the scheme - for the palmitic acid:

$$CH_3\text{-}(CH_2)_{14}\text{-}COOH \Rightarrow CH_3\text{-}(CH2)_{13}\text{-}CH_3 + CO_2 \quad (1)$$

The third process, product degradation is necessary to explain the presence of carbon and low BTU gas in the products from TDP.

$$CH_3\text{-}(CH_2)_{13}\text{-}CH_3 \Rightarrow 7C + 8CH_4 \quad (2)$$

In the case of ideal TDP process (i.e. without degradation) the yield of liquid hydrocarbon products is ~ 79%. It falls to 63 % in real TDP process due to mentioned degradation.

(vi) Extrusion of mixed polymers (mainly polyethylene and polypropylene)

Using process of extrusion mixed plastics from municipal waste can be transformed into construction materials including cabling chambers – see Fig. 6. There is a US patent describing the production of various products.

Fig. 6. Extruded elements from mixed waste polymers

(vii) Methane fermentation

Fig. 7. Wet fermentation of separated communal waste in Linkoeping – Sweden

There are two main fermentation concepts for communal waste:

(a) fermentation of unsorted wastes using technologies represented by dry processes (above 15% of d.m.) Periodical Anaerobic Bioreactor[3], STRABAG Umwelttechnik GmbH, DRANCO or dry/wet technology with percolation of GICON or wet technology (less than 15% d.m.) after e.g. extrusion of organic matter or sorted fraction from RotoSTERIL process.

(b) fermentation of waste sorted at source - postulated in EU Directive 2008/98/EC due to easier applicable digestate - see Fig. 7.

Two-stage GICON fermentation combines dry fermentation (I phase hydrolises) and wet (II phase methanization) - see Fig. 8. The first stage uses the percolation method.

The problems with application of digestate produced from municipal waste lead to intensive investigations of hydrothermal lyses resulting in decrease of amount of digestate and increased biogas production [4]

[3] Białowiec A., Siudak M., Jakubowski B., Wiśniewski D., Wpływ recyrkulacji odcieków na produkcję i kaloryczność biogazu wytwarzanego w okresowym bioreaktorze beztlenowym, IV Forum Biogazu, IMP PAN Gdańsk, 2014.

[4] A. Cenian, T. Zimiński, J. Dach, A. Lewicki, Hydrothermal lyses as the means to control amount of biogas and digestate production, Conference on Monitoring & process control of anaerobic digestion plants, 17.-18. March 2015 in Leipzig

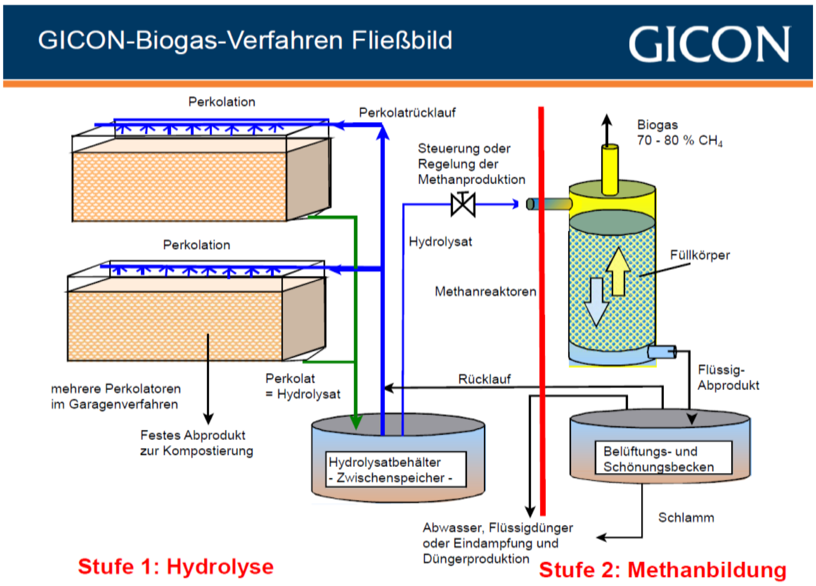

Fig. 8. Scheme of GICON fermentation installation

(viii) Gasification and pyrolysis (biocoal production)

Gasification is an optional process (next to combustion) for utilization of dry waste with calorific value above 6 MJ/kg. There has been extensive R&D work related to the development of small installations for gasification of pre-RDF for distributed thermal treatment of dry waste.

Fig. 9. 400 kW container-like gasification for pre RDF utilization

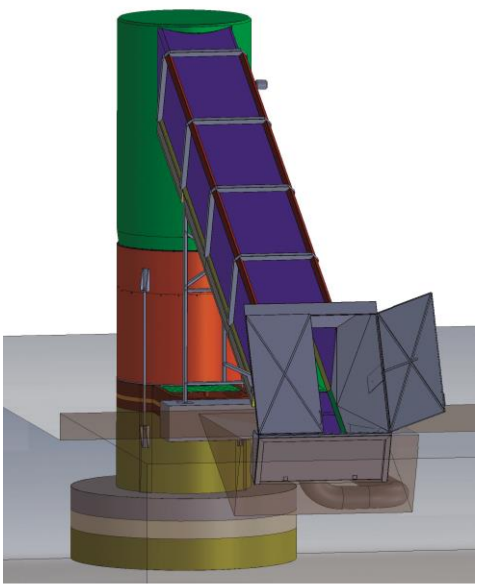 

Fig. 10. Project and realization of Xenenergo reactor

Innovative container-like installation with power in syngas 400 kW has been built in Zakładzie Zagospodarowania Odpadów, Nowy Dwór (near Chojnic) - see Fig. 9. Gasification installation is being built by IMP PAN group (prof. D. Kardas et al.) in frame of WFOS RX 09/25/2014 project, financed by Wojewódzki Fundusz Ochrony Środowiska, Zakład Zagospodarowania Odpadów Nowy Dwór Sp. z o.o., Eco-Construction Sp. z o.o. and IMP PAN. Installation results from R&D of distributed energy and heat production from waste including municipal waste. Another example is the Xenergo reactor built by polish-Swedish company MöreMaskiner, Warszawa - Fig. 10, with a rated power of 1 MW.

Fig. 11. Biochar (see https://pl.wikipedia.org/wiki/Biowęgiel)

However, it should be underlined that according to EU regulations combustion and gasification should be limited in order to maximize the level of recycling, because energy recovery is a category lower than recycling.

The thermal process which can be qualified as recycling is related to bio-coal production by method of pyrolyses - see Fig. 11. Biochar is a very valuable pro-duct similar to charcoal and can be produced from forest residues, agricultural biowaste, sewage sludge and communal waste. Biochar can be used in energetics, as fertilizer in agriculture (increasing sorption), in environmental protection to remove water pollution, etc. Especially important is the possibility of producing biocoal from sewage sludge and its application as a fertilizer. Results of research led by Dach and Malińska show that bio-coal can increase the rate of organic matter mineralization and methane production [5].

3. Zero waste/ circular economy

Figure 12 presents the idea of circular economy proposed by dr Vogt from Wrocław University.

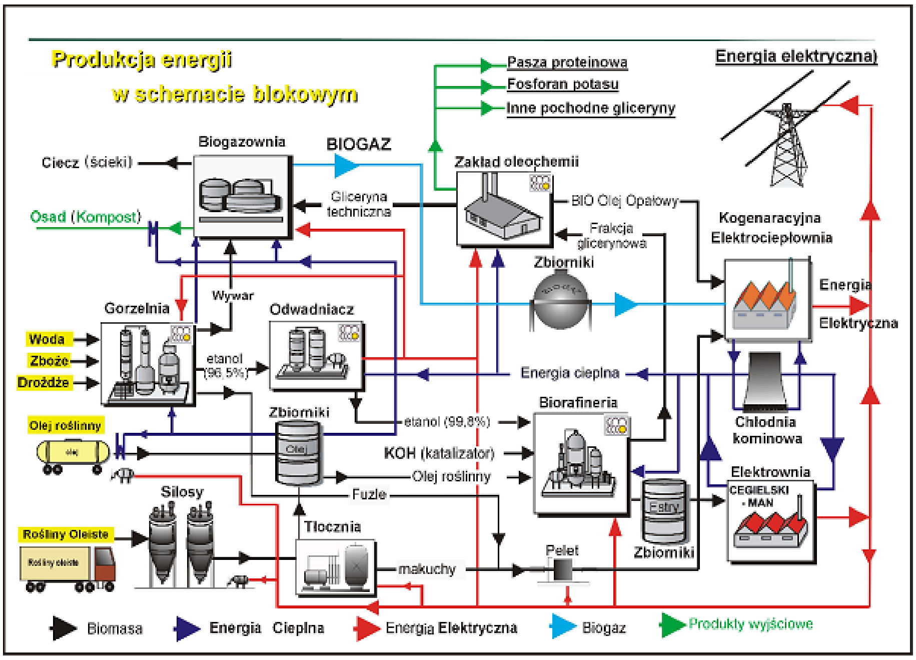

Fig. 12. A scheme of exemplary circular economy installation

[5] Białowiec A Malińska K., Dach J., **Biowęgiel jako materiał pomocniczy w procesie produkcji biogazu,** Inży-nieria Ekologiczna 2015 (41) 117-124.

4. Project sustainable SWM solutions

4.1 Innovative sorting and collection methods of household waste

The cases are selected and described in collaboration with the Danish Waste Association. They represent five special challenges relevant for the living labs of the South Baltic Region "WasteMan" project. The study includes examples on collection methods for multiple fractions in old downtown areas, and old villages with lack of space for collection bins, as well as innovative suction systems and approaches for using shared recycling facilities to create awareness and changing user habits in large housing development.

Figure 13. Public collection point (a) with suction system in Helsingør (for medieval towns with constricted space and pathways)[6] and (b) public collection points in Kultorvet, central Copenhagen[7]

Studies in Helsingør and Kultorvet (Fig. 13) pointed to the fact that the best solution must be a combination of systems, decided upon with involvement of the users. Solutions must fit both residents needs for sorting at home and the public collection point. It was found that the distance to the collection point is of lesser importance as long as residents are motivated to sort.

Fig. 14 Municipality of Kalundborg system of decentraly assembled containers.

[6] https://genanvend.mst.dk/projekter/projektbibliotek/2015/bedre-affaldssortering-i-middelalderbyer/

[7] http://a21.dk/wp-content/uploads/2017/08/Smarte-løsninger-affaldssortering-i-KK-2017-Miljøpunkt-Indre-By-Chr.pdf

The purpose of the study in Kalundborg (Fig. 14) was to investigate if sorting of organic waste, paper and glass from holiday houses will increase through establishment of sub-surface containers.

The project in Płock (Fig. 15) focused on improved control and quality of waste separation by hiring trained personnel to advise citizens on the rules of separation. Results: up to 75% recycling achieved - up to 45% of recyclable materials (plastics 16%, paper 14%, glass 10% and metals 3%) and 20-35% biowaste.

Fig. 15 Common collection points in large housing development (pl. PSZOK)

The overall conclusion was that there is no all-encompassing solution for sorting in medieval towns and modern cities. The best solution must therefore be a combination of systems, decided upon with involvement of the users (see more at Design Manual For Circular Change).

5. Composting and fermentation solid fraction of municipal solid waste

During project implementation IMP PAN in cooperation with Eco Dolina Ltd performed several experiments related to fermentation and composting/(EM treatment) of kitchen biowaste see Fig. 16. The results are presented in the attached on the WEB "Report on kitchen waste fermentation, composting/(EM treatment) and fertilizer formation activities.

Fig. 16 Source sorted kitchen wastes without (left side) and with EM addition

It was found that:

- the applied effective microbes (EM) may slightly influence odour emission (making it a bit acidic) and such treated kitchen waste can be formulated into effective fertiliser or soil improver;
- EM treatment does not increase the fermentation yields;
- acidic or thermal-acidic treatment also does not increase biogas yield from kitchen wastes;
- the composting leachate is good substrate for fermentation process;

- the highest yield of biogas and methane was found for the mixture of source separated kitchen wastes in co-fermentation with leachate from the composting plant;
- the stabilized kitchen waste, using EM can be formulated into effective and well looking fertiliser – see Fig. 17;

Fig. 17 Fertiliser from EM treated wastes.

More on the fermentation and EM treatment one can find on our WEB in Detailed Report: Fermentation composting.

6. Fertilisers from separated at source solid fraction of municipal solid waste

6.1. Municipal solid waste organic fraction (kitchen waste) management via urban green areas fertilization – Polish case.

The green areas in cities and urban areas are becoming a higher concern for city planners, urbanists and local authorities as progressing climate change induces new actions towards better rainwater infiltration, circulation as well as the comfort of the local city climate.

In parallel the quantity of solid biowaste remains at a high level. In Poland, in 2018 approximately 3.5 million tonnes of biowaste is available for novel management techniques, one of which may be Effective Microbes (EM) modification of the organic fraction of municipal solid waste (OF-MSW) and production of fertiliser for urban green areas. Returning nutrients, contained in OF-MSW, back into soil close the nutrients loop, is an environmentally friendly solution for waste utilisation.

This proposal is in line with the objectives of the Circular Economy Action Plan, which focuses on the sectors using a high amount of resources, where the potential for improvement is high, like water and nutrients. The proposal is also coherent with the EU Green Deal, namely it replaces the inorganic fertilisers (currently produced by heavy chemical industry) with organic ones derived from waste. This contributes to the aim of reducing net greenhouse gas emissions by at least 55% by 2030, compared to

1990 levels. Moreover, clean water, healthy soil and biodiversity would be maintained. This action is also in line with the Waste Framework Directive, where EU countries are obliged among others: for reuse and the recycling of municipal waste to a minimum of 55 %, 60% and 65% by weight by 2025, 2030 and 2035, respectively. The Directive also requires that waste will be managed without endangering human health or harming the environment, without risk to water, air, soil, plants or animals. The Directive criteria also specify when certain wastes cease to be waste and become a product, or a secondary raw material.

The study was undertaken by IMP-PAN. The OF-MSW was treated with effective microorganisms onsite, pelletized and dried for use as an organic fertilizer. The goal of later studies was: (1) to verify the fertilizing value of the OF-MSW modified by Effective Microorganisms (EM), (2) to compare its efficiency under winter conditions (October – April) to that of market accessible NPK mineral fertilizer, (3) to evaluate the residual effect on soil after OF-MSW fertilizer application.

Lessons learned:

1. Fertilizers based on separated at source OF-MSW are a good candidate for bringing back the nutrients to the environment,

2. Using OF-MSW as organic fertilisers even at higher dosages does not limit grass growth unlike mineral fertilisers.

3. OF-MSW fertilisers provided up to two times better N utilization at higher dosages as compared to mineral fertilisers. This proves its lower vulnerability to nutrient losses via leaching, thereby reducing the risk of eutrophication of water bodies.

4. The verification was done under winter conditions, so analogical experiment carried out in spring and summer are required (planned),

5. Further investigation to compare the effect of real-scale OF-MSW (sorted at a plant, not at the source), possibly anaerobically digested, on grass growth to check for any inhibiting effects (microplastic, heavy metals, organic pollutants effect on grass growth and its uptake), is required.

More – see report “Poland: Municipal solid waste …”

7. Plastics recycling

Waste plastics fraction constitutes a serious problem for environment (micro-plastics in ocean) and waste management, especially due to its mixed content as well as costs. The serious consideration should be devoted to careful design of packaging in order to enable its circularity (e.g. avoiding material mixing, proper labelling and information, etc.)

In the case of uniform plastic waste (e.g. from bottle collections systems) its remoulding and secondary use (typical recycling) should be promoted (even if the process can be repeated only few times before plastic deteriorates). Another important group of technologies are related mechanical nonthermal processing and use for other purposes (e.g. as textiles and geotextiles) - see Fig. 18.

Fig. 18. Fisher nets waste management plant in Taurage

There are several low temperature technologies (still qualified as recycling) related to production of roof tiles, construction element (Fig. 19), etc., that should be considered as secondary choice.

Fig. 19. Well construction elements from plastic waste

As the plastics deteriorates the high temperature polymer-reforming usually related to pyrolysis can lead to generation of some monomers and smaller molecules (usually in liquid and gas phase) and carbonizate. The products can be used as materials for other processes (material recycling). Plastic waste-based pyrolytic products such as waxes effectively increase soil stability parameters (compression strength, sealing, frost resistance) and can be used for road construction. Some legal barrier limit the technology development and should be reconsidered.

Fig. 20. The soil and binding material mixing and road finishing.

Final process of deteriorated plastics (packeging) reforming is related to syngas generation which can be used for Fischer–Tropsch process (and start the second life for the new plastic or other materials).

The actions directed to stimulation of market for recycled plastic are necessary in order to increase plastic recycling – more in Report on plastics recycling

8. Conclusions

EU regulations challenge the standard waste management technologies and methods. The high target of recycling (70%) for 2030 challenges the easy solution i.e. 'combust all' or dispose to landfill. Only a small residue, after sorting plastics, metals, papers, glass and biodegradable organic waste, can be combusted or gasified. Besides, small distributed cogeneration using pre-RDF enables local waste companies to gain some income from energy and heat production. Also long distance transportation of waste is far from being a sustainable solution.

The most effective technology should be based on separation at source biodegradable waste and its fermentation, which enables use of the digestate as fertilizers and phosphorus economy. In the case of mixed waste additional separation of biowaste by hydroseparation set-up is needed. The RotoSTERIL technology looks like another possible solution.

9. Recommendations

EU regulations challenge the standard waste management technologies and methods. The high target of recycling (70%) for 2030 challenges the easy solution i.e. 'combust all' or dispose to landfill. Therefore:

- Only a small residue, after sorting plastics, metals, papers, glass and biodegradable organic waste, can be combusted or gasified. Besides, small distributed co-generation using pre-RDF enables local waste companies to gain some income from energy and heat production. Also long distance transportation of waste is far from being a sustainable solution.
- In the current context centered on reorganization of the Danish waste sector, Danish public authorities' public tenders for treatment of recyclable waste should take into account recycling quality and the technologies required for reaching high levels of real recycling rates.
- For the biodegradable waste, the most effective technology should be based on separation at source and its fermentation, which enables use of the digestate as fertilizers and phosphorus economy.
- There is no all-encompassing solution for sorting in medieval towns and modern cities. The best solution must therefore be a combination of systems, decided upon with involvement of the users. Through such an approach, satisfactory waste sorting can be achieved even when implementing shared waste collection systems involving transport of waste from households up to 300meters
- In the case of mixed waste additional process of biowaste separation e.g. hydro-separation set-up or separation of sterilized waste (RotoSTERIL technology) is necessary.
- Fertilisers based on organic fraction of municipal solid waste provided up to two times better N utilization at higher > 170 kg N/ ha dosages in the cold season as compared to mineral fertilisers. In warm season, the undigested performance was 10-40% (in total over 20%) of the mineral fertilizer performance, and for digestates: 10-80% (in total over 30%) of the mineral fertilizer performance with the best efficiency at the begininng of growth. This, apart from providing nutrients to plants more gradually over time, proves its lower vulnerability to nutrient losses via leaching, thereby reducing the risk of eutrophication of water bodies as well as overdoses.
- When producing the organic fertilisers from the separated fraction of MSW, the hygienisation step has to be taken into account however due to war-driven current high natural gas prices affecting the mineral (chemical) fertilizers production, such investment can have a payback time of 2-6 years depending on sales fragmentation for different packagings and product volumes.
- Waste plastics fraction constitutes a serious problem for waste management, especially due to its mixed content as well as costs. The serious consideration should be devoted to careful design of packaging in order to enable its circularity (e.g. avoiding material mixing, proper promotion and information, etc.)

* In the case of uniform plastic waste its remoulding and secondary use (typical recycling) should be promoted (even if the process can be repeated only few times before plastic deteriorates). Another important group of technologies are related mechanical nonthermal processing and use for other purposes (e.g. as textiles and geotextiles).
* There are several low temperature technologies (still qualified as recycling) related to production of roof tiles, construction element, etc., that should be considered as secondary choice.
* As the plastics deteriorates the high temperature polymer-reforming usually related to pyrolysis can lead to generation of some monomers and smaller molecules (usually in liquid and gas phase) and carbonizate. The products can be used as materials for other processes (material recycling).
* Plastic waste-based pyrolytic products such as waxes effectively increase soil stability parameters (compression strength, sealing, frost resistance) and can be used for road construction. Some legal barrier limit the technology development and should be reconsidered.
* Final process of deteriorated plastics (packeging) reforming is related to syngas generation which can be used for Fischer–Tropsch process (and start the second life for the new plastic or other materials).
* The actions directed to stimulation of market for recycled plastic are necessary in order to increase plastic recycling.

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