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MATERIAL RECOVERY AS AN OPPORTUNITY OF IMMEDIATE INTRODUCTION OF ECO-FRIENDLY TRANSPORT SYSTEM (VEHICLES)

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Abstract

The article presents an analysis of the need to introduce pro-ecological solutions at the fuel sector of industry, resulting from dynamic economic development, and environment protection requirements. The forecasts on the number of vehicles in the world and the subsequent growth of interest in alternative fuels are presented. The advantages of using these fuels as compared to petroleum fuels and electricity are described. The presented analysis emphasizes the context of EU legislation on environmental requirements. At the same time, it was pointed out the need to obtain the required technical and energy characteristics of alternative fuels, the competitive costs of their production, and important environmental aspects. Taking into account these premises and the principle of circular economy closed circuit, alternative fuels from organic waste, in particular from enormous amounts of organic non-biodegradable wastes (packaging, multi-material fabric, rubber, tires) were proposed. It has been shown that thermal decomposition by thermolysis, described briefly in the article, can be a method suitable for a wide economic application within the alternative fuel production system. Based on literature data and own experience, it has been found that the quality of fuels (oil, gas) obtained from the thermal decomposition of organic and mixed waste is not different from the requirements for the best quality raw materials used in the production of petrol and may even exceed the properties of petroleum. Introduction of the system of regional production and distribution of alternative fuels from waste could be remarkable driver of small towns and rural areas revitalization and development, while supporting build up and improvement of local communities.

Keywords: *road transport, material recovery, environmental protection, thermolysis, alternative fuels*

1. Introduction

Dynamic economic growth causes a great increase in demand for raw materials and energy. Today, car transportation is based primarily on fuels made of fossil hydrocarbons. An increasing public awareness about environmental protection has been a driver for the development of alternative sources of vehicle power. Environmental and health requirements have led to the introduction of more stringent emission standards for motor vehicles and industry. The change of ecological attitude has also contributed to the so-called. Energy crises, related to the shortage of hydrocarbon fuels or the rise in market prices of crude oil. The rapid increase in fuel prices, triggered by the political and economic events of the Seventies, has resulted in a sudden end to the inexpensive supply of fossil energy resources. The Rome Report, published in 1972, gave the world a sense of the scarcity of natural resources, particularly oil and coal.

In the 80's and 90's, mature and environmentally friendly waste management projects were developed in the United States and in Eastern Germany and the first efficient recycling systems were introduced. Pioneering technologies for the processing of polymeric waste (plastics) and elastomers (tires) have been proposed for material recovery and energy (fuel). The devised methods have not been so far competitive with coal and petrochemical industries. It is only the overall treatment of energy and transport as components of the economy and of environmental, health and climate change policies that give positive results in the economic balance.

The need to find solutions other than petrol powered engines, or diesel and the introduction of new fuels, in particular low-carbon and emission-free technologies are becoming increasingly urgent. Car manufacturers are forced to produce more environmentally friendly vehicles to meet growing environmental requirements. For this reason, there has been an increased interest in vehicles driven H2, EV and HEV and other alternative fuels.

In the near future, engines fuelled with traditional petroleum derivatives will not be able to meet the emission standards. Although the engines are becoming more reliable, safer and more efficient, these benefits are reduced by the rapid increase in the number of vehicles. According to the International Energy Agency, 634 million vehicles travelled around the world in 1996, which represents an increase of almost 30% within a decade. These vehicles emitted a total of 3.7 billion tons of CO_2 [6]. Fig. 1 presents the forecast growth in the number of vehicles in the world, clearly indicating the existing trends.

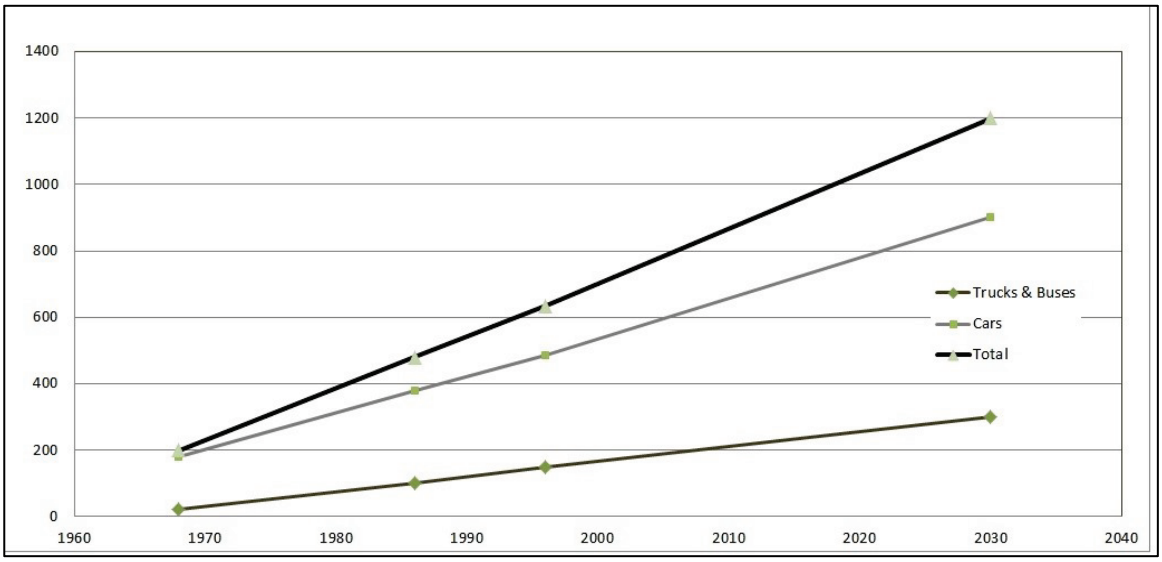

Fig. 1. Forecast of growth in the number of vehicles in the world [4]

2. Sources of alternative fuels

Rising ecological requirements stimulate the search for alternative energy sources and modern design of efficient drives. Research is directed mainly to the gradual reduction of the emission of harmful components – greenhouse gases hazardous to human health, such as carbon monoxide, sulphur dioxide, benzene, nitrogen oxides, formaldehyde, soot (particulate matter).

The introduction of alternative fuels and their research focus on gaseous and liquid fuels (Figure 2). The main emphasis is on fuels whose sources are not limited and resources are renewable as in the case of organic waste.

Over the next 23 years, by 2035, global energy consumption will increase by up to 30%, compared to an increase of 55% over the past 23 years. 95% of this growth occurs in the developing countries. BP experts in their "Energy Outlook 2017" predict that natural gas and hard coal will account each about 25% share of global energy stocks by 2035. Crude oil share will drop up to 30%, however the transport sector remaining to consume most of the world's oil with the share of global demand close to 60% in 2035. The rest of global energy consumption will fall by estimates for nuclear and renewable energy [8]. Dynamics of liquid fuel consumption growth by the end of century is comparable to the increase of renewables' use [1]. Figure 2 presents historical data of consumption and a forecast of global use of energy sources.

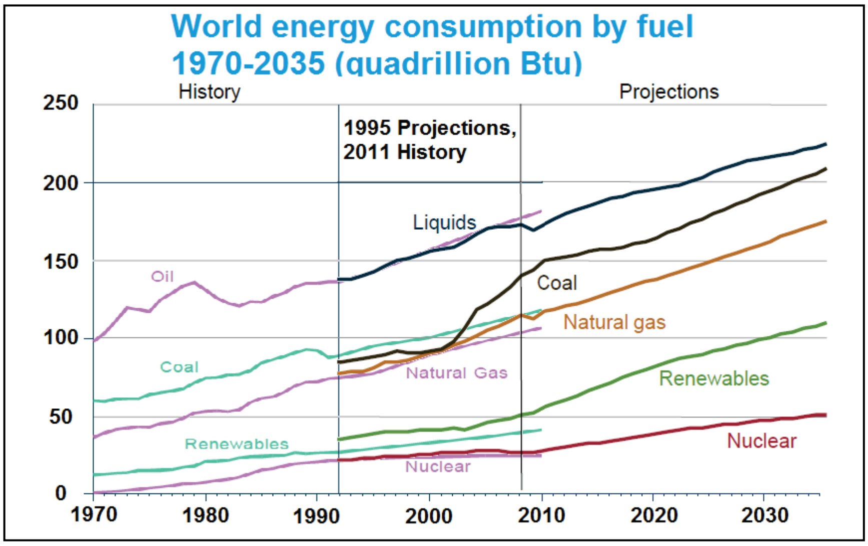

Fig. 2. Forecast of global use of energy sources (source: Wikimedia Commons, Delphi 234)

The advantages of using alternative fuels as compared to petroleum fuels and electricity include:

- increased national security (diversification of energy sources, import decoupling, minimization of supply risks, etc.) in the event of political and economic crises and tensions,
- limitation of consumption of fossil hydrocarbons and coal including hard coal, crude oil and natural gas,
- reduction of emission of carbon dioxide and other harmful emissions,
- reduction in municipal waste and industrial landfills.

Directive 2009/28 / EC of the European Parliament and the Council "On the promotion of the use of energy from renewable sources" do not indicate the products obtained from material recovery of waste as a source of renewable fuels. Alternative fuels are not products of petroleum processing, but must demonstrate the technical and energy similar characteristics, should be inexpensive to manufacture, formed in large quantities, and also pose less of a threat to the natural environment than conventional fuels (i.e. Carbon footprint).

The production of alternative fuels (Fig. 3) from waste as compared to petroleum derivatives has several important advantages:

- diversification of energy sources (energy independence),
- the possibility of production from local available resources, among others, from postconsumer waste, agriculture and farming waste,
- reduced emission (reduction of toxic emissions),
- lower transport costs,
- economically justified waste management.
- minimizing the negative environmental effects of their acquisition, treatment and development.

On 29th March 2017, the Council of Ministers of Poland adopted a strategy for the development of alternative fuels infrastructure through the "National Framework for Alternative Fuels Infrastructure Development Policy". This document is crucial for supporting the development of the market and infrastructure for electricity and natural gas in the form of CNG and LPG, used in road transport and in water transport. In addition, the objectives of the National

Policy Framework are consistent with the “Electro-mobility Development Plan”. Although there are some other resources, omitted from the strategy which application for fuel production would affect the environment improvement, and be economically justified. The fastest and most economically feasible is the introduction of alternative hydrocarbon fuels produced from non-biodegradable organic waste (polymer, elastomer and multifunctional fabric material) and their use in currently manufactured vehicles with internal combustion engines.

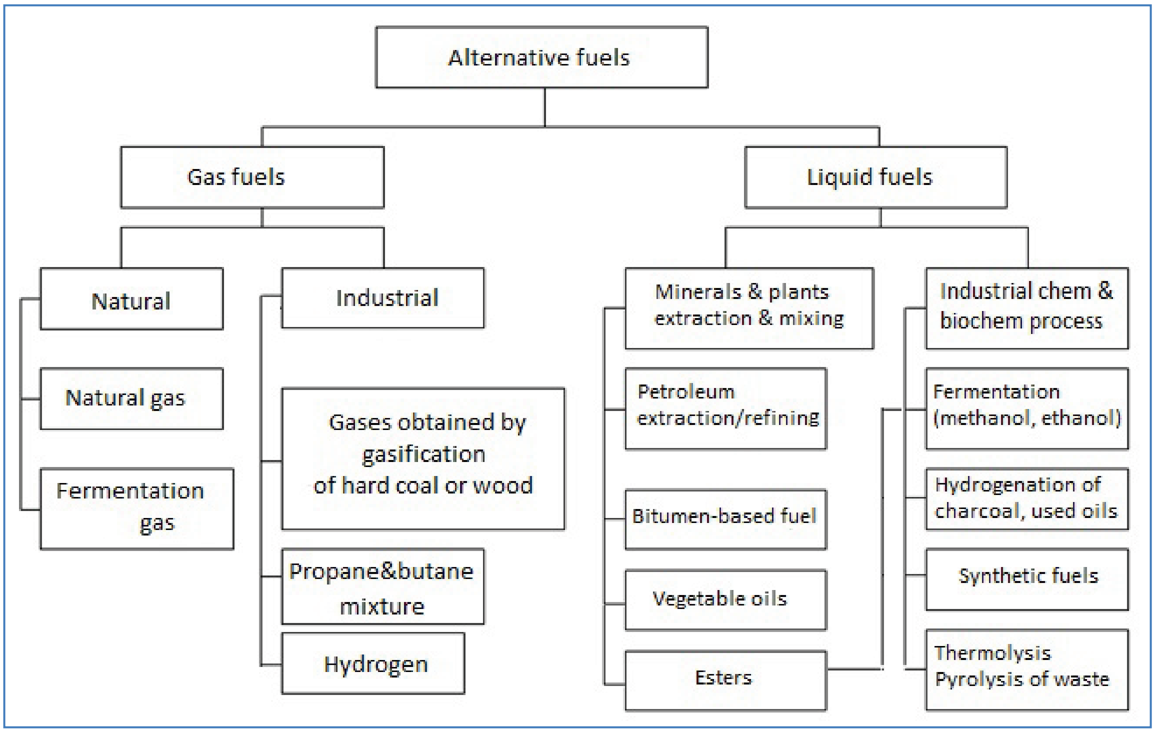

Fig. 3. Types of alternative fuels used in combustion engines (based on [3])

3. Fuels for transportation

For decades, the development of the automotive industry has a dominant influence on the progress in both technology and environmental protection. Competition and customer requirements both with the newly created European Union regulations impose on the car manufacturers specific environmental requirements:

- facilitation of ELV disposal (material and product recycling and recovery),
- reducing emissions of harmful combustion products,
- use of alternative power sources,
- reduction of particulate emissions from combustion systems and friction couples.

Currently, the most popular alternative fuels or technologies for powering vehicles in advanced stages of development include:

- additives of ethanol and esters of vegetable oils for traditional fuels,
- gas installations for natural gas, propane-butane or liquefied petroleum gas (LPG) and CNG (Compressed Natural Gas),
- biofuels, biogas (mainly ethanol and bio-methane),
- P-Series fuels (blend of ethanol, natural hydrocarbons and methyl-tetra-hydrofuran (MeTHF), a co-solvent derived from biomass),
- hybrid (combustion-electric) propulsion systems,
- hydrogen systems and hydrogen fuel cells (HIT – Hydrogen Infrastructure for Transport),
- synthetic fuels, synthetic naphtha, dimethyl ether, ammonia, flammable industrial gases (light, water, generator),

– electric photovoltaic cells, supercapacitors, Li-I, Me-H batteries, etc.,
– alternative fuels from organic waste (post-process oil and gas),
– pneumatic drive.

The needs of the environment and health care require that ecological solutions in car transport should be implemented effectively. The re-introduction of large-scale electric vehicles has been going on for more than thirty years. EV passenger car prices are difficult to accept for the mass market. Prices of Tesla cars range between 70-100 thousand EU. The city cars: Nissan e-NV200 and Mitsubishi i-MiEV – cost about 25 thousand EU. From the point of view of urban dwellers, electric vehicles do not emit any pollutants in use. However, due to the technology applied and the significant use of rare earths, the process of producing electric vehicles generates much more pollutants than it does with combustion engines. The electric car when released is responsible for the emission of about 14 Mg CO_2, and the diesel car more than twice as low as 6 Mg CO_2. In addition, in countries where most electricity comes from coal, the electric car will be responsible for the same amount of CO_2 as a petrol vehicle throughout its lifetime. Only in countries with the majority of nuclear or renewable energy an electric car will emit 24% less CO_2 than a car with an internal combustion engine. The share of electric cars in the market is negligible – 2.4% for hybrid cars and 0.1% for EV cars or hybrid plug-in, which has recently changed drastically in favour of electric vehicles.

The waste management requirements and the plan for the implementation of the Circular Economy (Closed-loop Economy) in the EU introduce the need for full utilization of waste from end-of-life vehicles (ELV). Raw materials used for the production of alternative fuels from ELV include worn tires (elastomers), plastics (polymers), wastes of operating fluids (e.g. mixtures of used oils, fuels), textiles, wood, foams etc. The average share of materials in car production is shown in Fig. 4.

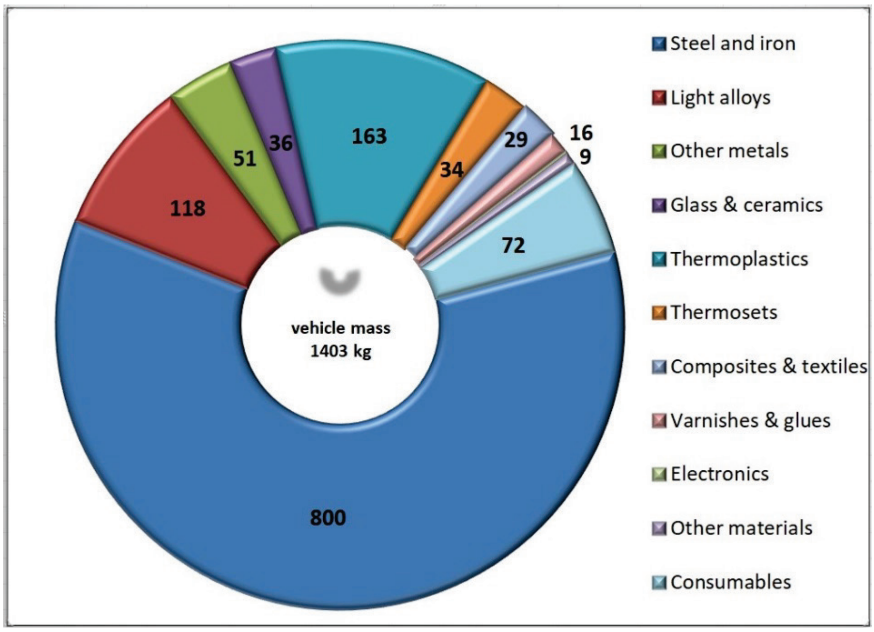

Fig. 4. Average share of materials in passenger car production [2]

4. Methods and products of waste materials processing

Waste processing technologies that meet requirements are based on methods of thermal decomposition of large molecular organic materials, in particular catalytic cracking, thermolysis/pyrolysis and gasification of organic materials. Methods of thermal treatment of organic and mixed waste are presented in Fig. 5.

Due to relatively low thermal energy demand, the thermolysis is high efficient process for a wide range of economic applications in the alternative fuels production system (at least 50% by weight of oil is obtained). So far the thermal decomposition of automobile tires is the most developed and widely applied because of the high-energy value of the base material (SBR – styrene-butadiene copolymer), and due to the absence of adverse or harmful components, especially the halogens and their homologues. A comparison of the energy value of tires over materials traditionally used as fuel is shown in Table 1.

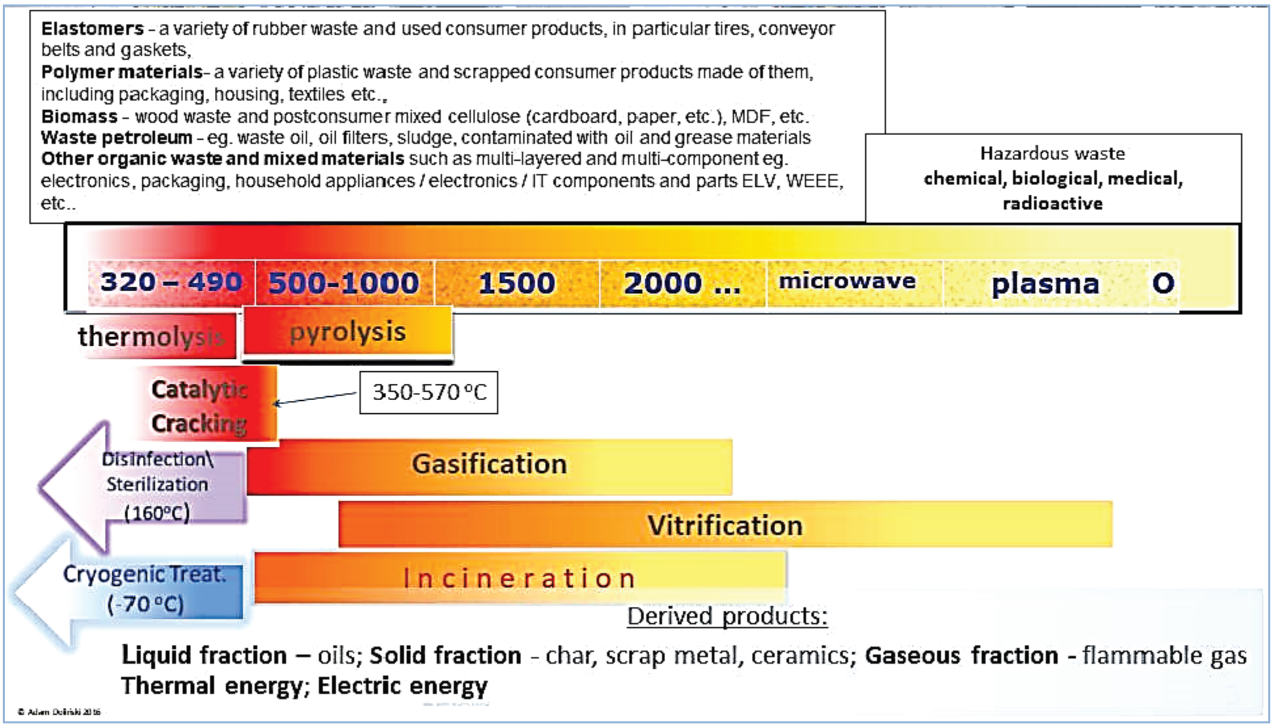

Fig. 5. Methods of thermal treatment of organic and mixed waste [2]

Tab. 1. Energy value and CO_2 emissions of selected fuels [7]

Fuel type	Energy value [GJ/t]	CO_2 emission [kg CO_2/t]	Unit emission [CO_2/GJ]
Tires	25.0-35.0	2.72	85
Hard coal	27.0	2.43	90
Petroleum coke	32.0	3.24	100
Petroleum	46.0	3.22	70
Natural gas	39.0	1.99	51
Wood	10.2	1.12	110

Acquired alternative fuels, which can be considered as substitutes of ones produced from crude oil should meet the following requirements:

– be produced in sufficiently large amounts to meet social needs,
– have technical and energy characteristics that determine their suitability to power car engines,
– be less threat to the natural environment than traditional fuels,
– be inexpensive in production, distribution and sales,
– provide required engine performance and safety indicators.

Currently the most preferable is material recovery by thermal processing of polymeric and elastomeric waste. In the process thermal energy supply results in degradation of the material structure, involving the breaking of polymeric chains or thermoset networks. The low temperature thermal decomposition called thermolysis takes place at range of 320-490°C in the reactor with no access of atmospheric air. Vapours of different hydrocarbons formed during thermal decomposition of macromolecules are mixtures of aliphatic and aromatic hydrocarbons of various particle mass. The process consists of two successive stages: vapour formation and condensation of evaporated products. During the stage of the vapours' condensation, hydrocarbon vapours can be divided into two or more fractions, depending on selected temperatures of liquefaction. The lightest fraction is a mixture of gaseous hydrocarbons pumped out and collected in the dedicated vessel. The products of thermolysis are chemically similar to diesel or heating oil and bio-methane gas. The physico-chemical properties of the oils obtained by thermal decomposition of car tires compared to petrochemical products are presented in Table 2. Data ranges placed in the fifth column of the table covers measurement results of products sampled from several thermolysis processes in 2014-2017 years, taken independently by certified laboratories, i.e. Oil and Gas Institute NRI, ORLEN Lab Ltd., Tesmo Ltd., Pachemtech Ltd. Laboratory.

Tab. 2. Results of examination of thermolysis oil compared to diesel and fuel oil properties and waste oils characteristics

Examination standard/ Property	Diesel oil requirements by Minister of Economy regulations	Heating oil requirements by standard PN-C-99024:2011	Fuel oil by standard PN-EN 590:2013	Research results oil from thermal decomposition of car tires	Reg. Minister of Economy of Oct. 5, 2015 on the detailed way of dealing with waste oils (Journal of Laws of Oct.23, 2015, item 1694)
PN-EN ISO 12185 – Density in temp. 15°C [kg/m^3]	820-845	860	820-860	875-916.7	870-930
PN-ISO 6296 – Water content [% m/m)]	max. 200 mg/kg	2	2	0.03-0.100	10.0%
PN-EN ISO 3104 – Kinematic viscosity at 50°C [mm^2/s]	1.5-4.5	6 6.171 (temp. 20°C)	2-4.5 3.612 (temp. 40°C)	1.494-3.524	-
PN-EN ISO 2592 – Flash-point [°C]	above 55	56	55	below – 79 (14°C-44°C)	below 56
PN-EN ISO 2592 – Melting point [°C]	-	-20	-	below – 57 (-39°C-16°C)	-
PN-86/C-04062 – Calorific value [kJ/kg]	-	42600	42000-44000	38328-40690	-
PN-86/C-04062 – Heat of com-bustion [kJ/kg]	-	-	-	39704-42709	-
PN-EN ISO 6245 – Residue after combustion [% m/m)]	0.010	-	0.010	0.002-0.004	-
UOP 779-98 – Chlorides content [mg/kg]	-	-	-	196	0.2%
Sulphur content [% m/m)]	-	0.1	0.1	0.30-0.67	1.0%

The gaseous fraction of thermolysis products has a composition similar to biogas, and it can be applied as a fuel for gas burners heating the thermolysis reactor. The result of composition analysis of the gas obtained through decomposition of automobile tires is presented in Table 3.

Tab. 3. Comparison of thermolytical gas and biogas

Type of gas	Typical biogas composition [7] [%]	Composition of thermolytic gas tested [%]
Hydrocarbons	52-85	57.7
Carbon dioxide	14-18	167.
Carbon monoxide	0-2.1	6.7
Nitrogen	0.6-7.5	not found
Hydrogen	0-5	not found
Hydrogen sulphide	0.08-5.5	not found
Oxygen	0-1	not found

In the era of sustainable development and continuous reduction of the environmental impact of transport, other gas products, which are waste products of industry and thermochemical processing of carbon materials, can be considered as an important source of alternative fuels. Table 4 summarizes the fuel properties of different gas produced industrially.

Tab. 4. Characteristics of selected gaseous fuels [7]

Gas fuel	Density under normal conditions [kg/m^3]	Fuel calorific value [MJ/m^3]	Stoichiometric heating value. [MJ/m^3]	The stoichiometric oxygen-fuel ratio [%]	Coefficient λ at lower flammability limit	Octan number LO_M (LO_B)
Metane	0.655	36	3.4	19	1.88	110(140)
Propane	1.800	83	3.3	20.2	1.96	95
Butane	2.370	110	3.4	20.3	1.83	92
Natural gas	0.695	34.7	3.4	18.9	2.10	100-110
Coke oven gas	0.468	13	3.35	-	-	95
Generator gas	1.015	5.65	2.6	10.9	4.35	105
Urban (light) gas	0.614	17	3.25	16.9	2.50	90
Fermentation gas	1.200	24.2	3.2	18.2	1.94	110
Propan&butan mixture 50% / 50%	2.080	96.5	3.35	20.25	1.91	95(100)

5. Fuel from Waste – the competition for petrochemicals

Natural energy resources such as oil and coal and natural gas gradually run out and make more and more difficulty in obtaining them from natural deposits. At the same time, the amount of waste to be deposited in landfills is rapidly growing. The depletion of oil and natural gas as well as increasing demands for environmental protection enforce research on fuels that could replace the previously used.

The alternative fuel obtained from waste may be many times less expensive compared to conventional fuels of a similar calorific value. The noteworthy feature of these fuels is the wide possibility of modelling their composition at the stage of the thermo-chemical process, as well as the elimination of costly purification of the petroleum, so- “Rock oil”, from toxic and non-combustible components. Currently, the process of mixing fuel with additives that eliminate the effects of thiols, phenols, naphthols, contained in petroleum burden the environment and it is significant component of fuel production cost. This operation is not required for fuels made by method of elastomers and polymers thermal destruction. On the other hand, recycling of waste into a high-demand product will allow for faster implementation of key environmental objectives (reducing environmental degradation, reducing emissions, disposing of dumps), as well as increasing security through diversification of energy resources. To meet this goal should significantly be increase energy efficiency and cost of existing methods, developing new fuel production systems, more tailored to regional needs and opportunities (diversification) in contrary to the existing system, which depends on the concentration of resources and simultaneous divergence and dissipation of the total cost throughout the world. Global circuitous system of mining, transportation, processing, storage and distribution of fuels can be supplemented and eventually replaced by a more effective and less environment aggravating system of regional production and distribution of fuels from waste.

The change in strategy towards sustainable development of the fuel sector of economy will be very difficult to achieve, as the present global economic system, developed and improved in the twentieth century, is based on the extraction of fossil fuels and production and distribution of fuels. It is a major source of income for many countries, international oil companies and automotive industry. At the same time, the system was and still is the cause of the creation of monopolies and oligopolies, distorting free economy rules and weakening budget revenues. The system has been a root cause of many economic and political conflicts that deplete the population and threatening international security. While maintaining the energy system and transport at every level of society on the basis on the continuous and far-distant access to raw materials, transported through and around the entire continent, is a risky undertaking, as well as dangerous for the environment. Failures pumping systems and tankers were often the cause of environmental disasters. Leaks in disrepair oil and gas pipelines cause continuous poisoning ecosphere. Armed conflicts, acts of terrorism, natural disasters cause disruption of supply of fuel desired for transport of goods and for modern communities to function.

Systems based on locally available raw material, which is postconsumer waste do not have these disadvantages. Production of fuels from waste will allow the regionalization of energy sources for transport and electricity; will reduce dependence on political decisions, thereby increasing the energy security for people. Moreover, the system brings environmental benefits, saving natural resources and helping to tackle the problem of non-biodegradable waste management as well as supporting measures to reduce greenhouse gases emission.

The production of fuels from waste in the regional waste treatment plants will have a significant impact on economic development. In particular, it will reduce costs by shortening supply chains and by eliminating central maintenance, trade and logistics. Furthermore, it will significantly reduce fuel prices, which in turn will cut down operating costs of local business. New technologies and new workplaces will boost employment in the regions. They reduce the social and financial costs of labour migration to large cities. There will be economic revitalization of rural areas and small towns. While maintaining the existing forms of distribution will be pro immediate introduction of environmental solutions for transportation. This lets enter alternative fuels produced from waste to a group of c limate-neutral fuels.

Climate neutral fuels are characterized by the absence of positive balance of greenhouse gas emissions and reduced carbon footprint, without causing increase of greenhouse gases in the atmosphere. This includes synthetic fuels such as methane, gasoline, synthetic diesel or aviation fuel – produced from renewable energy sources, including the hydrogenation of carbon dioxide recovered from engine and industrial exhaust. If the climate neutral fuels are to replace fossil fuels or if they are produced from waste containing carbon either with applying carbonic acid contained in seawater, their combustion will take place with the participation of carbon sequestration, as a result a negative balance of contents of carbon dioxide in the atmosphere is reachable. Consequently, gradual removal of carbon dioxide from the atmosphere will begin. There will be a start of remediation process of the atmosphere from greenhouse gases [5].

Fuels from waste are competing for petrochemical products and an alternative of electric-powered transport, in particular in emergency and crisis interference, especially when supplies of fossil fuels and electricity are disrupted.

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