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Fuels from waste for energy source diversification

ABSTRACT: The dynamics of economic development determines the need to develop technologies for waste recycling especially the acquisition of condensed fuels for the needs of the local diversification of energy sources. In a short time, Poland will probably lack its own produced electricity. To apply the process of diversification of energy sources, by developing methods of generating energy from waste, it becomes crucial to protect the environment. The use of cogeneration technology based on fuels derived from waste, in particular concentrated oil and gas fuels, is becoming more common and provides the basis for securing the energy supply in the preferred diversification process. Plastic waste processing in the controlled depolymerization process, which is the reverse of the polymerization process for hydrocarbon recovery – uses petroleum derivatives its production. At present, the greatest interest arises in the material recovery of plastics and rubber in the process of anaerobic thermal decomposition (thermolysis/pyrolysis), which is used on an industrial scale and consists in the degradation of polymer bonds into low molecular weight. The imperative of a modern economy is to obtain energy from fuels from waste treatment, including hazardous waste, preferably in the cogeneration process. The fuel obtained from waste may be used to obtain thermal or electric energy in order to diversify energy sources. The article presents innovative Polish technologies of obtaining fuel in processes of anaerobic thermal decomposition

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mainly of elastomeric and polymeric waste (including hazardous ones) for direct application in power generators of various power.

KEYWORDS: waste, energy, alternative fuels, energy sources, diversification

Introduction

The pursuit of the needs of society is closely related with energy security, which is particularly affected by the diversification of energy sources in individual regions, based on easily available resources of fuels obtained, in particular from renewable energy sources (RES).

In accordance with the theses of the EU Climate and Energy Policy as well as the National Cohesion Strategy “Energy Security and the Environment” Perspective 2020, these technologies should be focused in particular on:

- ◆ energy efficiency and reducing emissions,
- ◆ acquiring new alternative energy sources,
- ◆ diversification of energy sources in order to strengthen the economy’s resilience to a periodic supply deficit (blackout),
- ◆ promoting conscious consumption (e.g. selection of products using recycled materials or reusable products) based on the circular economy.

The problem of the European Union and other industrialized countries is the energy and natural resources deficit as well as the increasing costs of their import (acquisition). Therefore, a number of actions are undertaken, the most important of which is to increase the share of recycled raw materials (including fuels) in the material and energy balance of individual national economies. It has been proved that the goals formulated in this way are economically justified (real) because:

- ◆ the majority of natural resources can be replaced with recyclable materials contained in waste,
- ◆ much more electricity, heat and fuels can be produced from waste,
- ◆ the transition to a closed material circulation economy is favorable for environmental protection and is economically profitable.

The circular economy embodies the idea of recycling and recovery from organic waste, and among others, obtaining condensed fuels. In this way, the desire to minimize hyper-consumption in the global scope is strengthened, as well as taking actions related to the system of energy supply security (diversification of energy sources) for the needs of local communities, in particular in emergency conditions (war, terrorism, rebellions, riots, disasters, etc.).

At present, the Polish energy sector is facing a major challenge. The growing demand must be met, while most assets for centralized heat and electricity production need modernization. At the same time, new global regulations are being introduced to reduce climate change and secure

energy supplies. In connection with the above, the European Union is striving to increase the use of renewable energy sources in the field of energy policy, which is to contribute to a 20% decrease in CO₂ emissions by 20% in this sector in 2020.

1. Fuel and energy received from waste

1.1. Energy consumption forecasts

Over the next 23 years, i.e. by 2035, global energy consumption will increase by 41% compared to a 55% increase over the past 23 years.

About 95% of this increase is in developing countries. The forecast of the global use of energy sources in the future (until 2100) is shown in Figure 1.

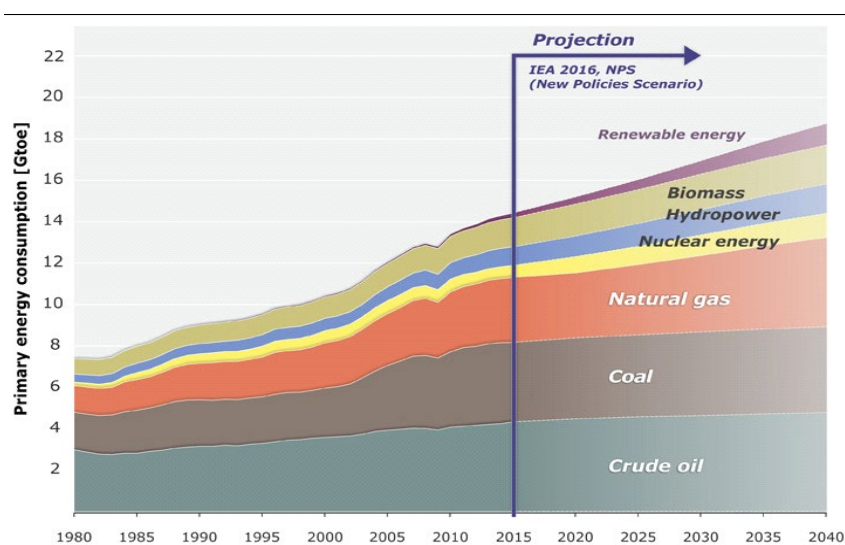


Fig. 1. Forecast for the use of potential energy sources in the future (until 2040) and sources of energy obtained (www.bgr.bund.de/EN/Home/homepage_node_en.html&prev=search)

Rys. 1. Prognoza wykorzystania potencjalnych źródeł energii w przyszłości (do 2040 r.) i źródła uzyskania energii

In addition, Figure 1 presents a forecast of the development of global primary energy consumption and energy sources, including a possible scenario of future changes until 2040.

BP experts forecast that in 2035 oil, natural gas and coal will have a 25% share in the global energy balance. The rest will be spent on nuclear and renewable energy (RES) (<https://optimal-energy.pl/aktualności/dystrybucja-pradu/popyt-na-energie-wzrost-o-41-do-2035-roku/>).

The coal combustion method (0.58 kg CO₂/ kWh) or gas combustion is mainly used for the production of electricity. On the other hand, renewable energy sources comes from solar, wind, sea energy, surge energy, geothermal energy or energy from the difference in water levels, as well as from the conversion of organic waste into alternative fuels (biomass, cellulose, fibers, etc.) (Wasielowski et al. 2011).

1.2. Alternative fuels from waste

The processing of organic and mixed waste into alternative fuels in the process of their transformation:

- ◆ **Gaseous fuels:** e.g. from the fermentation process, biogas, gasification products and anaerobic thermal decomposition (thermolysis/pyrolysis), catalytic cracking.
- ◆ **Liquid fuels:** waste oils (mineral and synthetic), fats and cooking oils, waste solvents, biodiesel, bioethanol, concentrates from industrial processes (e.g. distillation, membrane separation, centrifugation, etc.), oils from anaerobic thermal decomposition in processes thermolysis/pyrolysis and post-cracking oils.
- ◆ **Solid fuels:** plastics (polymers), rubber (elastomers), wood, cellulose, textiles, leather, multi-layer and multimaterial packaging, bio-waste, various types of fuels produced from non-hazardous waste, including municipal waste (WDF, RDF, SRF), animal by-products, dried sludge, carbonizate from the thermal decomposition process, etc.

According to the applicable provisions of the Waste Provision Act:

- ◆ the use of solid secondary fuels is the **R1** recovery process (used as a fuel or other means to generate energy – according to Annex 5 to the Waste Act),
- ◆ the production of solid secondary fuels is the **R15** recovery process (waste treatment to be prepared for recovery, including recycling).

Table 1 shows the ranges of individual classification parameters for solid secondary fuels (Wasielowski et al. 2011).

The classification and quality system of solid secondary fuels developed by CEN allows for the unambiguous classification of fuel into a specific class and a very detailed specification of its physico-chemical properties. This system requires a very detailed characterization of solid secondary fuel, which guarantees the avoidance of abuse, sometimes occurring when placing fuels produced from waste on the market. At the same time, it enables operators of energy installations in which solid secondary fuels can be used to obtain reliable information on the quality of this material, and above all to select fuel of guaranteed quality that meets the technical requirements of a particular installation (Wasielowski et al. 2011).

TABLE 1. Values of classification parameters for solid secondary fuels by CEN

TABELA 1. Wartości parametrów klasyfikacyjnych dla stałych paliw wtórnych według CEN

Classification parameter	Statistics	Unit	Class				
			1	2	3	4	5
Calorific value (NCV)	average	MJ/kg, in operating state	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3
Chlorine content (Cl)	average	% in a dry state	≤ 0.2	≤ 0.6	≤ 1.0	≤ 1.5	≤ 3.0
Mercury content (Hg)	median	mg/MJ, in operating state	≤ 0.2	≤ 0.03	≤ 0.08	≤ 0.15	≤ 0.50
	80 th percentile	mg/MJ, in operating state	≤ 0.4	≤ 0.06	≤ 0.16	≤ 0.30	≤ 1.00

Source: Norma CEN/TS 15359.

2. Cogeneration – energy gaining technology

When developing the concept for the development of the energy sector, attention should be paid to the complementarity of the development strategy, which should include primary energy savings, the development of renewable energy sources and cogeneration sources (simultaneous generation of heat and electricity or mechanical energy during the same technological process), the promotion of clean coal combustion technology with CO₂ and other hazardous substances capture technology.

The process of combined heat and electricity production (cogeneration) is characterized by high efficiency and the maximum use of chemical energy of the fuel supplied. Cogeneration helps adapt the economy to real energy needs as well as reduces fuel consumption (reduction of emissions) which is economically and ecologically more beneficial compared to the system of obtaining energy used so far (separate generation of electricity and heat).

The production of electricity is associated with high energy losses because about 35–40% of the energy contained in the fuel is used in standard technology. However, in the case of cogeneration systems, approx. 80% of primary energy can be used. The possibility of using waste heat is contained, among others, in exhaust gas. In a system with an internal combustion engine, water cools the turbocharger of the air-fuel mixture, engine block, oil pan, and the most heat is collected from the exhaust gas. When using heat exchangers in the exhaust system, waste heat can be used to heat water or to generate process steam.

In industrial conditions and production capacities up to several MWe (megawatt of electric power), the most common cogeneration aggregates are piston engines, in which natural gas or biogas (possibly pyrolytic gas, etc.) is used as a fuel. Gas cogeneration is the most supported, which is characterized by a greater flexibility of work and lower emission of harmful substances into the atmosphere in comparison to coal-based cogeneration systems used in large professional CHP plants.

3. Polish proposal for meeting energy needs

According to forecasts, the demand for electricity in our country by 2030 will increase compared to 2010 by about 35–40%. The structure of power installed in the National Power System (NPS) is presented in table 2.

TABLE 2. The structure of installed power in the National Power System (NPS) [MW]

TABELA 2. Struktura mocy w krajowym systemie elektroenergetycznym (KSE) [MW]

	2015-12-31	2016-12-31	2017-12-31
Total	40,522	40,852	43,421
Professional power plants	32,317	32,318	34,268
Professional water power plants	2,290	2,292	2,328
Professional thermal power plants, based on:	30,027	30,025	31,939
◆ coal	19,266	19,083	20,247
◆ lignite	9,290	9,332	9,352
◆ gas	1,472	1,610	2,341
Wind power plants and other renewable	5,384	5,706	6,341
Industrial power plants	2,821	2,828	2,813

Source: <https://www.pse.pl>

Equipment that allows for the recovery and energy use of biogas is increasingly being used for the production of electricity. These installations are set up e.g. at sewage treatment plants and landfills. Electricity is also obtained from so-called agricultural biogas. It arises as a result of fermentation of agricultural by-products or animal droppings with the addition of biomethane bacterial cultures.

In addition to traditional or conventional sources of electricity, Poland obtains energy from alternative sources, such as: solar energy, wind energy, geothermal energy, hydropower and biomass energy. Alternative forms of energy are “ecological” for the environment as they draw power from the Earth’s natural renewable resources, you only need to act in compliance with the environmental protection principles to exploit them while minimizing environmental degradation. The power system provides us with universal access and use of electricity. Such actions require a well-developed and efficient arrangement of devices for energy production, transmission and distribution.

Optimal recovery and recycling technologies, in particular reducing the amount of waste deposited, are the most important waste management goals that local governments (municipalities) must achieve. To achieve these environmental goals, it is necessary to focus on efficiency, process optimization and the use of technologies that allow clean secondary raw materials of the

expected quality to be obtained. Obtaining fuels (liquid and gaseous) with high calorific value, easy to use for energy purposes, seems to be the best solution.

4. Waste – unused potential

4.1. Energy recovery from obtained fuel concentrates

Used tires and plastics are used particularly often as fuel in energy processes. The burning of used tires and polymers in cement plants and heating plants is a simple method of energy use, while obtaining fuels from them can facilitate their optimal use for social purposes.

Figure 2 shows schematic examples of currently used types of thermal decomposition technologies for organic and mixed waste.

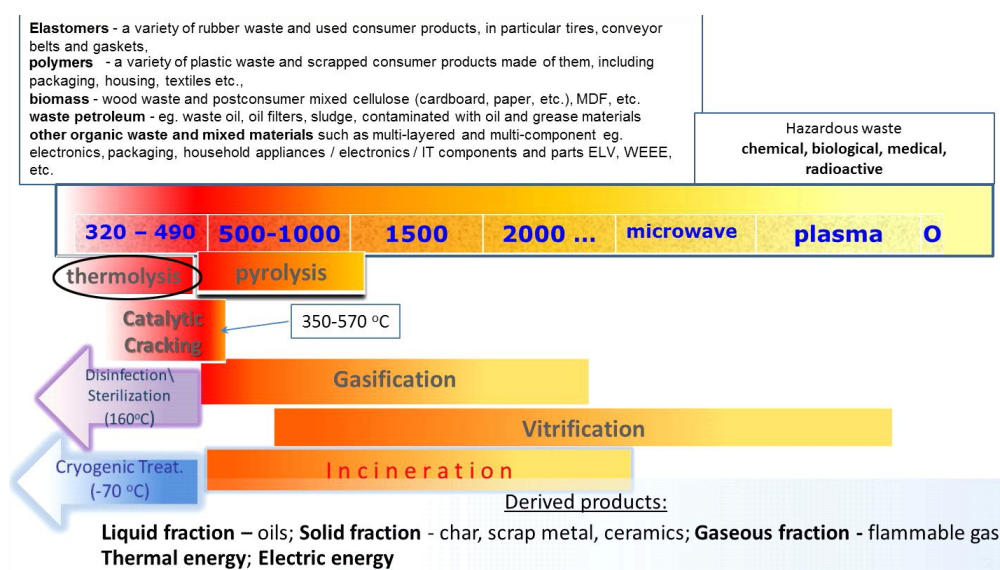


Fig. 2. Scheme of the types of waste thermal decomposition technologies (own study)

Rys. 2. Schemat rodzajów technologii termicznego rozkładu odpadów

At present, the greatest interest arises in the material recovery of plastics and rubber in the process of anaerobic thermal decomposition (thermolysis/pyrolysis), which is used on an industrial scale and consists in the degradation of polymer bonds into low molecular weight. The main advantage of the thermal neutralization process and disposal of waste in the thermolysis/

pyrolysis process over the classic combustion (oxidation) of an organic substance consists in the fact that in the process of full thermal decomposition, which takes place without oxygen, extremely toxic polychlorinated (brominated) dibenzodioxin PCDD, PBrDD and polychlorinated (brominated) dibenzofurans PCDF, PBrDF, because the thermolysis/pyrolysis process takes place without the participation of oxygen, and oxygen is a component of the listed hazardous substances (one or two oxygen bridges connect two benzene rings with chlorine (or bromine) (Communication from the Commission... 2014).

4.2. Extraction of fuels from waste

4.2.1. Plastic waste (mixed/multi-material) (PlasticsEurope 2018)

Main applications of plastics in Europe (EU 28 + Norway/Switzerland) by application segments in 2016:

- ◆ packaging – 39.9%,
- ◆ construction – 19.7%,
- ◆ automotive – 10.0%,
- ◆ electronics and electrical engineering, household appliances, sport, leisure – 10.4%,
- ◆ other (agriculture, machinery and equipment, furniture, medical equipment, etc.) – 20.0%.

The total consumption of plastics in Europe is 49.9 million Mg (Poland 6.3%).

Plastic waste management in 2016 (EU 28 + NO/CH) amounted to:

- ◆ 27 million Mg of post-consumer plastic waste, including 16.7 million Mg of packaging waste,
- ◆ Poland 2016: 1.72 million Mg post-consumer plastic waste, including 960 thousand Mg packaging waste.

4.2.2. Material recovery in the process of thermal decomposition

The Act on Waste of 14.12.2012 (last amendment from 2020), Art. 3.1. Whenever the Act refers to: 29. thermal waste treatment – it means:

- a) waste incineration by oxidation,
- b) thermal waste treatment processes other than indicated in point a, including: pyrolysis, gasification and plasma processes, as long as the substances generated during these processes are then incinerated.

The Regulation of the Minister of Economy of October 21, 1998 on detailed rules for the removal, use and disposal of hazardous waste is closely related to the Act (Regulation... 1998). This regulation specifies thermal transformation processes:

“§ 9. Thermal transformation of hazardous waste in boiler furnaces or in waste incineration plants, the following conditions must be met:

1) the duration of keeping exhaust gases in the combustion chamber should be at least 2 sec. in a temperature:

a) not lower than 850°C – if the chlorine content in organic compounds in the transformed waste it does not exceed 1% of dry weight of waste,

b) not lower than 1100°C – if the chlorine content in the organic compounds in the transformed waste it exceeds 1% of the dry waste,

2) oxygen content in flue gas must not be less than 6%,

3) process waste gases should be monitored for continuous registration of temperature in the combustion chamber, as well as the measurement of pressure, oxygen content and water vapor.

§ 10. Thermal conversion of hazardous waste in rotary kilns up to cement and lime production, in which high temperature processes and time maintaining exhaust gases at these temperatures within 4 to 8 sec. guarantee the efficiency of the decomposition of organic ingredients requires fulfillment the following conditions:

1) the composition of the process waste gas must not deteriorate compared to the operation of the installation without introducing hazardous waste into it,

2) waste storage devices and their preparation for transformations should be made in a way that ensures environmental protection.

§ 11.1. The thermal transformation of hazardous waste through its pyrolytic decomposition requires the following conditions to be met:

1) content of organic halogen compounds in vapors and waste gases from the process of pyrolytic decomposition of hazardous waste should not exceed 0.5 nanogram in one cubic meter [0.5 ng/m³],

2) gases from the pyrolysis process should be used as fuel auxiliary in furnaces of heating boiler rooms; in cases of absence, the possibility of such use is allowed to burn gases in the flare”.

Plastic waste processing in the controlled depolymerization process, which is the reverse of the polymerization process for hydrocarbon recovery, petroleum derivatives are used in their production. Installations of this type are equipped with a reactor, heat exchangers, separators, purifiers with a charge capacity of up to approx. 0.5 Mg/h. A depolymerization process is carried out in the reactor at max. 480°C. During the process, thermal decomposition occurs (reactive distillation) of plastics and the process of evaporation of hydrocarbons, directed further to a diaphragmless multi-zone condensation system. This makes it possible to process most of the plastic waste used in everyday life and industry, i.e. plastics mainly from the group of polyolefins, such as polyethylene (PE), polypropylene (PP), polystyrene (PS) and polycarbonate (PC) polyethylene terephthalate (PET) and their copolymers (Matuszewska et al. 2019).

A scheme of the process of processing plastic waste into motor fuels according to the Handerek Technology method is presented in Figures 3 and 4.

The process will contribute to increasing the efficiency of the depolymerization process of waste plastics and will allow high quality of light, mainly heating oil to be obtained.

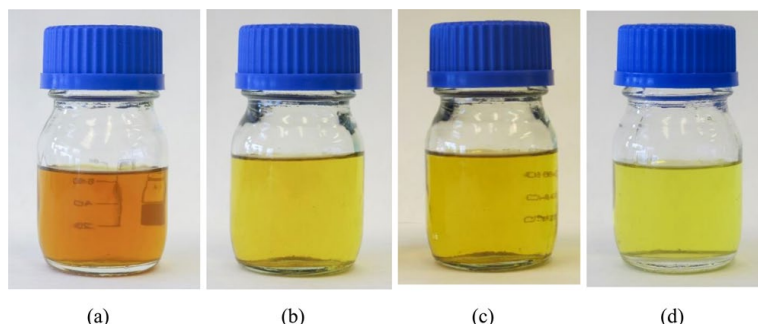
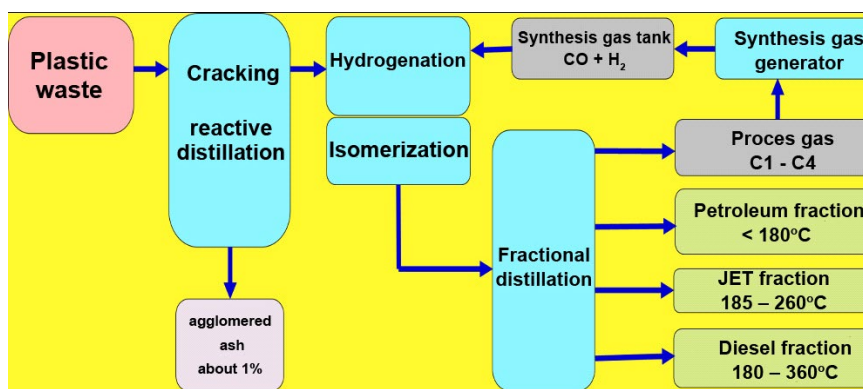


Fig. 3. Photographs of samples obtained in the process: (a) thermolysis under N₂, without hydrogenation; (b) thermolysis under N₂, hydrogenation under syngas; (c) both thermolysis and hydrogenation under syngas mixture N₂ and in ratio 1:1; (d) both thermolysis and hydrogenation under syngas (Matuszewska et al. 2019)

Rys. 3. Zdjęcia próbek uzyskanych w procesie: (a) termolizy w N₂, bez uwodornienia, (b) termolizy w N₂ i uwodornienia w gazie syntezowym, (c) termolizy i uwodornienia w mieszaninie gazu syntezowego i N₂ w stosunku 1:1, (d) termolizy i uwodornienia w gazie syntezowym



Cracking → reactive distillation column with mobile bed according to Adam Hańderk's patent

Hydrogenation → pressureless hydrogenation method according to the patent of the Institute of Industrial Chemistry

Isomerization → pressureless isomerization process on a palladium catalyst

Fig. 4. Diagram of the plastic waste processing process

In the production of hydrocarbon fuels from waste polyolefin materials (PE, PP, PS), by liquefying the raw material and hydrogenating the liquid intermediate to fuel fractions in the process of anaerobic thermal decomposition, the product is produced only in the form of a boiling fraction up to 350°C in one thermal decomposition process and do not condense in normal process gases C1 to C4 (Matuszewska et al. 2019)

Rys. 4. Schemat procesu przetwarzania odpadów z tworzyw sztucznych

Produkcja paliw węglowodorowych z odpadowych materiałów poliolefinowych (PE, PP, PS), poprzez upłynnienie surowca i uwodornienie ciekłego półproduktu do frakcji paliwowych w procesie beztlenowego rozkładu termicznego, produkt powstaje wyłącznie w postaci frakcji wrzącej do 350°C w jednym procesie rozkładu termicznego i bez kondensacji w normalnych gazach procesowych C1 do C4

The obtained light heating oil has a calorific value: approx. 44–45 MJ/kg, ignition temperature min. 66°C, boiling point max. 365°C, flow temperature max. – 30°C, 0.005% sulfur content. High physicochemical parameters will allow for their full use as valuable products in the refining and chemical industries.

4.2.3. Wastes from elastomers (in particular tires)

It is estimated that about 1 billion Mg of used car tires are generated each year in the world. In Poland, as in other European Union countries, about 80% of used rubber products are tires, where in the process of thermal decomposition by thermolysis you can process about 250,000 Mg of rubber waste per year, from which approx. 130,000 Mg of oil and about 25,000 Mg of gas can be obtained. They can be used as a fuel for obtaining heat or electricity (diversification of energy sources).

Examples of tire storage sites:

- ◆ Huge amounts of old tires in the Sesena Nuevo landfill near Madrid. 5 million (approx. 11 hectares) old tires (Fig. 5).
- ◆ The world's largest tire storage site in Al Jahra – Kuwait (Fig. 6).

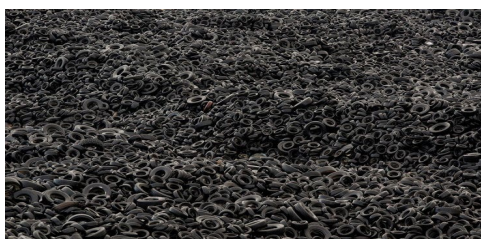


Fig. 5. Landfill for used tires in Sesena Nuevo
(www.maryscullyreports.com)

Rys. 5. Składowisko zużytych opon w Sesena Nuevo



Fig. 6. Landfill for used tires in Al Jahra
(www.photos.wikimapia.org)

Rys. 6. Składowisko zużytych opon w Al Jahra

At the same time, it should be noted that it is possible to adapt the internal combustion engines of oil-fired power generators from anaerobic thermal decomposition (thermolysis/pyrolysis) processes, reactive distillation (controlled depolymerization) mainly polymers and elastomers, which are of adequate quality as shown in Table 3.

4.2.4. Other wastes including hazardous

Fuel from medical waste

Medical waste which is subject to incineration is due to the threat to life and human health have been classified as hazardous and non-hazardous waste that may be the cause of infection. Assuming the need to meet the primary goal of hospital waste incineration plants, which is the

TABLE 3. Test results of oil obtained from tires compared to the requirements of the relevant standards

TABELA 3. Wyniki badań oleju uzyskanego z opon w porównaniu z wymaganiami odpowiednich norm

Test method/properties	Diesel according to the Regulation of the Ministry of Economy	Heating oil according to PN-C-9024:2011	Diesel According to PN-EN 590:2013	Oil test results from thermolysis processes. A dozen tests carried out in accredited laboratories	Regulation of the Minister of Economy of October 15, 2015 on the detailed manner of dealing with waste oils (Journal of Laws of 23.10.2015, item 1694)
PN-EN ISO 12185 – Density at 15°C [kg/m ³]	820–845	860	820–860	875.0–916.7	870–930
PN-ISO 6296 – Water content [% m/m]	max. 200 mg/kg	2	2	0.030–0.100	10.0
PN-EN ISO 3104 – Kinematic viscosity at 50°C [mm ² /s]	1.5–4.5	6	2–4.5	1.494–3.524	–
PN-EN ISO 2592 – Flash-point [°C]	pow. 55	56	55	14–44	below 56
PN-86/C-04062 Calorific value [kJ/kg]	–	42 600	42 000 – 44 000	38 328–40 690	–
PN-EN ISO 6245 – Ash residue [% m/m]	0.010	–	0.010	0.002–0.004	–
Sulfur content [% m/m]	–	0.1	0.1	0.30–0.67	1.0

destruction of all pathogens, the incineration plant should meet the following combustion conditions according to American tests (Berbeito):

- ◆ first combustion chamber – temperature above 760°C,
- ◆ second combustion chamber – temperature above 980°C and burning time > 2 s.

On the basis of NIK data and an analysis of the current situation, carried out by the National Association of Waste Management “3R”, it follows that today only 2% of medical waste (approx. 4,000 Mg/year) requires utilization by incineration and these are mainly human remains (from surgical wards).

Other types of medical waste should, in accordance with the principles of modern knowledge and global trends, be disposed of only by alternative methods to combustion, mainly by means of thermal decomposition technology. The process of disposing of medical waste should take the economic and logistics aspects into account Figure 7.

In the process of thermal decomposition of medical waste, apart from oils, it is also possible to recover stainless steel (Cr-Ni) and high-quality glass, while in the combustion process everything goes back to ashes and slag.



Fig. 7. Thermal decomposition of medical waste (after diagnostic)

Rys. 7. Rozkład termiczny odpadów medycznych (podiagnostycznych)

Fuel from fat waste from sewage system

A source of energy (diversification) may not only be renewable energy, but also organic waste such as: fats, dirty polymer containers for oils, all kinds of elastomers, etc. You can use the fat and fats thrown away, used vegetable and animal oils as well as heaps of fat that get into the sewage system in an environmentally friendly way – together with water, used e.g. for washing dishes and then flowing through the municipal sewage system, clogging it similarly and as effectively as in our circulatory system – it settles along the walls of pipes and channels, causing troublesome blockages over time.

The largest fat plug found ever seen in the sewerage was discovered in central London in 2018, where it plugged the sewer in Whitechapel. The British media has already proclaimed it a “fat monster” because of its 250 m length and weight of about 130 Mg (<https://www.fakt.pl>).

For example, the British company Thames Water in London is able to extract a fat mixture called FOG (fat-oil-grease) from the channels every day. Sediments and piles of concentrated residual fat formed and mixed with other waste must regularly be removed from the sewage system to prevent blockages and to clear the flow (www.gadzetomania.pl).

One way to eliminate the troublesome and expensive sewage treatment is to collect fat at the source, including installing under the sink filters that filter grease from water and installing containers for used cooking oils and industrial, greasy waste including trimmings, used lard, etc., mainly in mass catering outlets (in particular restaurants and etc.).

5. Diversification of energy sources

In order to apply the process of diversification of energy sources, in particular by developing methods of generating energy from waste, this has become a necessity at the current stage of development in order to protect the environment as well as to ensure supplies and the proper functioning of the society. The diversification of energy sources should be a response to the growing environmental requirements set for the energy sector.

The current Directive of the European Parliament and of the Council 2009/28/EC of April 23, 2009 on the promotion of the use of energy from renewable sources, does not indicate waste recycling products as a source of alternative fuels, which significantly affects the amount of fires in landfills.

In the 2030 Package, the European Council assumes as much as 40 percent in the proposed form of the reduction of greenhouse gas emissions and reaching a share of 27% of renewable energy in the EU energy mix by 2030. The determined indicators will be difficult to achieve without adapting the regulations to other organic waste (polymers and elastomers) as RES.

The use of fuels obtained from organic waste in power generators:

- ◆ small power generators – 2–10 kWe (commercially available),
- ◆ large power generators – 70–120 kWe (e.g. Cummins engines),
- ◆ cogeneration power plants – 2–15 MWe (e.g. H. Cegielski – Poznań SA).

The solid SRF/RDF secondary fuel currently produced from waste, even when meeting strict quality standards, is still treated as waste. This situation significantly limits energy interest in the use of these fuels. This can, however, be improved by using appropriate economic and legal incentives (transformation of waste into useful raw materials). For the energy sector, such an opportunity may be the possibility of including part of the energy obtained from solid secondary fuels as so-called green energy (renewable) and the reduction of reported CO₂ emissions.

The dynamics of economic development determine the need to develop technologies for waste recycling and the recovery of valuable raw materials, especially the acquisition of metallic raw materials and condensed fuels for the needs of local diversification of energy sources.

In order to secure Poland's own production of electricity to meet the needs of society and guarantee energy security even for small towns (diversification of energy sources), we propose building approx. 8–10 plants in Poland for oil from recovery or additionally gas (dual-fuel engines), together with installations with Polish patents for anaerobic thermal decomposition (plastics and car tires), in particular in the north and north-east, which should result in synergy of impact in the area of environmental protection and waste management. Obtaining energy from segregated and collected organic waste and mixed electricity and heat also affects the reduction of greenhouse gas emissions and waste management in an environmentally friendly manner as well as diversification with cogeneration will reduce Poland's independence on the supply of fuels and energy from other countries.

More information related to the construction and operation of a cogeneration plant can be found at: http://klasteroze.it.kielce.pl/upload/DOKUMENTY/SEMINARIA/02032011/11_Elektrownia_kogeneracyjna_4_2_MW_na_olej_palmowy.pdf

For example, H. Cegielski – Poznań SA (www.klasteroze.it.kielce.pl) implemented:

- ◆ in 2010, a 4.2 MWe Brake cogeneration power plant was commissioned, Germany. This is the first installation in the world with a two-stroke engine burning biofuel – raw palm oil,
- ◆ in 2010–2011 H. Cegielski – Poznań SA will provide two 13 MW rapeseed oil engines to two power plants in the suburbs of London.

Parameters of the power plant in Brake:

- ◆ mechanical power of the 7L35MC-S engine: 4,520 kWm,
- ◆ generator efficiency 97%,
- ◆ electric power for sale (after taking the efficiency of the generator and own needs into account): 4,209 kWe,
- ◆ thermal power for sale: 3,480 kWth,
- ◆ fuel consumption (for ambient conditions and calorific value 38 MJ/kg) 0.88 Mg/h, 21 Mg/day, e.g. fuel from thermal decomposition of organic waste (tires, plastics).

Conclusion

In view of the growing demand for raw materials and energy, as well as environmental protection requirements, waste treatment is becoming an imperative in the functioning of the modern economy. In order to implement the diversification of energy sources using fuels obtained from waste, the use of thermal decomposition installations for tires and polymers (two to guarantee an appropriate amount of fuel consumption), which are protected by Polish patents, is proposed.

For the thermal decomposition of tires – two reactors in combination – one is working, the other is prepared for the next process, where the charge is unloaded and loaded cyclically – 15 Mg/pcs (60% oil, 20% gas). Amount of oil obtained – about 8–9 Mg per day x 2 = 16–18 Mg/day.

Two installations for polyolefin waste – depolymerization controlled by 0.5 Mg/h in a continuous process. The amount of oil obtained from polymer waste – 80% oil, 15% gas – oil around 10 Mg/day. Together with both types of installations we will receive about 20 Mg/day of oil.

The power plant's demand for fuel (such as the 4.2 MW Brake) is 21 Mg/day x 365 days = 7,665 Mg/year oil.

Waste managed during the year in one complete installation:

- ◆ elastomers (mainly tires) – 15 Mg/day x 2 (in operation) = 30 Mg/day x 365 days = approx. 11,000 Mg of tires,

- ◆ plastomers (mainly polyolefin plastics) – 2 installations x 0.5 Mg/h x 24 h = 24 Mg/day x 365 days = approx. 8,760 Mg of polymers.

It is estimated that around 19–20 thousand Mg of organic waste for one power plant produced by H.Cegielski – Poznań SA can be managed together.

For 10 cogeneration plants, 20,000 x 10 = 200,000 Mg of organic waste is needed, which can be used to a great extent to diversify energy sources combined with cogeneration.

Environmentally friendly waste management should be sought:

- ◆ RECOVERY of materials and fuels from waste as a PRINCIPLE,
- ◆ Waste incineration only in EXCEPTIONAL cases.

Considering climate change and the increased demand for energy, the problem concerns, in particular, the central and local government administration as well as the Polish Army and other special services.

References

- Act on Waste of 14 December 2012, Journal of Laws of 2012, item 942 (*Ustawa z dnia 14.12.2012 r. o odpadach z póź. zm.*) (Dz.U. z 2020, poz. 797) (*in Polish*).
- BP Statistical World Energy Review, 2016. British Petroleum. [Online] <http://oilproduction.net/files/especial-BP/bp-statistical-review-of-world-energy-2016-full-report.pdf> [Accessed: 2019-12-02].
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Towards a circular economy: A zero waste programme for Europe, 2014, COM(2014) 398 final. [Online] <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014DC0398> [Accessed: 2020-04-25].
- MATUSZEWSKA et al. 2019 – MATUSZEWSKA, A. HAŃDEREK, A. BIERNAT, K. and BUKREJEWSKI, P. 2019. Thermolytic Conversion of Waste Polyolefins into Fuels Fraction with the Use of Reactive Distillation and Hydrogenation with the Syngas under Atmospheric Pressure. *Energy & Fuels* 33, DOI: 10.1021/acs.energyfuels.8b03664.
- Norma CEN/TS 15359 Solid Recovered Fuels – Specifications and Classes. [Online] https://biom.cz/data/normy/15359_Specifications-Classes.pdf [Accessed: 2020-06-20].
- [Online] https://www.bgr.bund.de/EN/Home/homepage_node_en.html&prev=search [Accessed: 2020-04-25].
- [Online] <https://www.fakt.pl/wydarzenia/swiat/londyn-potezna-gora-tluszczu-zatkala-kanaly-sciekowe/yvs5y3l> [Accessed: 2020-04-25].
- [Online] <https://www.gadzetomania.pl/3429,elektrownia-zasilana-tluszczem-paliwo-prosto-z-miejskiej-kanalizacji> [Accessed: 2020-04-25].
- [Online] http://www.klasteroze.it.kielce.pl/upload/DOKUMENTY/SEMINARIA/02032011/11_Elektrownia_kogeneracyjna_4_2_MW_na_olej_palmowy.pdf [Accessed: 2020-04-25].
- [Online] <https://www.maryscullyreports.com/neoliberal-waste-management-2/> [Accessed: 2020-04-25].
- [Online] <https://www.optimalenergy.pl/aktualności/dystrybucja-pradu/popyt-na-energie-wzrost-o-41-do-2035-roku/> [Accessed: 2020-04-25].
- [Online] http://www.photos.wikimapia.org/p/00/03/32/69/68_full.jpg [Accessed: 2020-04-25].
- [Online] https://www.pse.pl/dane-systemowe/funkcjonowanie-rb/raporty-roczne-z-funkcjonowania-kse-za-rok/raporty-za-rok-2017#t1_1 [Accessed: 2020-04-25].

- PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH. Plastics – the Facts 2017. PlasticsEurope, 2018. [Online] https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf [Accessed: 2020-04-25].
- Regulation of the Minister of Economy, October 21, 1998, Journal of Laws 1998.145.942 (*Rozporządzenie Ministra Gospodarki z dnia 21 października 1998 r. w sprawie szczegółowych zasad usuwania, wykorzystywania i unieszkodliwiania odpadów niebezpiecznych*) (Dz.U. 1998 nr 145, poz. 942) (*in Polish*).
- WASIELEWSKI et al. 2011 – WASIELEWSKI, R. STELMACH, S. and SOBOLEWSKI, A. 2011. Production and use of solid recovered fuels (*Wytwarzanie i wykorzystanie stałych paliw wtórnych*). IChPW, *Chemik* No 6, Iss. 65, pp. 572–575 (*in Polish*).

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Paliwa z odpadów dla dywersyfikacji źródeł energii

Streszczenie

Dynamika rozwoju gospodarczego determinuje potrzebę rozwoju technologii recyklingu odpadów, w szczególności pozyskiwania paliw skondensowanych na potrzeby lokalnej dywersyfikacji źródeł energii. W niedługim czasie, w Polsce prawdopodobnie będzie brakowało wyprodukowanej własnym sumptem energii elektrycznej. Stosowanie procesu dywersyfikacji źródeł energii ma za zadanie, opracowanie metody wytwarzania energii z odpadów w celu ochrony środowiska. Zastosowanie technologii kogeneracji opartej na paliwach pozyskiwanych z odpadów, w szczególności skoncentrowanych paliw typu olej i gaz, staje się coraz bardziej powszechne i daje podstawę bezpieczeństwa dostaw energii w preferowanym procesie jej dywersyfikacji. Obecnie największe zainteresowanie budzi odzysk materiałów z tworzyw sztucznych i gumy w procesie beztlenowego rozkładu termicznego (termolizy/pirolizy), który stosuje się na skalę przemysłową. Polega on na degradacji wiązań polimerowych do niskiej masy cząsteczkowej. Imperatywem nowoczesnej gospodarki jest pozyskiwanie energii z paliw pochodzących z przetwarzania odpadów, w tym niebezpiecznych, najkorzystniej w procesie kogeneracji. Pozyskane z odpadów paliwa mogą znaleźć zastosowanie w produkcji energii cieplnej lub elektrycznej w celu dywersyfikacji źródeł energii. W artykule przedstawione zostały innowacyjne polskie technologie pozyskiwania paliw w procesach beztlenowego rozkładu termicznego, głównie odpadów elastomerowych i polimerowych (w tym niebezpiecznych), do bezpośredniego zastosowania w agregatach prądowców o zróżnicowanej mocy.

SŁOWA KLUCZOWE: odpady, energia, dywersyfikacja, paliwa alternatywne, źródła energii

