

SWOT analysis of technologies applied for thermal treatment of municipal solid waste

[Anna Foteva, Yana Topalova]

Abstract— Technologies for thermal treatment of waste are essential for integrated municipal solid waste (MSW) management, not only because the potential for reduction of quantity and volume of MSW, but also because the prospective for utilization of their energy content. The selection of thermal treatment technology is a key stage in the process of strategic planning of waste management systems. Therefore, for specific waste management system it is necessary a SWOT analysis to be performed, based on evaluation of specific, concrete and clear factors for each thermal treatment technology. The aim of this study is to perform SWOT analysis, based on assessment of technological, environmental, financial and social factors for direct combustion, pyrolysis, gasification and plasma-based gasification.

Keywords— Municipal solid waste (MSW), Waste-to-energy (WtE), thermal treatment, SWOT analysis

I. Introduction

Over the past decade Waste-to-Energy (WtE) technologies have been part of the development of more sustainable waste management practices [1]. According to the literature survey there are about 2170 WtE facilities worldwide [2]. It was established that Asian countries have the largest number of facilities for thermal treatment of waste, which has resulted in solving problems such as limited open space for siting of landfills and high urban population [2]. For example, Japan has been processing about an estimated 70% of MSW in WtE facilities [2]. The number of facilities in Europe is large—above 450, which is primarily due to the EU Circular Economy Package and the EU aims for gradual reduction of municipal waste landfilled to 10% by 2030 [2]. The number of facilities in United States ensure baseload electrical generation capacity of approximately 2700 MW to meet the power needs of more than two million homes [2].

WtE technologies can be divided into different categories [1]. The conventional approach for energy recovery of waste is direct combustion with direct generation of heat [1].

Anna Foteva

Sofia University “St. Kliment Ohridski”, Faculty of Biology, Center of competency “Clean technologies for sustainable environment – water, waste, energy for circular economy” (Clean & Circle).
 Bulgaria

Yana Topalova

Sofia University “St. Kliment Ohridski”, Faculty of Biology, Center of competency “Clean technologies for sustainable environment – water, waste, energy for circular economy” (Clean & Circle).
 Bulgaria

Additionally, there are some advanced methods, such as pyrolysis, gasification, plasma-based gasification. Pyrolysis and gasification differ from direct combustion in that they can be used for recovering of chemical value from waste [1].

Pyrolysis involves heating the waste in the absence of oxygen, resulting in formation at a different level of gaseous, liquid or solid products, depending on the temperature to which the waste is heated [3]. Gasification involves partial combustion of the waste in a limited supply of oxygen, producing a combustible gas and ash residue, which may also be combustible [3]. Version of gasification process, developed for waste processing is plasma-based gasification. The heat source is a plasma arc torch, a device that produces a very high temperature plasma gas leading to destruction of waste components into a simple molecules and atomic constituents, resulting in a pure syngas as a product and in a vitrified slag residue [2,3].

According to the literature survey direct combustion is the most widely applied technology- overall throughput and operational hours of pyrolysis and gasification on the main European waste streams is low compared to incineration [1].

TABLE I Summary information for thermal treatment technologies [1,2,3,4]

Direct Combustion	Very wide range of wastes; often used for combustion of MSW and refuse derived fuel (RDF); oxygen supply is very important; traditional method is burning in combustion chamber and grate; the temperature usually is above 850°C; hot combustion gases from the grate flow into a boiler, where the heat is used to generate steam; outputs are flue gas, heat and power, ash, slag.
Pyrolysis	Often require waste pre-treatment; used for wide range of wastes; degassing of wastes in the absence of oxygen, during which pyrolysis gas, liquids and solid residues are formed; Conventional reactors are equipped with one of the following configurations: fixed bed, fluidized bed, entrained flow, moving bed, rotary kiln, ablative reactor; temperature range between 250-900 ° C.
Gasification	Often require waste pre-treatment; used for wide range of wastes; partial combustion of organic substances to produce gases that can be used as feedstock or as a fuel; temperature range 500 –1800 °C or higher; The syngas can be used for efficient production of electricity and/or heat, second generation fuels or chemicals.
Plasma gasification	Sustainable for all types of waste; the process uses temperatures that can be in excess of 5000 ° C; the plasma that is used to heat the waste material is created by passing an extremely high voltage through a gas in a chamber; the products are clean syngas, a glass-like solid slag;

II. Methods

The strengths & weaknesses and opportunities & threats on the basis of different factors for direct combustion, pyrolysis, gasification and plasma-based gasification are determined.



Figure 1 Factors used in the assessments of SWOT analysis

All positive and negative elements of the SWOT analysis are evaluated with values from 1 to 2. With value 2 are evaluated those elements that are with higher importance. The points are summarized for all elements of the respective position in the SWOT. The obtained values are used for determination of percentage ratio of SWOT sides for each technology. The results are presented as circles with diameters representing the percentage values. For better visualization of circles, percentages are divided to 10. The ratio between the sizes of the circles visualizes the percentage ratios of the individual technologies in their strengths and weaknesses, opportunities & threats.

The ratio between strengths & weaknesses and opportunities & threats has been determined for each of studied thermal treatment technologies.

III. Results and discussion

The results are presented as a SWOT analysis for each of the studied technologies. Based on the results from analysis, different combinations of ratios are presented.

A. SWOT analysis

A SWOT analysis for each of the four studied technologies is made, referring to the consideration of various technological, environmental, social and financial factors.

Table II presents a SWOT analysis of direct combustion, pyrolysis, gasification, plasma-based gasification. The main elements of the strengths and weaknesses, opportunities and threats are systematized. The darker shade of the color illustrate elements rated with value 2 (higher importance). Respectively, the lighter shade of the color indicates for elements, rated with value 1.

TABLE II SWOT analysis of direct combustion, pyrolysis, gasification, plasma-based gasification [1,2,3,4,5,6,8,9]

<i>Direct Combustion</i>			
<i>Strengths</i>		<i>Weaknesses</i>	
-Widely applied; -Mixed, heterogeneous waste;	2	-Emissions into the atmosphere; -Depending on the type of flue gas treatment technology- different amounts of hazardous waste and waste water; -Social disapproval because of air pollution;	2
-Wide size ranging; -Part of integrated waste management systems in Europe; -Utilization of heat in district heating & cooling; -Effect on reduction of greenhouse gas (GHG) as replacement installation in TPP;	1	-Does not completely eliminate the amount and volume of waste; - Literature survey- the lowest net energy production to grid	1
<i>Opportunities</i>		<i>Threats</i>	
-Leaching of metals from slag and ash; -Reducing the impact to the environment by utilization of the slag; -Development of innovative biotechnological solutions for bioremediation and reduction of toxicity of hazardous ashes; -Development of bioremediation complexes for minimization the impact of air polluters and GHG emissions; -Development of low-oxygen combustion process	2	-Development of competitive technologies with better environmental performance; -Development of new technologies with lower operational and maintenance costs; -Development of new technologies with higher energy production;	2
	1	-Threat of suspension of EU grants for direct combustion plants with limited energy recovery;	1
<i>Pyrolysis</i>			
<i>Strengths</i>		<i>Weaknesses</i>	
-Wide range of wastes; -Reduced flue gas volumes, which can lead to reduction of investments; -Concentration of some pollutants in pyrolysis treatment is lower than their concentration after incinerators of similar waste; -Compact and modular plants; -Literature survey net energy production to grid is higher than incineration; -The bulk of heavy metals pass into the solid residue	2	-Require waste pre-treatment;	2
	1	-Rarely used in Europe for treatment of MSW; -Consistency in the chemical and physical composition of the waste; -Requirements for drying of waste; -Energy production kWh/t is lower than gasification;	1
<i>Opportunities</i>		<i>Threats</i>	
-Development of bioremediation complexes for minimization the impact of air polluters and GHG emissions; -Possibility of recovering the material value of the organic fraction, e.g. as methanol; -Possibility for external use of pyrolytic oil as an energy resource; -Meeting specifications for external use of the produced char after treatment procedure e. g. by washing chlorine content)	2	-Development of thermal WtE technologies with higher energy production; -Development of syngas production technology without specific requirements for consistency in chemical and physical composition of waste.	2

1		1	
Gasification			
<i>Strengths</i>		<i>Weaknesses</i>	
<ul style="list-style-type: none"> -Smaller waste water flows from synthesis gas cleaning; -Smaller gas volume compared to the flue gas volume in incineration; -Predominant formation of CO rather than CO₂; -Treatment of wide range of waste; -Lower concentration of some pollutants than incinerators of similar waste; -Wide size ranging; -Small and compact aggregates; -Literature survey net energy production to grid is higher than pyrolysis; 	2	<ul style="list-style-type: none"> -Require waste pre-treatment; 	2
<ul style="list-style-type: none"> -Wide size ranging; -Small and compact aggregates; -Literature survey net energy production to grid is higher than pyrolysis; 	1	<ul style="list-style-type: none"> -Rarely used in Europe for treatment of MSW; -Requirements for drying of waste; -Energy production kWh/t is lower than plasma based technology; 	1
<i>Opportunities</i>		<i>Threats</i>	
<ul style="list-style-type: none"> -Bioremediation and utilization of slag/ash residues; -Production of Ethanol from Syngas by chemical process; -Production of Ammonia from Syngas; -Production of Methanol from Syngas; -Production of Synthetic Natural Gas from Syngas by Chemical Synthesis process; -Production of Ethanol from Syngas by biochemical process; 	2	<ul style="list-style-type: none"> -Development of thermal WtE technologies with higher energy production; -Development of syngas production technology without specific requirements for waste pre-treatment; 	2
<ul style="list-style-type: none"> -Highest net energy production to grid; 	1		1
Plasma gasification			
<i>Strengths</i>		<i>Weaknesses</i>	
<ul style="list-style-type: none"> -Variety of different wastes; -Minimal requirements for waste pre-treatment; -Vitrified slag can be used as a construction material; -Syngas can be produced without releasing pollutants into the atmosphere; -Non-leaching slag; -Reducing or even eliminating waste disposal on landfill; -Possibility existing landfills to be used as raw fuels for plasma plants; -Destruction efficiency: >99,99%; -Social approval, due to indicated sustainability. 	2	<ul style="list-style-type: none"> -Limited operating experience; -It can be very complex, expensive and operator intensive technology; 	2
<ul style="list-style-type: none"> -Highest net energy production to grid; 	1		1
<i>Opportunities</i>		<i>Threats</i>	
<ul style="list-style-type: none"> -Production of Ethanol from syngas by chemical process; -Non-leaching slag can be used as a road material -Non-leaching slag can be used as a construction material; -Production of Ammonia from Syngas; -Production of Methanol from Syngas; -Production of Synthetic Natural Gas from Syngas; -Production of Ethanol from Syngas by biochemical process; 	2	<ul style="list-style-type: none"> -Availability of lower in investments, operational and maintenance costs and easier for operation technologies for thermal treatment of MSW, covering the present requirements of environmental legislation 	2
<ul style="list-style-type: none"> -Highest net energy production to grid; 	1		1

B. Ratios between the four technologies

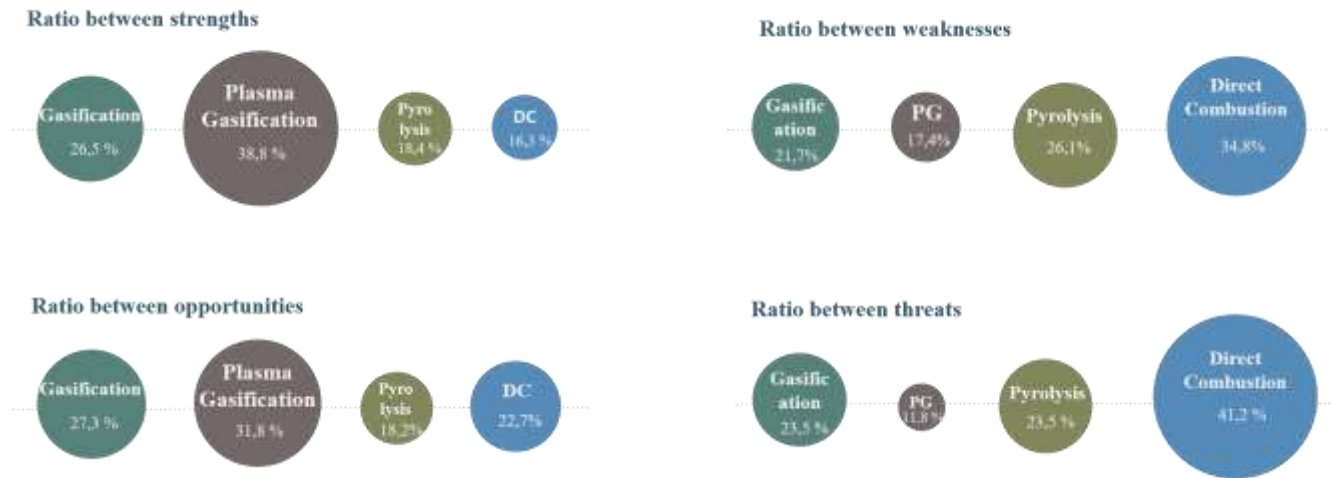


Figure 2 Ratios between strengths, weaknesses, opportunities and threats for direct combustion, pyrolysis, gasification, plasma-based gasification

Figure 2 presents ratios between strengths & weaknesses and opportunities & threats for direct combustion, pyrolysis, gasification and plasma-based gasification. The ratio between the sizes of the circles visualizes the percentage ratios of the individual technologies in their four sides.

C. Ratio between SWOT sides

The ratio between the four sides of the SWOT for each of the studied technologies is also determined. Results are presented in Figure 3.

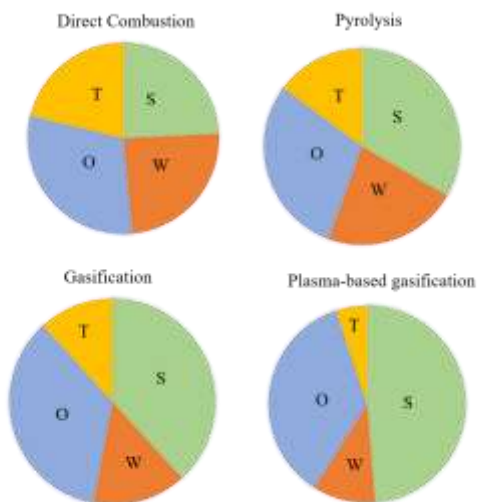


Figure 3. Ratios between S & W & O & T

D. Discussion

Currently in Bulgaria MSW is treated mainly by mechanical treatment and/or mechanical-biological treatment for obtaining recyclable materials and refuse derived fuel

(RDF). Presently, RDF is utilized as fuel mainly in cement industry. In addition a project is being implemented in Bulgaria for utilization of 180 000 t/yr RDF by grate-type combustion process, ensuring combined heat and power production with high level of efficiency. The heat will be supplied to Sofia's district heating network and the electricity will be fed into the national grid [7].

According to the literature survey direct combustion or incineration is the most widely applied technology [1].

Non-incineration thermal treatment technologies have been defined as technologies with greater potential for energy and materials recovery, with reducing of hazards emissions and other waste problems [6]. Both non-incineration and incineration thermal treatment technologies continually undergo development [6]. The possibility of future restrictions on EU sets for emission limit values (ELV) let some waste management companies and local authorities to choose gasification process, because of possibilities for achievement of tighter requirements for NO_x emissions [6]. In addition, advanced thermal treatment, which exclude direct combustion, promise better recovery of resources [6]. WtE incinerators also have undergone improvements, focused on improvement of flue gas treatment, which could fulfil more strength requirements of ELVs [6]. High energy efficiency in combined heat and power production is also priority in WtE incinerators. Development of WtE incineration is focused on low-oxygen combustion process that could increase the potential for efficient recovery of energy and materials, avoiding hazardous emissions [6].

IV. Conclusions

A comparison of strengths, weaknesses, opportunities and threats of each technology have been made.

It is established that plasma gasification has the greatest strengths – in comparison with the other three technologies it is found that this one have the most environmental benefits, with the highest energy production to the grid [5]. The weaknesses of this technology is the limited operating experience and high operating costs [2].

It is established that direct combustion has the most weaknesses, primarily because social disapproval, air emissions, hazardous residues. On the other hand direct combustion is widely applied and solution must be sought for mitigation of weaknesses. This can be achieved through development of innovative biotechnological solutions for bioremediation and reduction of toxicity of hazardous ashes, development of bioremediation complexes for minimization the impact of air pollutants and GHG emissions, leaching of metals from slag and ash, which would lead to a cleaner environment.

Both pyrolysis and gasification may be used for recovering of chemical value. Pyrolytic oil may be used as energy source and pyrolytic char could meet the specification for external use after some treatment processes [4].

Plasma-based gasification has the most opportunities, because of non-leaching vitrified slag, as well as opportunities for different types of chemical or biochemical utilizations of syngas into products, which is also strengths opportunities of gasification [5].

Acknowledgment

This analysis and evaluation scheme are supported by the Grant № BG05M2OP001-1.002-0019: "Clean Technologies for Sustainable Environment - Waters, Waste, Energy for a Circular Economy", financed by the Science and Education for Smart Growth Operational Program (2014-2020) and co-financed by the European Union through the European structural and investment funds.

References

- [1] A. Bosmans and L. Helsen, "Energy from waste: Review of thermochemical technologies for refuse derived fuel (RDF) treatment", Proceedings Venice 2010, Third International Symposium on Energy from Biomass and Waste Venice, Italy; 8-11 November 2010 by CISA, Environmental Sanitary Engineering Centre, Italy.
- [2] Marc J. Rogoff, Francois Screve, Waste-to-Energy Technologies and Project Implementation, Third Edition, 2019 Elsevier, Imprint: William Andrew Applied Science Publishers.
- [3] Paul Breeze, Energy from waste 1st edition, 2017 Elsevier, Imprint: Academic press.
- [4] Neuwahl, F., Cusano, G., Gómez Benavides, J., Holbrook, S. and Roudier, S., Best Available Techniques (BAT) Reference Document for Waste Incineration: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control), EUR 29971 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-12993-6 (online), doi:10.2760/761437 (online), JRC118637.
- [5] <http://www.b-t-einc.com/waste-municipal-waste-to-energy.htm>
- [6] Les Levidow and Paul Upham, Socio-technical change linking expectations and representations: Innovating thermal treatment of municipal solid waste, Science and Public Policy, 44(2), 2017, 211–224

doi: 10.1093/scipol/scw054, Advance Access Publication Date: 29 September 2016, Oxford Article, Published by Oxford University Press

- [7] https://ec.europa.eu/regional_policy/en/projects/Bulgaria/cogeneration-unit-in-sofia-to-produce-heat-and-electricity-from-refuse-derived-fuel
- [8] Ana Ramos, Carlos Afonso Teixeira and Abel Rouboa, Environmental Assessment of Municipal Solid Waste by Two-Stage Plasma Gasification, Article, Published: 1 January 2019, Energies 12.1 (2019): 137, Licensee MDPI, Basel, Switzerland
- [9] <https://www.explainthatstuff.com/plasma-arc-recycling.html>