Waste-to-Energy plants are an integral part of modern municipal Waste Management Systems. Today recycling and energy recovery from waste are the only methods of dealing with municipal waste. This is demonstrated by Waste Management Systems in countries such as Germany, Sweden, the Netherlands, Belgium, Denmark and Austria, where the municipal waste management is limited solely to recycling and energy recovery from waste. The currently discussed concept of the latest circular economy package can hardly change anything in this matter. Poland, as one of the leaders among the new EU member states (since 2004), has still a lot to do within the scope of recycling and waste-to-energy. The effects, however, can already be seen in terms of the share of recycling, which is currently over 30 percent and the share of waste-to-energy, which at the end of 2016 could reach about 20 percent in the Polish Waste Management System.

The present paper presents genesis and the latest achievements in the development of waste-to-energy in Poland.

Development of waste-to-energy plants – hereinafter referred to as WtE plants – in Poland is connected with the decision of 7 December 2007 when the European Commission approved the Operational Programme Infrastructure and Environment 2007 to 2013 [1] (Figure 1).

This program implements large investment in the Polish sectors: environmental protection (5.1 billion EUR available from EU funds), transport (19.6 billion EUR), energy industry (1.7 billion EUR), culture and national heritage (0.53 billion EUR), health (0.395 billion EUR) and higher education (0.586 billion EUR). The main goal of this program, based on the Cohesion Fund (CF) and the European Regional Development Fund, was to improve the investment attractiveness in Poland and its regions through the development of technical infrastructure while protecting and improving the environment, health, preserving cultural identity and developing territorial cohesion.
Within the framework of the program 15 priorities have been carried out, called axes of the program. The second axis concerned investments in development of waste management and protection of the earth's surface. Within the framework of this axis the so-called key projects were determined, i.e. investment projects, implementation of which was extremely important for achieving the strategic goals of development in municipal waste management in certain regions and cities in Poland.

In 2007 the key projects were grouped into the indicative list of 12 projects, which included construction of WtE plants, located in major Polish cities or regions of the country (Figure 1).

In view of the requirement for timely completion of stages of the WtE construction projects, especially the requirements related to obtaining the final environmental decision (2010 to 2011) and the building permit decision (2013) as well as the final settlement of the eligible expenditure until 15 December 2015 not all WtE projects planned in 2007 fulfilled the requirements. Other projects from the reserve list replaced them, as e.g. the region of the city of Konin. Finally there were only six WtE plants projects accepted to implementation. The location of all six plants shows Figure 2.
1. General characteristics of individual WtE plants

General characteristics of individual WtE plants in relation to basic information on each of them are presented in Table 1.

The comparison in Table 1 allows to conclude:

- The first building permit was issued for the WtE Bydgoszcz, which allowed them to commence construction works the earliest and finish first compared to other cities,

- WtE Bialystok received building permit as the last one – with the exception of Poznan – and managed to finish construction on time,

- Due to the delay in the beginning of construction in Szczecin, trial runs had to be postponed to end of 2016,

- Due to modification of the issued environmental decisions for the WtE plant in Poznan, the building permit was granted with delay. The Poznan plant is the only one among six plants to use the PPP model of cooperation.
Table 1: Basic characteristics of WtE plants

<table>
<thead>
<tr>
<th>Description</th>
<th>Bydgoszcz</th>
<th>Krakow</th>
<th>Bialystok</th>
<th>Szczecin</th>
<th>Konin</th>
<th>Poznan</th>
</tr>
</thead>
<tbody>
<tr>
<td>The beneficiary of EU funds</td>
<td>ProNatura Sp. z o.o. in Bydgoszcz</td>
<td>Krakowski Holding Komunalny S.A.</td>
<td>PUHP Lech Sp. z o.o. in Bialystok</td>
<td>ZUO Sp. z o.o. in Szczecin</td>
<td>MZGOK Sp. z o.o. in Konin</td>
<td>Poznan city</td>
</tr>
<tr>
<td>Contractor selected by tender</td>
<td>ASTALDI S.p.A., Termo-mecanica Ecologia S.A.</td>
<td>EPC model</td>
<td>EPC model</td>
<td>EPC model</td>
<td>EPC model</td>
<td>EPC model</td>
</tr>
<tr>
<td>Environmental decision</td>
<td>23.11.2010</td>
<td>11.07.2013</td>
<td>06.06.2013</td>
<td>21.06.2010</td>
<td>3.08.2012</td>
<td>17.10.2013</td>
</tr>
<tr>
<td>Building permit</td>
<td>30.08.2013</td>
<td>02.10.2013</td>
<td>02.12.2013</td>
<td>28.10.2013</td>
<td>28.10.2013</td>
<td>06.02.2014 and 06.03.2014 transferred to the private partner</td>
</tr>
<tr>
<td>The gross contract value (million PLN)</td>
<td>approximately 492</td>
<td>approximately 797</td>
<td>approximately 410</td>
<td>approximately 666</td>
<td>approximately 364</td>
<td>approximately 905</td>
</tr>
</tbody>
</table>

Table 2: Comparison of basic technical parameters of Polish WtE plants

<table>
<thead>
<tr>
<th>Description</th>
<th>Bydgoszcz</th>
<th>Krakow</th>
<th>Bialystok</th>
<th>Szczecin</th>
<th>Konin</th>
<th>Poznan</th>
</tr>
</thead>
<tbody>
<tr>
<td>The population covered by the plant</td>
<td>approximately 720,000</td>
<td>approximately 750,000</td>
<td>approximately 390,000</td>
<td>approximately 836,000</td>
<td>approximately 371,000</td>
<td>approximately 738,000</td>
</tr>
<tr>
<td>Technology</td>
<td>Grate furnace integrated with boiler</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual throughput</td>
<td>180,000 Mg/a</td>
<td>220,000 Mg/a</td>
<td>120,000 Mg/a</td>
<td>150,000 Mg/a</td>
<td>94,000 Mg/a</td>
<td>210,000 Mg/a</td>
</tr>
<tr>
<td>Number of processing lines</td>
<td>2 x 11.5 Mg/a</td>
<td>2 x 14.1 Mg/a</td>
<td>15.5 Mg/a</td>
<td>2 x 10.0 Mg/a</td>
<td>12.05 Mg/a</td>
<td>2 x 13.5 Mg/a</td>
</tr>
<tr>
<td>Range of a plant</td>
<td>Waste form Bydgoszcz, Torun and neighbouring municipalities</td>
<td>Waste from Krakow city</td>
<td>Waste from Bialystok and 9 neighbouring municipalities</td>
<td>Waste from Szczecin metropolis</td>
<td>Waste from Konin and 35 neighbouring municipalities</td>
<td>Waste from Poznan and a few neighbouring municipalities</td>
</tr>
<tr>
<td>Annual service availability (h/a)</td>
<td>7,800</td>
<td>8,100</td>
<td>8,050</td>
<td>7,500</td>
<td>7,800</td>
<td>7,800</td>
</tr>
<tr>
<td>LCV (MJ/kg)</td>
<td>8.5</td>
<td>8.8</td>
<td>7.5</td>
<td>10.5</td>
<td>8.5</td>
<td>8.4</td>
</tr>
<tr>
<td>Gross heating power (max) (MWh)</td>
<td>27.7</td>
<td>35</td>
<td>17.5</td>
<td>32</td>
<td>15.5</td>
<td>34</td>
</tr>
<tr>
<td>Power generator output (MWe)</td>
<td>15 condensation</td>
<td>16.2 condensation</td>
<td>8.68 condensation</td>
<td>14.1 condensation</td>
<td>6.77 condensation</td>
<td>15 condensation</td>
</tr>
<tr>
<td>Flue gas cleaning technology</td>
<td>Wet + semi-dry, SNCR</td>
<td>Semi-dry, SNCR</td>
<td>Semi-dry, SNCR</td>
<td>Multistage wet, SNCR</td>
<td>Semi-dry, SNCR</td>
<td>Semi-dry, SNCR</td>
</tr>
<tr>
<td>Bottom ash valorisation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Stabilization and solidification</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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2. Experience acquired during the pre-investment period

The WtE plants presented in the Table 2 were implemented in a country where there was almost no tradition in this regard so far; it is hard to consider a tradition a very small WtE plant, with a capacity of approximately 50,000 Mg/year, founded in 2000 in one of the peripheral Warsaw districts. There were neither companies specialised in designing complex plants of this type, nor the experience related to the organisation of tenders and construction of WtE plants. This represented an additional challenge for all six projects. The only potential in this regard were two Polish companies producing, so far, only by order of foreign contractors steam boilers for waste incineration plants built outside of Poland.

The most important experience from the pre-investment period includes:

- All currently completed construction of WtE plants were based on technically advanced, proven and reliable technology of moving grate [3], which meets the required standards of BAT [2]. It must be mentioned that other methods were taken into account, for example the plasma method but fortunately the most proven technology has been chosen,

- Flue gas cleaning stage was dominated by semi-dry and SNCR methods,

- Common for all currently implemented projects was installation of bottom ash valorisation as well as stabilisation and solidification of Flue Gas Treatment Residues (FGTR). Bottom ash valorisation is a well known technique in WtE plants however FGTR stabilisation and solidification may be considered as innovative and can cause some problems in the future,

- All projects built in Poland assume optimal use of the energy contained in the municipal waste. All plants mentioned in Table 2 operate in cogeneration producing both electricity and heat. This well known solution provides high values of R1 energy efficiency formula, above 0.65 for each plant, according to the author’s research [1] and is shown in Figure 3. According to article 158 of the Polish Act on waste of 14 December 2012 – Journal of Laws of 2013, item 21 – the process of thermal treatment of municipal waste taking place in incineration plants will then be a R1 recovery process and in the waste hierarchy it will be placed above the D10 disposal process. R1 values shown in Figure 3 need to be confirmed by the data obtained during the operation of the WtE plants but so far this has not been done,

- Some of the experience from the pre-investment period concerns elaboration of tender documents as well as conducting of tendering process. In almost every case many claims and objections were raised from the consortium side constructing WtE plant using EPC model. Responsible for examining the validity of the above mentioned appeals and objections was the Polish National Chamber of Appeal, established on the basis of Polish law – Public Procurement Law (Journal of Laws 2015, item 2164). This resulted in significant delays, exceeding in some cases several months, in investment phase of all WtE projects,
Last but not least observation is the issue of public acceptance for waste incineration plants. The process of obtaining acceptance was extremely tedious, difficult and took several months. Apart from the WtE Konin, determining a publicly acceptable location was almost impossible. Future projects planned for 2020 are expected to meet lower resistance due to reliable operation of the current WtE plants.

Figure 3: R1-formula values for Polish WtE plants


3. Current operational experience

As already mentioned, currently there are four Polish WtE plants in the stage of the trial run and at the beginning of the operation, i.e. Bydgoszcz, Konin, Krakow and Bialystok. WtE Poznan will commence the test run in June 2016 and WtE Szczecin at the end of 2016.

The experience from this period can be synthetically summarised:

- In all cases the trial run took place under supervision of a contractor’s specialists,
- Each new Polish WtE plant has made an effort to properly choose a competent crew and train them for operating plants, which were uncommon in Poland until now. Training was carried out in different ways – depending on the terms of the contract. In some cases, the crew held a brief training in incineration plants abroad, or the trial run was conducted under the supervision of specialists brought specially from foreign WtE plants. It can be said that the training process took place satisfactorily and in most cases Waste-to-Energy plants are already operating independently,
- During the trial run some both typical and more complex problems appeared,
• Transfer of generated heat to nearby networks, municipal in most cases, was tested,
• Taking into account the fact that this publication was prepared in May 2016, it must be noted that in some cases the operation of the WtE plant is not yet finally stabilised,
• Most cases correctly matched the characteristics of waste – the calorific value and the mass flow, which allows to work around the design point of the boiler and achieve optimal capacity of the incineration plant,
• Reorganisation of the municipal waste management systems in cities and regions, which have built new WtE plant is still in process,
• Based on the current results, it is extremely difficult to comment on the financial aspects, the adequacy of gate fees and revenues received by plant.

4. Conclusion

Six new Polish Waste-to-Energy plants with a total design capacity of approximately 1 million t/year put into operation in the years 2015 to 2016, has a crucial meaning for the development of Polish waste management systems. According to the Eurostat statistics, in 2014 the share of municipal waste incineration in Poland reached approximately 9 percent – achieved mainly by co-combustion in the cement industry – is to rise at the end of 2016 to approximately 20 percent. The growing share of recycling results is a significant decrease in the share of waste landfilling.

Cities and regions in which new WtE plants work, are now able to meet a number of requirements of the EU e.g. to reduce in 2020 the amount of biodegradable waste (required reduction by 65 percent compared to 1995) and regulations in force from 01.01.2016 imposing ban on the landfilling of combustible waste.

It should be added that at the present stage of the Polish WtE plants, public confidence in their ecological safety grows significantly. A very important role plays aesthetics and in case of Krakow unusual design of these plants.

Figure 4:
WtE Bydgoszcz, 180,000 Mg/a, 2 lines
New Polish Waste-to-Energy plants will pave the way for the construction of other incineration plants in Poland, although there is no intention of building a large number of new ones. Priority will be given to plants based on refuse-derived fuels such as RDF and SRF, due to a significant over-production of this type of waste in Poland.

All six new Polish WtE plants described in the article are shown on Figures 4 to 9.

Figure 5:
WtE Krakow, 220,000 Mg/a, 2 lines

Figure 6:
WtE Bialystok, 120,000 Mg/a, 1 line

Figure 7:
WtE Szczecin, 150,000 Mg/a, 2 lines (visualization, construction in progress)
5. References


The aim of this study is to demonstrate such discrepancies or dependencies between attainable emission reductions and the emissions-generating energy input necessarily incurred by flue gas treatment technologies in attaining those reductions.

The study initially focuses on current investigations and assessments related to this issue, as well as on the legal emission requirements. Due to the wide range of components involved in flue gas treatment systems and their consequent numerous combination possibilities, six different system Variants are presented and compared. It is notable in the context of the present study that both single and two-stage or multi-stage systems are considered in the set of Variants, which differ not only in their structure and additive use but also in their separation capacity. These six basic Variants reflect the systems frequently employed in practice and represent non-congruent procedural steps with their respective target emission levels. Based on the fact that each of these Variants is already in operation in thermal waste incineration plants, the assessment draws on many years of existing operative experience.

The individual energy demands for the Variants described are determined on the basis of mass, material and energy balances.

Evaluation criteria for energy demand at the different emission reduction ratios are educed from the formulation of emissions-related energy indicators. This establishes a set of tools with which to assess emissions-generating energy demand in the context of emission reduction ratios.