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PRODUCTION ENGINEERING ARCHIVES 2021, 27(1), 36-41

PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN 2353-7779 (online)

Exist since 4th quarter 2013
Available online at https://pea-journal.eu

Production and use of waste-derived fuels in Poland: current status and perspectives

Jurand Bień[1]

[1] Czestochowa University of Technology, Faculty of Infrastructure and Environment, Dabrowskiego73, 42-200 Czestochowa, Poland, Corresponding author e-mail: jurand.bien@pcz.pl

Article history
Received 08.01.2021
Accepted 28.02.2021
Available online 31.03.2021

Keywords
waste-derived fuels
refused derived fuels RDF
RDF production
energy recovery

Abstract
In the paper issues related to the production and utilisation of waste-derived fuel (alternative fuel) in Poland are presented. Alternative fuel comes from dry residue of waste, mostly municipal, and is treated as a waste. In European Waste Catalogue waste-derived fuel is marked with 191210 code despite their municipal, industrial or mixed origin. The production and utilisation of alternative fuel were analysed with the data from sixteen polish voivodships' annual reports. The total amount of waste-derived fuel produced in Poland exceeds 3 million tonnes annually. It means there is no balance between the amount of production and possibility of energy recovery in Poland. In 2018 only 1,54 million tons was recovered in R1 recovery process which is only half of the waste-derived fuel produced. In addition, the entire amount of fuel is used in the cement industry. In 2018 in the cement industry 1,46 millions tons of alternative fuel was used. It is estimated that the potential use of alternative fuel by cement plants in Poland is about 1.5-1.8 million tonnes. This means that greater use of alternative fuel in the cement sector is significantly limited. The difference between in the amount of fuel produced and the amount of fuel used for energy recovery in 2018 is around 1.67 million tons. This situation has a significant impact on the economy of waste management in the field of combustible waste production.

DOI: 10.30657/pea.2021.27.5 JEL: L23, M11

1. Introduction

In 2019 there are about 12.7 millions tons of municipal waste generated in Poland (Central Statistical Office, 2020). For several last years, the trend in the amount of generated waste has been clearly growing. In 2015, the amount of generated municipal waste was at the level of 10.8 million tons. This means that within five years the amount of municipal waste generated annually increased by nearly 2 million tons. As for the production of municipal waste per capita, the figure has risen sharply from 282 kg/per capita annually in 2015 to 332 kg/capita annually in 2019. A statistical Pole currently produces 50 kg more of municipal solid waste than in 2015, and still mostly it is a mixed waste. Still the amount of mixed municipal waste accounted for 68% of total municipal waste generated in Poland in 2019.

Municipal wastes must be managed in an environmentally safe manner. By the way both European and domestic legislation aims to reduce the environmental impact of disposal technology. In particular, EU Directive 2008/98/EC (European Commission. Directive 2018/851, 2018) of the European Parliament and of the Council adopted waste hierarchy as the order of priority to be followed by Member States in the field of waste prevention and management. The legislation therefore aims to focus on (in order): reduce waste, reuse process, recycling process, recovery process and disposal as a final solution (Ingaldi and Klimecka-Tatar, 2020). Waste management processes and their further management are key elements of the latest reverse logistics solutions (Deja et al.) This means that whatever techniques are used must primarily support the recycling of waste (Dzhuguryan and Deja, 2021). Recovering materials and energy is preferred over landfilling (Massarini, 2015).

According to data from the Central Statistical Office of Poland (Central Statistical Office, 2020), nearly 55.6% of municipal waste generated in 2019 was recovered, of which 25% was recycled, 9% was composted or fermented and 21.5% was transferred to thermal transforming with energy recovery. The residual amount of municipal solid waste was disposed mainly

by landfilling (43%), a small part of waste (1.4%) was subjected to thermal treatment without energy recovery.

The municipal waste management system in Poland has changed a lot in recent years as a consequence of adaptation to EU requirements in the scope of implementing the waste directive (Rakoczy, 2014; Smol et al., 2020). Since 2011 for the management of mixed municipal waste the waste management system is based mainly on mechanical-biological treatment installations and thermal treatment installations. The assumptions were that the installations for mechanical and biological processing were to perform the function of waste recovery, where valuable raw materials were recovered as a result of processing. Unfortunately, the quality of the recovered waste in a mechanical process has proven to be low and a huge volume of waste from this process is a high-calorific waste, of which the storage is prohibited under the regulation of Minister of Economy of 16 July 2015 on allowing waste to be stored in landfills. For this kind of waste other methods of management are recommended. The production of alternative fuels i.e. solid re-covered fuels (SRF) and other refuse-derived fuels (RDF) is such an opportunity (Rada, 2016; Bessi et al., 2016). In particular, waste stream of rather poor quality, where higher heating value is higher than 6 MJ/kg and lower than about 18 MJ/kg, could be fed to waste-to-energy plants. Other streams, with very high quality are suitable for non-dedicated facilities, such as cement plants or power plants, as a substitute for coal (Brunner et al., 2015; Sarc et al., 2019). In the European cement industry, the use of RDF is al-ready state of the art, and high thermal substitution rates (i.e., the degree to which fossil fuels are re-placed by RDF in cement plants) are achieved in some countries (Sarc et al., 2019; Viczek et al., 2020). In general, the use of alternative fuels, as a source of energy, gives the following benefits (Wasielewski et al., 2019; Tutak et al., 2020):

- the substitution of fossil fuels,
- the use of the energy contained in waste,
- the increasing energy recovery from waste,
- the increasing the amount of electricity from renewable sources (from the biomass fraction contained in waste),
- the economic benefits from reduced CO_2 emissions.

The issue of production and use of waste-derived fuels as an element of municipal waste management is also an important area of the European Commission's (EC's) interest and a significant element of the plan for transformation towards a circular economy (CE) in the European Union (EU).

2. Alternative fuels (191210 waste code)

It is not easy to find a definition of "alternative fuel" in Polish law. The name "alternative fuel" appears only in the Regulation of the Minister of Climate of 2 January 2020 on the waste catalog, where combustible waste is mentioned as alternative fuel under the code 191210. This placement has important meaning and further consequences. Although the "alternative fuel" is defined as a fuel, i.e. a substance that releases a large amount of heat during intense oxidation (combustion), it is not treated equally with other types of fuel, such as coal, gas or oil, which are classified as heating or diesel fuels. According to the regulation cited above, "alternative fuel" is not a product, is a combustible waste, fragmented, properly composed not to exceed the emission levels specified in the relevant regulation as a result of the combustion process. Currently, such a regulation is the Regulation of the Minister of Climate of 24 September 2020 on emission standards for certain types of installations, fuel combustion sources and waste incineration or co-incineration devices.

Any component for alternative fuel may be a substance that has an appropriate calorific value and does not contain toxic components. The main components of the alternative fuel are therefore plastics, rubber, paper, textiles, wood, composite waste, etc.

In 2003, the European Commission adopted a document defining the concept of refuse-derived fuels (RDF) as fuel from waste (EC, 2003). The document stipulates that such a fuel may contain selected fractions of municipal waste (e.g. paper, plastics, wood, textiles, etc.), industrial waste, sewage sludge, industrial hazardous waste and biomass. However, such a wide range of raw materials made it difficult to define quality standards for the produced fuel. As a result, a number of actions were taken to establish uniform quality standards for solid fuels produced from waste, limiting their range of raw materials. The name Solid Recovered Fuels (SRF) was adopted for such fuels. SRF represent a subgroup of RDF and it refers to solid fuels made from non-hazardous mixed or sorted solid wastes. SRF meet the criteria defined by EN 15359 and utilized for energy recovery. Waste code 191210 covers both RDF and SRF.

3. Experimental

The analysis of the production and management of alternative fuel (waste code 191210) was carried out on the basis of data obtained from voivodship reports on waste management for the years 2016-2018. Particular attention was paid to section 1 and section 4 of the reports. In general, in the section 1 the data reflect the amount of waste generated, in section 4 data presents the amount and process of waste management. This seems clear, although for alternative fuels, the management processes include operation process R12, which is defined as exchange of wastes for submission to any of the operations numbered R1 to R11. Thus, it should be noted that the R12 process does not end the waste management chain and is only an intermediate process. In R12 process, lower quality alternative fuels are enriched with another stream of high calorific waste. This improves the quality parameters of the alternative fuels, but also generates a new stream of fuel using some amount of waste reported in section 1. This relationship distorts the total amount of alternative fuels produced.

Therefore, it was assumed in the further analysis that the amount of alternative fuel produced in the R12 process is a new waste stream which will reflect the largest amount of alternative fuel produced.

Data on 191210 waste from voivodships reports were prepared, analysed and visualized using R, which is an extremely flexible statistics programming language and environment that is open source and freely available for all mainstream op-

erating systems. The data from waste reports were transformed to a 2-dimensional table of data stored in an R data frame object with rows and columns. Next methods from R tidy verse library were used for data manipulation and analysis, visualisation were done with R ggplot2.

4. Results and discussion

4.1. Production potential of alternative fuels

An alternative fuel in Poland is mainly produced by specialized producers who accept various types of combustible waste for processing, including even waste with the code 191210 generated by smaller producers and/or provided by the waste collectors. In result from derived stream of waste an appropriate fuel mixture is prepared that meets the quality requirements of the final customer. Since residual municipal waste is quite often allocated to mechanical treatment plants alternative fuel is also produced there. Actually such plants are called Municipal Installation (MI), previously Regional Installation For Municipal Waste Treatment (RIMWT). For MI, a production of alternative fuel is a way of waste managing that are not suitable for recycling and do not meet the requirements for landfilling.

As a result of data analysis from section 1 in voivodship reports it's clear that the stream of alternative fuel production in Poland in the years 2016-2018 exceeded 2.5 million tons. In 2016, about 2.61 million tons of alternative fuel was produced, while in 2018 it was already 2.71 million tons. Taking into account the amounts of fuel produced in the R12 process, the total amount of alternative fuels in the above years was nearly 3.2 million tones (Table 1).

Table 1. Changes of alternative fuel production in Poland in 2016-2018

Amount [mln Mg]	Year		
	2016	2017	2018
without R12 process	2.61	2.66	2.71
including R12 process	3.17	3.23	3.21

The largest amount of alternative fuel is produced in the following provinces: Masovian (over 700,000 Mg) and Silesian (over 500,000 Mg). On the other hand the smallest amount of alternative fuel is produced in the Podlasie Province (less than 20,000 Mg). Figure 1 shows the volume of alternative fuel production in each voivodship, where the numbers below blue columns give information about production in 2018.

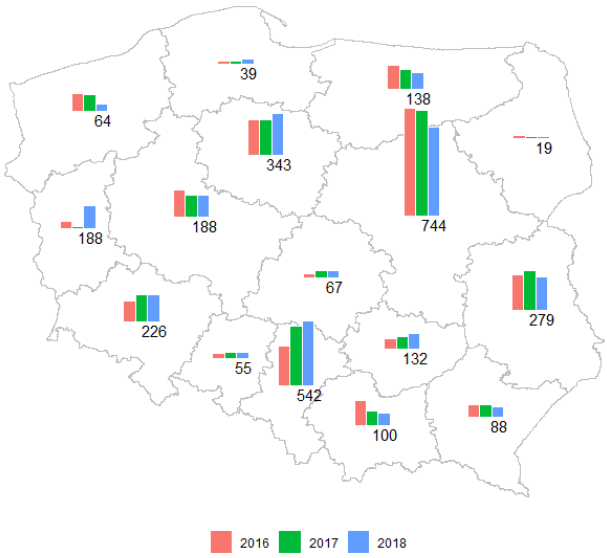

Fig. 1. The volume of alternative fuel production by provinces in 2016-2018

If we combine the amount of produced alternative fuels with the amount of waste generated by residents and the number of residents alone, then the situation changes (Fig. 2). The largest amount of alternative fuel produced per capita occurs in Lubusz Province (185 kg per capita) and in Kuyavian-Pomeranian Province (165 kg per capita). The smallest amount of alternative fuel per capita is generated in Podlasie Province (16.2 kg per capita) and in Pomeranian Province (16.5 kg per capita)

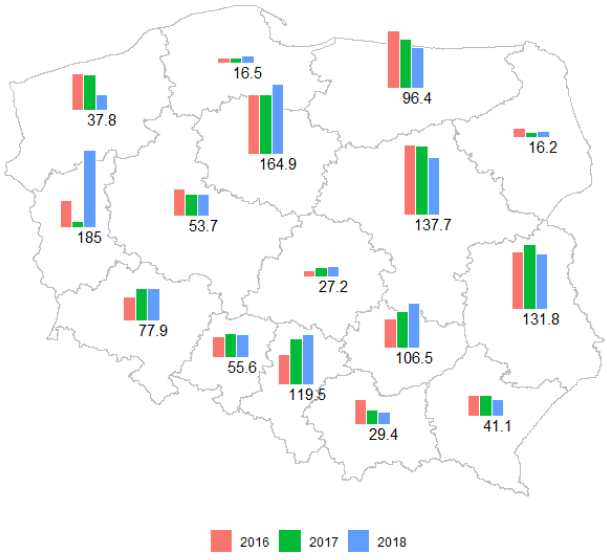

Fig. 2. Alternative fuel production per capita by provinces in 2016-2018

The number of installations producing alternative fuels in provinces of Poland in years 2016-2018 is given in Table 2.

Table 2. The number of alternative fuel producers by provinces in 2016-2018

Voivodship	Year		
	2016	2017	2018
Lower Silesia	17	8	8
Kuyavia-Pomerania	13	14	19
Lublin	19	18	17
Lubusz	8	2	8
Łódź	11	12	9
Lesser Poland	17	18	20
Masovia	26	27	24
Opole	5	5	5
Subcarpathia	11	10	15
Podlaskie	3	2	3
Pomerania	4	3	2
Silesia	32	33	39
Holy Cross Province	n.a.	n.a.	n.a.
Warmia-Masuria	6	5	4
Greater Poland	24	28	23
West Pomerania	7	5	5
Summary	203	190	201

In total, there are about 200 producers of alternative fuel with the waste code 191210 in Poland. The largest concentration of producers takes place in the Silesian and Masovian voivodships. In general, the domestic alternative fuel producers market is strongly dispersed and differential. The number of producers of alternative fuel is strongly correlated with the economic potential of a given voivodeship and the amount of waste that is available for processing. The alternative fuel production capacity is also highly diversified within producers. In 2018 more than half of the production potential were small producers who produced up to 5,000 Mg per year. Only three installations generated more than 100,000 Mg (Fig. 3).

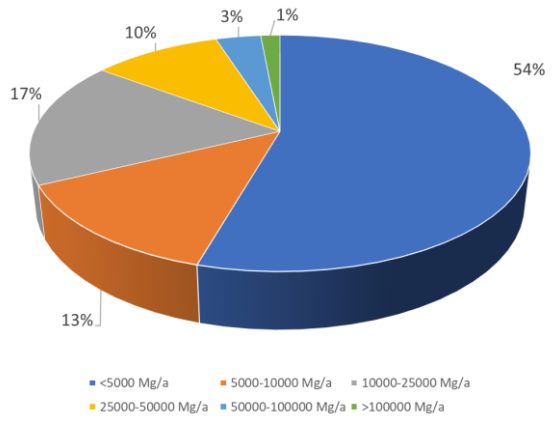

Fig. 3. The percentage share of installations with a specific alternative fuel production potential in 2018

Top five largest producers of alternative fuel in 2018 include the following companies: NOVAGO Sp. z o.o. (Masovian prov.), LAFARGE CEMENT S.A. (Kuyavian-Pomeranian prov.), MPO Sp. z o.o. (Masovian prov.), ZUO International Sp. z o.o. (Lubusian prov.) and Chemeko System ZZO Sp. Z o.o. (Lower Silesian prov.). As it could be seen from Figure 4 some of them are quite new producers.

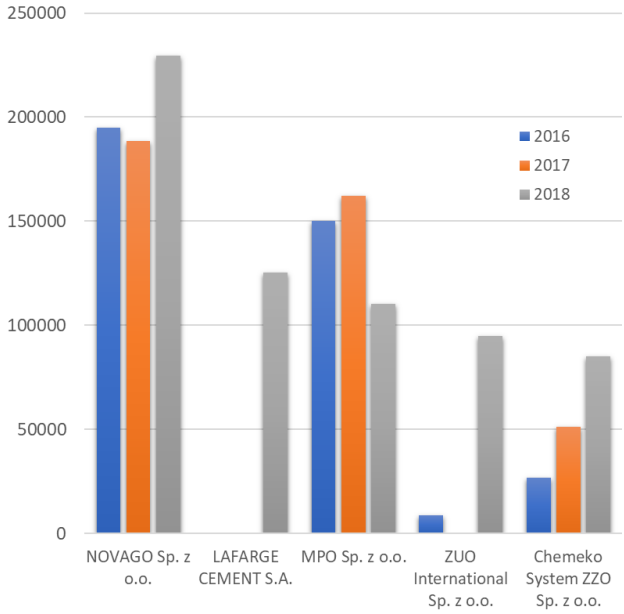

Fig. 4. Top five alternative fuel producers in 2018 (y-axis is given in tones)

4.2. The use of alternative fuels

The use of an alternative fuel for energy recovery from waste is the leading recovery process. The non-exhaustive list of recovery operations presented in Annex II of the Waste Framework Directive (WFD) defines R1 as a recovery operation which is understood as "use principally as a fuel or other means to generate energy". By using alternative fuels we can generate heat and power. Alternative fuel could be managed in dedicated installations or municipal solid waste power plants as well as in industrial installations. The use of alternative fuels in a cement production industry has been used in European Union countries for many years (EC, 2003). It is also possible to use alternative fuel in the power industry and heating, but still this way of waste-fuel management is limited, mostly due to waste characterization.

As it was mentioned alternative fuels are also used by specialized producers in the R12 recovery process, mostly due to requirements of cement industry. However due to fact that this recovery process is temporary and connected with alternative fuel production further the analysis of alternative fuel use in R1 recovery process was analyzed. The possibility of using alternative fuel in the R1 recovery process is closely related to the available infrastructure. Installations for energy recovery from alternative fuel are much less common than plants producing alternative fuel. In addition, they are located mainly in the southern part of Poland, mainly in the following voivodeships: Opole, Lublin and Holy Cross Province. In the northern region, a significant part of the alternative fuel used in the R1 process takes place in Kuyavia-Pomerania province (Fig. 5).

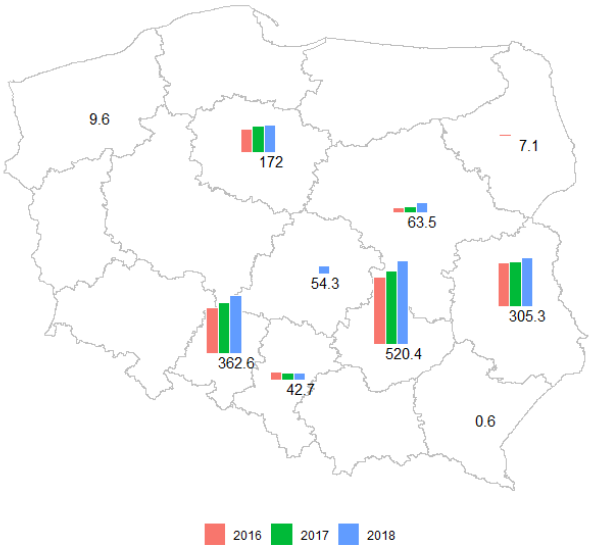

Fig. 5. The use of alternative fuel in the R1 energy recovery process by provinces in 2016-2018

In general, the amount of alternative fuel driven to thermal treatment in R1 recovery operation in the analyzed period of time was 1.22 million Mg in 2016 and 1.54 million Mg in 2018, and as it could be seen from data of table 3 its usage is increasing annually.

Table 3. Changes in the use of alternative fuel in R1 recovery process in Poland in 2016-2018

Amount [mln Mg]	Year		
	2016	2017	2018
R1 recovery process	1.22	1.32	1.54

The largest recipients of alternative fuels in the years 2016–2018 are presented in Figure 6.

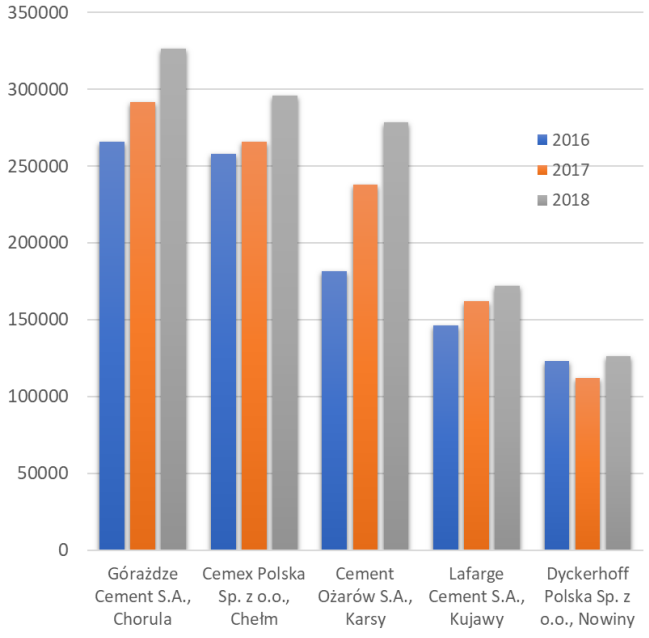

Fig. 6. Top five alternative fuel recipients (sorted according to 2018 data; y-axis is given in tones)

The presented data confirms that the cement industry has been the most important recipient of alternative fuels in Poland for many years. In 2018, 94.7% of fuel recovered in R1 process took place in cement industry.

4.3. Perspectives for alternative fuel market in Poland

The stream of alternative fuel generated by producers in Poland is still greater than the possibility of its usage in R1 recovery process (Fig. 7).

Fortunately, the investment gap is narrowing each year. The difference in the amount of fuel produced and the amount of fuel used for energy recovery in 2018 was around 1.67 million tons. In 2019, the gap could be even smaller. Some waste-to-energy plants have been launched recently, and the data show a potential reduction of the gap by another 300,000 Mg of alternative fuels energetically recovered (Table 4).

Further, there are also action taken to build next waste-to-energy plants in Gdańsk, Olsztyn and Warsaw. This will clearly reduce the supply gap, but it should be noted that the cement industry will continue to be a significant recipient of alternative fuels in Poland.

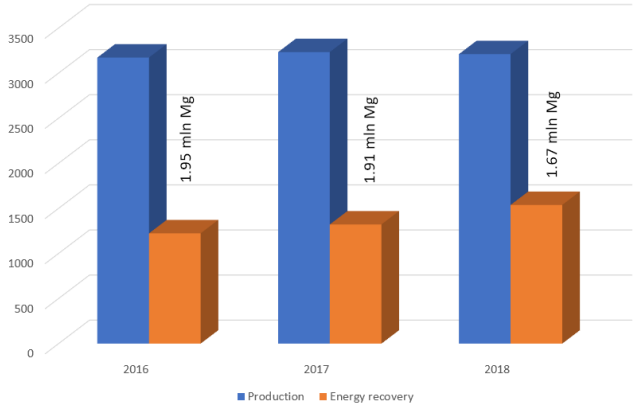

Fig. 7. The difference between the amount of fuels produced and recovered in R1 recovery process in 2016-2018 (y-axis is given in thousand tones)

Table 4. Changes in the use of alternative fuel in R1 recovery process in Poland in 2016-2018

Waste-to-energy plant	Real capacity 2019 [Mg/a]	% of alternative fuel used in R1
Białystok	115200	30.5
Bydgoszcz	168900	33.1
Konin	86113	26.4
Kraków	219600	50.4
Poznań	209861	0
Szczecin	85500	17.1
Warszawa	149600	80.6
	Sum	Average
	1085704	31.8

5. Summary and conclusion

The situation on polish alternative fuel market was analysed. The amount of alternative fuels produced can be estimated at 2.7 million Mg/year. However, taking into account the amount

of fuel generated in the R12 recovery process the total amount of alternative fuels production could be estimated at 3.2 million tons in Poland. Currently, there are about 200 producers. More than half of the production potential are small producers who produce up to 5,000 Mg of alternative fuel per year. Only three installations generate more than 100,000 Mg.

The stream of alternative fuel generated by producers in Poland is still greater than the possibility of its usage in R1 recovery process. This is due to fact that the possibility of using alternative fuel in the R1 recovery process is closely related to the available infrastructure. It could be noticed the distribution of production and consumption capacities of alternative fuel is uneven. Cement industry has been the most important recipient of alternative fuels in Poland for many years. In many cases alternative fuels account for 70-80% of the stream of all energetically used waste in cement industry. In 2018, 94,7% of all alternative fuels recovered in R1 recovery process took place in cement industry.

However, data for 2019 may show a further reduction in the percentage use of alternative fuels by the cement industry. Some waste-to-energy plants have been launched recently in Poland, and it is estimated that about 300,000 Mg of alternative fuels was recovered in R1 recovery process in 2019. This will reduce the gap between demand and supply, but still the oversupply is a significant volume on polish market. In result it causes the prices of alternative fuels to fall, and even increases the need for subsidies when it comes to the recovery or disposal of alternative fuels of lower quality at existing installations.

Acknowledgements

The research was funded by the statute subvention of Czestochowa University of Technology, Faculty of Infrastructure and Environment. The support is gratefully acknowledged.

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波兰废物产生的燃料的生产和使用：现状和观点

關鍵詞

摘要

在本文中，提出了与波兰废物衍生燃料（替代燃料）的生产和利用有关的问题。替代燃料来自废物的干残渣，大部分为城市废物，被视为废物。在《欧洲废物目录》中，尽管源自城市，工业或混合来源，但源自废物的燃料仍标有 191210 代码。结合十六个波兰省年度报告中的数据对替代燃料的生产和利用进行了分析。波兰每年生产的废物衍生燃料总量超过 300 万吨。这意味着波兰的生产量与能源回收的可能性之间没有平衡。 2018 年，在 R1 回收过程中仅回收了 154 万吨，仅占产生的废物衍生燃料的一半。此外，水泥行业使用了全部燃料。 2018 年，水泥行业使用了 146 万吨替代燃料。据估计，波兰水泥厂潜在使用替代燃料的量约为 1.5-180 万吨。这意味着水泥行业替代燃料的更多使用受到严重限制。 2018 年生产的燃料量与用于能源回收的燃料量之间的差异约为 167 万吨。这种情况对可燃废物产生领域中废物管理的经济性有重大影响。