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Review Article

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Green Technologies in Polish Energy Sector - Overview

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Abstract

Green technologies presented in Polish power generation are based on biomass. Poland has considerable potential for biomass produced using forest, agricultural, and municipal waste. Currently biomass is used in several hundred power stations, co-incineration of biomass with coal powers 39 CHP and power plants. The largest establishments producing bioethanol are located in Starogard, Gdański, Oborniki, and Wroclaw. The largest producer of biodiesel is the Trzebinia Refinery S.A., located in the villages of Surochów, Tychy, and Malbork. Through cogeneration with biogas electricity and heat are produced in 76 water treatment biogas plants, 94 biogas plants on municipal waste landfills, and 29 agricultural biogas plants. In the near future Poland expects further development of bioenergy technologies.

Keywords: Green technologies; Bioenergy; Biomass; Poland

Introduction

The development of humanity and the world economy is closely tied to the use of energy. The oldest form of heat energy was derived from combustion of wood, plants, or dry fertilizer. A little later the man began to harness light energy in the form of an oil lamp and a torch. About 3 thousand BC began the use of wind power (sailboats and windmills), water energy was applied by the end of the antiquity era (water wheel). Charcoal obtained in the process of pyrolysis has become the primary source of energy for what was then called the metallurgy [1].

The rapid development of industry and energy has been observed for about 250 years. Key factors in these developments were:

- The invention of the steam machine in 1769 and the utilization of coal for drive.
- Construction of an internal combustion engine in the 19th century, which contributed to the rapid development of motor transportation and the increase in fuel consumption.
- The discovery of large natural gas deposits, which were used as fuel and raw chemical materials.
- Production of electricity [1].

Energy sectors worldwide, including the Polish energy sector, stand currently in front of large challenges. High demand for energy, inadequate level of infrastructure development for manufacturing and transport of fuel and energy, and dependence on external supplies of natural gas and oil. This dependence on external supply comes with obligations regarding the protection of the environment; including climate change and the need to take decisive action to prevent the deteriorating situation of the recipients of the fuel and energy [1,2].

According to the Polish energy policy in effect till 2030, the political direction of Polish energy policy is [3].

- To improve energy efficiency.
- Increase in fuel and energy supply security.
- The diversification of the structure of electricity generation by introducing nuclear energy.
- The development and use of renewable energy sources, including biofuels.
- Become more competitive on the fuel and energy market.
- Reducing the impact of energy production on the environment.

The article shows the ecological projects implemented in the Polish energy sector over the past years. They are designed to improve energy efficiency and reduce the nuisance to the environment through the introduction of renewable energy. The article focuses on biomass, which represents 85% of renewable energy in Poland.

Polish Energy - History, Current State and Problems

In Poland until the mid-19th century wood was the primary source of raw material used for energy. It was mainly used for heating, drying, and preparing meals. At the end of the middle ages windmills and water mills became increasingly popular which mainly served to grind cereals [1].

An important breakthrough in large-scale energy use was made in the 18th century through the use of coal, also related to the metallurgical industry developing, as well as the use of coke for iron and zinc smelting. During the second half of the 19th century crude oil emerged as an energy source that was followed with the invention of the oil lamp by Ignacy Łukasiewicz and the discovery of an oil refining method. In 1854, Ignacy Łukasiewicz in Bóbrka built the first oil well [4].

The first gas plant that generated coal gas was constructed in the second half of the 19th century in Poland. Into the last years of the 19th century the first electrical generators were built with low power capacities which were installed at power stations and industrial plants. Generated electricity was initially mainly used to illuminate the city. Several professional plants emerged with the beginning of the 20th century in big cities [1].

After World War 1, engineering of electrical power quickly began. Small coal and hydro power plants arose in large numbers. In 1938,

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38 million Mg of coal were mined which allowed Poland to achieve 7th place worldwide. Along with the production of 3977 GWh of electricity, 584 million m^3 of natural gas and 507 thousand Mg of oil were excavated that was processed in 27 Polish refineries. Contemporary Polish energy was overwhelmed. In 1938 electricity was generated with 3198 units fueled by coal, biomass, and water [1].

The early years after World War II, the effort started to rebuild power plants or build new ones, very large coal-fired units. Unfortunately, most small hydro power plant fell into disrepair. Peak coal mining took place in 1979 and reached 201 million Mg. As a result of the recession and the introduction of energy - efficient technologies, coal mining dropped to 142 million Mg in 1990, and 102 million Mg in 2000 (decreased export of coal). Over the last 30 years consumption of electricity in Poland is at a similar level (140-145 TWh) [1].

The location of the plant depends primarily on the presence of coal Figure 1. One-third of Poland's energy comes from coal mining based in *Górnośląski Okręg Przemysłowy*, where the most important power stations are Rybnik and Jaworzno. The second factor is a close proximity to a water source for cooling purposes, the larger the power plant the greater the amount of water is needed for cooling. For this reason power plants are located near large volume rivers, like power plants in Połaniec, Kozienice, and *Ostrołęka*. The power plant in Bełchatów supplies 20% of domestic electricity using lignite coal as fuel. Turow, Konin, Adamów, and Pątnów have a great influence as well [1].

Hydroelectric plants such as *Żarnowiec, Porąbka-Żar, Solina, Włocławek*, and *Grzybowo* produce a significant amount of electricity. In addition it is note worthy that in recent years more and smaller hydro power plants (small capacity) are being built, located near small water sources. Also in recent times there has been an increase in the use of wind energy. In Poland there are currently more than 600 wind *mills* mainly in the northern and north-western part of the country [5].

A major concern of the Polish energy sector is a large consumption of currently active blocks. A significant number of them have been operated for more than 40 years. Competitive considerations and ecological requirements mean that by the year 2020, 80% of existing blocks should be replaced [4].

The classic approach to economic evaluation includes internal costs- Investment costs, the cost of fuel, and Operating costs. In the Polish energy sector there is practically no concern about external costs associated with the production of energy from conventional fuels. In the case of coal energy; significant external costs are associated with coal mining. The production of electricity in Poland is associated with the work of thousands of miners. In addition to the direct threat (e.g. methane explosion), they are exposed to inhalation of coal dust, and this leads to pneumoconiosis [6]. Mining exploitation and operation construction is deforming natural geological structure and terrain; this also compromises the level of groundwater and surface water, also chemicals pollute the soil and vegetation cover. Open cast mining is causing devastation to the land; furthermore the draining of water is the cause of sinking groundwater and surface water. In 2010 the Polish lignite coalmines drained more than 505 million m^3 of water, which flows to the Baltic Sea or evaporates. The problem deepens because of the country's aridity and very small water resources; in fact Poland is comparable to Egypt.

A hallmark of the Polish is burning large amounts of coal in household furnaces for heating purposes. Every year about 10 million Mg of coal are burnt without any filters or emission reducing equipment. Turning to the most important pollutants emitted into the atmosphere by conventional power plants include dust, SO_2, and NO_x. Air pollution particles of dust shall entail an increase in morbidity and mortality. The most dangerous faction of dust; are the tiny particles with a diameter less than 2.5 μm (PM 2.5) which penetrate through the natural respiratory system filters and settle deep in the lungs. It causes serious respiratory organ diseases, including lung cancer. Unfortunately, these fine dust particles penetrate easily through the exhaust filters installed for the flue gases from thermal power plants based on coal. Along with dust there are also heavy metals emitted. Elements such as lead and mercury are also emitted into the atmosphere and can cause lasting health damage such as arsenic, beryllium, and cadmium is also carcinogenic [7].

For several years Poland has been producing energy from solid biomass, liquid biofuels, and biogas. This is especially of great importance in the north of Poland, where there are no deposits of coal and lignite.

The Use of Solid Biomass for Energy Purposes

Poland makes 85% of its renewable energy through incineration or co-incineration of biomass. Forest and agricultural biomass waste are used for energy purposes.

Solid biomass resources

Poland has a large resource of biomass. Straw, cereal, rapeseed, wastes from agro-food industries, and wood waste give the greatest potential for energy production. Significant amounts of waste wood are formed during the stretch and thinning of forests. Given that the 15% of this wood is waste wood (parts of core, small branches, and pieces from workers), meanwhile in Poland approximately 2 thousand m^3 of wood is sufficient for a year's energy supply.

A major amount of biomass waste is formed in the lumber industry, saw mills, furniture industry, the paper industry, and cellulosic. Another source is post-consumer wood. Until recently, post-consumer wood in Poland went mostly to landfills. Now, increasingly, it is used for wood energy purposes, mainly to produce heat. Most of it is wood used during construction, remodeling, or building demolitions. Large quantities of post-consumer wood come from households and public institutions: furniture, fences, benches, gazebos, and etc. An important source of post-consumer wood in Poland is packaging (mainly used in trade and transport). Wood produces boxes, cages, baskets, barrels, and pallets. Life span of wood products range in Poland from several weeks (baskets, boxes, pegs), to several years (poles, furniture, windows, *etc.)*. It is estimated that yearly in Poland about 3 thousand m^3 of wood can be collected.

In Poland, energy willow plantations (Salix viminalis) are mainly established, but measures are being taken to attempt to use other energy crops. For example; in Nowy Dwór Gdański, there is a Virginia Mallow flower plantation (Sida hermaphrodita) which covers an area of 750 acres. The purpose of the plantation is for supply of bioenergy for the city heating plant in Nowy Dwór Gdański with a power capacity of 10 - 15 MW. The Agricultural Sciences Institute also cultivates the Virginia Mallow in Zamość. One hectare can yield from 12 to 17 Mg of dry weight. Virginia Mallow is also being tested as fresh biomass or silage for the production of biogas in the fermentation methanol process. There is various ongoing research on the Jerusalem artichoke (H*elianthus tuberosus*), Amur silver grass (*Miscanthus sacchariflorus* [Maxim] Hack), and Big bluestem (*Andropogon- gerardi*) [8,13,14].

In recent years, Polish agriculture has been dominated by the cultivation of cereal, from which straw is acquired for energy purposes.

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Crops like wheat, rye, and barley produce the largest harvest. Poland produces about 25 million Mg of straw annually. For decades straw was used mainly for livestock production, as a bedding material, and feed. It was also applied to cover mounds, for home insulation, and to prepare the mat in horticultural holdings. Since 1983 the straw harvest began to exceed the demand resulting from agricultural production. In the years 1983-1990 the average annual surplus in agriculture amounted to 5.3 million Mg and in the period between 1995-2010 it was already 10.9 million Mg. These calculations include the straw needed for plowing, in order to maintain the sustainable balance of organic matter in the soil. The straw surplus began the search for an effective way in which to manage its development [15]. One of the possibilities is to utilize straw in the energy field. Its calorific value ranges from 14.3 to 17.2 MJ/kg, which means that in terms of energy, 1.5 Mg of straw is about equivalent to 1 Mg of coal [16]. It is worth mentioning that Poland has 900 thousand ha of land set aside and 480 thousand ha of wasteland – some of them could be converted to grow energy crops.

Incineration and co-incineration of biomass

Production of heat through wood has a long tradition in Poland, especially when it comes to burning wood in an individual boiler with low power. The number of households equipped with manually loading boilers for wood is estimated at about 100,000, but their power is a mere few KW [17]. The largest biomass heating plants are located in the vicinity of Szczecinek, Barlinek, Brodnice, Morąg, Hajnówka, and Pisz. Pisz has the largest biomass boiler-room – 4 Polytechnik type boilers working together for a power total of 21 MW with an efficiency of 87.4% [17]. The boiler-room utilizes woodchips, shavings, chips-chips, wooden planks, wood edgings, sawdust, pallet pieces, and common osier willows. A similar type of biomass is consumed in the majority of boiler-rooms in Poland. An example of another fuel is the burning of cones as a surface biofuel, a method employed in Nadleśnictwo Białogard (near Szczecinek). Each year 300 - 400 Mg of cones is incinerated [8]. International Paper Kwidzyn S.A. is a plant involved in the pulp and paper industry, the plant has a sodium boiler, which burns away black liquor. The boiler has a thermal power of 204 MW. In combination with the production of heat, electricity is also produced. Poland also uses dried fruit seeds, cereal grains, and particularly oats. The cost of heating with grain is two times cheaper than using gas and three times cheaper than burning coal [8].

Exploiting straw as a fuel in primitive ovens to heat residential buildings in the village and even under the kitchen floorboards in poor rural family homes has been a hardship long endured by the Polish. The first straw boiler was launched in 1996, now there are dozens of them operating. In 1998, Lubań with their boiler of 1 MW capacity joined producers of thermal energy from straw. A system was applied in order to shred the straw and its transport enabled the moist straw to be burnt in the grate boiler. The introduction of the chain-conveyor between the straw shredder and the rotary valve feeder, in the place of the previously used screw conveyor, and this made work much easier especially because it also eliminated the phenomenon of transports with shredded straw being blocked [19].

In 2002 the city and community of Frombork acceded to the modernization of the traditional heating system in the city. In the modern boiler-room there have been two boilers installed with a capacity of 2.5 MW, and another 1.5 MW boiler. The entire heating network has been replaced; 6 km of new insulated pipes have been installed along with 69 modern heating nodes single– and dual-functional with controlled supply of heat if needed for central heating and warm water. Equipment was also purchased for transportation and loading of fuel (straw). Recently successful attempts were conducted with plants from energy plantations; such as Miskantor or Virginia Mallow, which can further improve organization and economic supply of fuel for boiler-rooms [20].

The municipal heating network in Grabowiec employs straw as fuel to power two boilers with a capacity of 550 KW, which were installed in 2005. The heating plant supports 7,000 sq m, and the annual production of heat is about 5000 GJ. Excess heat is stored in two water accumulation containers. Zakład Ułlug Komunalnych Gminy Ulhówek utilizes three straw boilers, with a total capacity of 900 KW–heating schools, kindergartens, and housing complexes. Functioning in Studzianki since 2003 is a straw fueled boiler with a capacity of 200 KW. The boiler-room in Bystrzyca has been in use since 2004, it has a capacity of 280 KW. In 2010, a boiler -room was put into service with a capacity of 900 KW, which heats the community building, health center, the culture house, and the shopping pavilions. In the winter season it burns from 900 to 1500 Kg of straw per day [21,22].

The first bubbling fluidized bed boiler in Poland, which only burns biomass on an industrial scale, was put into operation in 1997 at the thermal power station in Ostrołęka Figure 1 [23].

The boiler is the result of the modernization of the OP-100 steam boiler. The boiler produces steam with a capacity of 13 kg/s, at a temperature of 450°C, and a pressure of 4.0 MPa. The OKF-40 boiler was adapted to burn wood bark. As a result of change in fuel, fuel ash reduced along with removal. In addition, this investment has contributed to increased efficiency in combustion of about 5-7%. At the beginning of 2010 a biomass feeding installing was put into service in the power station. It is the largest such installation in Poland, it operates in a closed system with a direct feed of biomass into the boiler. The installation will allow an increase in the annual renewable energy production to a level of 600 GWh [23].

The power plant in Połaniec Figure 2 has been operating since 2004, co-incinerating of biomass with coal. In May 2006, the production of "green" energy had reached a level of 0.5 TWh. The primary

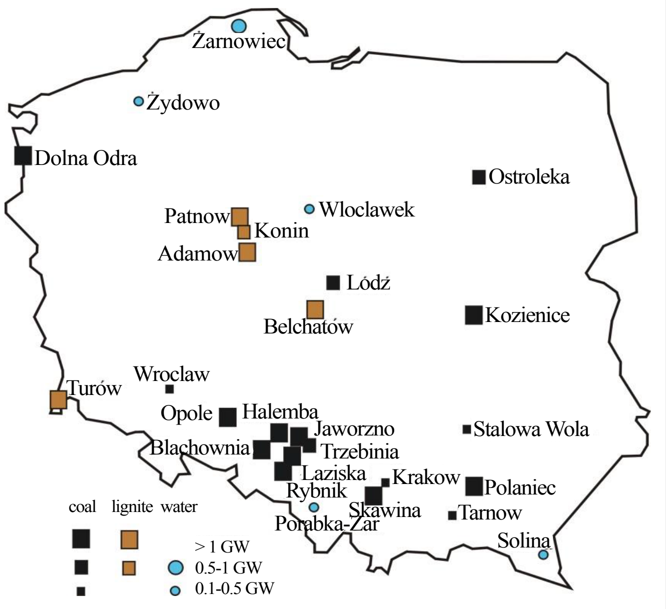

Figure 1: Location and the power output of the largest power plants in Poland.

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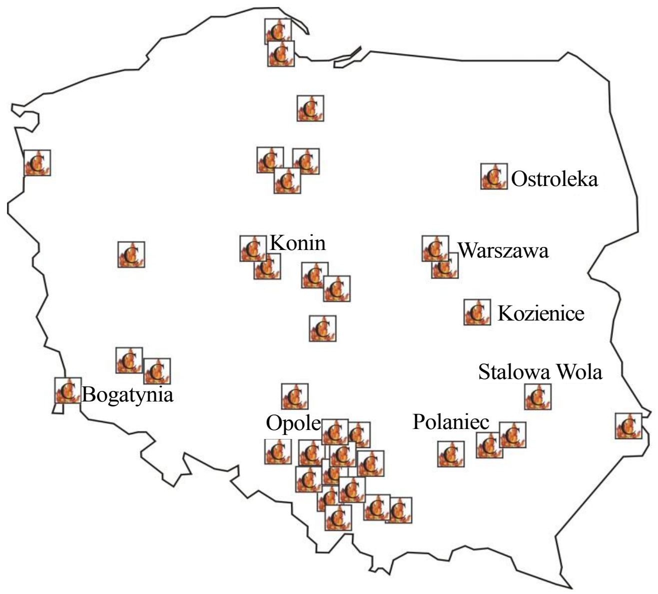

Figure 2: Power stations and thermal power stations \ co-incinerating of biomass with coal.

fuel, which is used in the process of co-incineration, is wood waste obtained through the National Forest Association from thinning and from sanitary cuts. Other types of biomass are dried raspberry, dried redcurrants, dried cherries seeds, sawdust briquettes, straw and willow shaving briquettes. Since 2010, in a power plant in Połaniec, the world's largest biomass energy block is being built with a capacity of 205 *MW* [8,12].

The Turow power plant in Bogatynia Figure 2 is equipped with a closed circuit water-cooling system. From July 2009, the Turow power plant has a working installation for co-incinerating biomass on the energy blocks; No. 5 and 6. For safe co-incinerating of biomass with lignite; forestry origin biomass, agricultural and energy crops was selected for a total of 180 Gg per year. In October 2011, the Turów power plant launched an installation that will allow co-incinerating of biomass in boiler energy blocks 1-4. A new installation with metering performance above 80 Mg biomass/h will allow the production of up to 9% of "green energy" on blocks 1-4, just as it has already done on blocks 5 and 6. Due to the inability to install biomass feeding installations in the Turów power plant for the needs of blocks 1-4, the purchase of ready biomass pellets harvested through agriculture and forestry waste. When the second installation becomes operational, its capacity will grown to about 240-260 Gg per year [12].

In 2012 the Szczecin power plant (Zespół Elektrowni Dolna Odra S.A.) was ready for operation as the biggest in Poland and one of Europe's largest fluidized boilers fueled by biomass; technological parameters: 230 t/h, 535°C, 70 bar. The production of "green" electricity is going to be 440 GWh/year, and the production of heat will be 1.9 TJ/year. Biomass consumption amounts to 550 Gg/year. Ecological effects achieved: zero CO_2 emissions, reduction of SO_2 emissions by 69%, reduction of dust emissions by 63%, reducing the amount of waste by 80%, compared to the current situation. In Table 1, it is shown how biomass will be provided for the power plant [25].

In May 2012, the power plant was synchronized with the National Energy System with the biomass block in the Konin power plant. The most important element of the block is the fluidized boiler "K9" with circulating fluidized bed, fueled by biomass for steam output of 215 Mg / h with a capacity of 154 MW. Buildings and associated facilities are all contributing elements of the technology. The main fuel consumed in the Konin power plant is a biomass composed of a blend of woody biomass and agricultural origin. The share of agricultural biomass in the total amount of biomass burned in Konin power plant is planned to be 20%. The primary fuel will be wood biomass with wood chips and sawdust from pine and leafy trees, wooden pallets, and bark as shavings [26].

The Kozienice power plant has 10 generating units with a combined installed capacity of 2820 MW and an attainable capacity of 2880 MW. Connected to the 110 KV and 220 KV network, including the two largest generating units in Poland rated at 500 MW operating on the 400 KV network. On blocks of 200 MW, co-incineration is realized through biomass with coal. Its share in the fuel is 10%. Biomass is administered applying an additional installation on carburizing strings. Then, the mixture of biomass with coal is sent to the boiler bunkers. After grinding in coal mills, it's blown by burners into the combustion chamber of the boiler. In the first half of 2011, the Kozienice power plant burned about 55% more biomass in comparison to a similar period of last year. In Kozienice production in the first half of the year totaled 188 GWh of electricity using coal and biomass co-incinerating technology for this purpose. The power plant required 104.5 Gg of biomass for this purpose, while in the first six months of last year in Kozienice 66 Gg of biomass were burned. In the future, Kozienice power plant intends to use liquid biomass in co-incinerating. (technical Glycerin) [28].

In the Opole power plant the following biomass types are burned:

- Sawdust (calorific value 7-15 GJ/Mg).
- Wood shavings with a maximum size of 25 mm (7-15 GJ/Mg).
- Bark (fragmented to 25 mm) (7-15 GJ/Mg).
- Energy Willow shavings or other energy crops; poplar, Jerusalem artichoke, rose, and etc. (6-15 GJ/Mg).
- Pellets from straw, grasses, other raw materials of agricultural origin, bran, husks, shells, and etc. (14-18 GJ/Mg).
- Briquettes from straw, grasses, or energy crops with a diameter of less than 55 mm (13-17 GJ/Mg).
- Cereal bran (13-16 GJ/Mg).
- Rape (15-17 GJ/Mg).

The purchase of the above types of biomass is run on the basis of annual contracts (for forest biomass), five-year agreements (for biomass of agricultural origin), and ten-year contracting agreements (for the plantation of energy crops). Contract for forest biomass and biomass of agricultural origin are concluded with companies which have submitted the most favorable terms and conditions in their offer. The Opole power plant is expecting annual sale offers of agricultural and forest biomass during the period from mid-September until mid-Octo-

Type of biomass	Supply [Mg]	Type of transport	Interest [Mg]
Wood chips	1 604 314	barge	111 744
		railway	330 480
		car	1 162 090
Wood chips from energy crops	369 924	car	369 924
Straw pellets	40 897	car	40 897

Table 1: Methods of delivering biomass to the Szczecin power plant [25].

ber. The Opole power plant is currently contracting approximately 150 Gg of biomass per year, however from 2012 biomass is planed to increase to a level of about 300 Gg. To this end, it intends to run an installation for direct administration and burning of biomass in the boiler. As the primary fuel for this installation pellets are foreseen made from raw materials of agricultural origin (straw, bran, scales, and etc.) [30].

The Stalowa Wola power plant is one of the first power plants in the country, which began the implementation of renewable energy production technologies using biomass. Since 2004, the energy is produced from biomass originating from wood production, forestry industry, and energy crops like willows or hay. Sunflower husks, rapeseed oilcake, and fruit seeds are also burned [31].

The Żerań and Siekierki CHP plants in Warsaw began using biomass in the production of heat and electricity in 2006. This launched co-incineration of biomass at Żerań CHP plant in fluidized bed boilers OFz-450. Implemented in 2009 was the second installation for co-incinerating biomass pellets in four block boilers at the Siekierki CHP plant. In 2011 the companies used about 100 Gg of biomass at the Żerań CHP plant and about 60 Gg of biomass at the Siekierki CHP plant. This allowed the production in 2011 to be 166 GWh of green energy [31].

Incineration and co-incineration of waste

In Poland bioenergy is also produced from the result of burning organic waste in medical waste incineration plants, to a small extent at municipal waste and sewage sludge incineration plants. Currently, Poland has one functional municipal waste incineration plant located in Warsaw (yearly in it burns almost 60 thousand Mg. In the near future incinerators are to be risen in: Łodz (250 Gg), Krakow (250 Gg), Warsaw (265 Gg), Białystok agglomeration (100 Gg), Tri-city agglomeration (250 Gg), Śląsk agglomeration–Ruda Śląska (250 Gg), Śląsk agglomeration–Katowice (250 Gg), Poznań (200 Gg), and the Szczecin metropolitan area (180 Gg). Municipal waste is an alternative fuel. The calorific value of unsorted municipal waste is comparable to the calorific value of lignite, which is the primary fuel for generating energy on a professional level [8].

Cement kilns can be successfully used as devices for thermal waste disposal. Advantages of cement kilns are results of their principles of operation, temperature operated range, and the chemical character of the baked mixture, which is:

- The combustion temperature and clinker process reaches 2000 °C. Outlets from the expansion vessels, in the dry temperatures reach 1100-1200 °C. Combustion takes place in an oxygenated atmosphere.
- Time gases spend at high temperature–temperature of the gases exceed 1100 °C for 8 to 10 seconds, wherein the temperatures above 1600 °C shall be maintained for 2-3 seconds.
- Very high thermal capacity of the kiln–is the result of mass from the; fireproof brick laid expansion vessel kiln, together with material located inside, depending on the type and size of installation it harnesses from a few hundred to several thousand Mg. Capacity of a heated up boiler drum is so large that even in case of emergency interruption of combustion, for about another 30 minutes the surface temperature along with the temperature of the material located inside the kiln will not be reduced.
- No waste after combustion of fuels–ash reacts with burnt material and its components are included in the composition of the cement clinker. An alkaline environment–burnt material is highly alkaline. Acidic compounds are contained in the exhaust gases e.g. sulphur oxide (IV), and the remaining components form part of the clinker. Thanks to the mentioned features above it can be concluded; cement kilns are one of the best technologically equipped devices for the co-incineration of waste. Disposed in them may be organic compounds, even those most resistant to temperature [32].

Alternative fuels are solid and liquid waste; municipal and industrial waste exploited for industrial and energy plants as a replacement for conventional fuels. Regularly we deal with the following forms of fuel:

- Fragmented solid fuel (PASr) began as a result of grinding waste to a specific granulation determined by the buyer. Solid alternative fuels replacing coal or coal dust, including dry fuel from shredded waste (detergent, plastics, wood, gum, and others) that is produced in a technological process, consisting of segregation and grinding of selected waste while separating out unsuitable waste. The final product; granules with a diameter up to 70 mm and physicochemical parameters conforming to the requirements of the customer.
- Impregnated solid fuel (PASi), resulting from the mixing of liquid waste with substances containing absorbing properties.
- Liquid fuel, resulting from the mixing of liquid waste [33].

In Poland there are 11 working cement plants equipped with full a production line. Their production capacity is 15 million Mg of clinker and 20 million Mg of cement per year. The fuel waste is co-incinerated in 9 plants. With each year more and more heat is extracted from use of alternative fuels Figure 3 [34].

Replacing conventional fuels with waste reduces production cost of cement, mainly due to significantly lower price of alternative fuels. Adaptation of production installations for the incineration of a different type of fuel is by far cheaper than building traditional incinerators [34].

Production of Biofuels and Biocomponents in Poland

Bio component and Liquid Biofuels Act of 25 August 2006 were obtained in Poland, which clearly defines the concept of biofuels. In accordance to the Act for liquid biofuels the following were considered:

- Motor fuels containing more than 5.0% v/v of biocomponents or

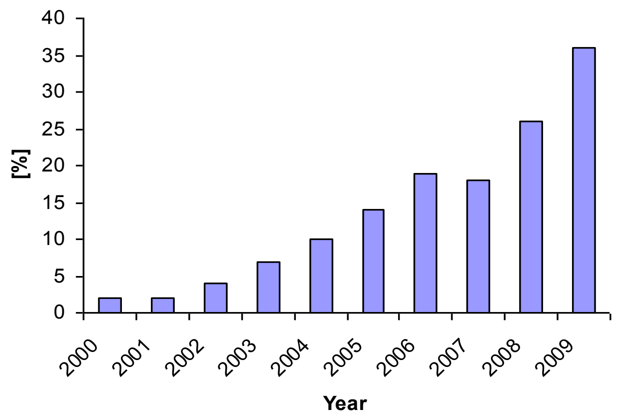

Figure 3: The share of heat from alternative fuels in Polish cement plants [32].

above 15.0% v/v of ethers.

- Diesel oil containing more than 5.0% v/v of biocomponents.
- Ester, bioethanol, biomethanol, dimethylether, and pure vegetable oil forming a self-contained fuel.
- Synthetic biofuels – synthetic hydrocarbons or mixtures of synthetic hydrocarbons produced from biomass forming a self-contained fuel.

In Poland, biofuels and biocomponents are produced on the basis of rapeseed oil *(Brassica napus L.)* and ethyl alcohol [36].

Production of rapeseed oil in Poland

Rapeseed *(Brassica napus L.)* takes the first place among oilseed crops cultivated for food and motorized purposes [37].

In Poland, there are three basic oil-milling technologies, dependent on the scale of final product yielded. Large industrial mills use technology based on an initial extraction of the oil by means of screw presses from seed previously subjected to conditioning in the roaster. The second stage is extraction of the rest of the oil from the pressing using solvent (hexane and light gasoline). This technology allows obtaining three final products: crude oil, solvent-extracted oil, and oilseed cakes. The yield of oil obtained with this technology is in the range of 0.41-0.42. Production capacity of mills employing classic technology amounts to 200-700 Mg of rapeseed per day. However, classical technology has some drawbacks. The oilseed cakes have definitely reduced the usefulness of fodder due to a strong denatured protein and the content of residual solvents. The largest plants producing rapeseed oil for the fuel purposes are situated in Kruszwica, and Szamotuły [37].

Small mills with a production capacity of around 50 Mg per day use the one-or two-step hot processing oil extraction from rapeseed. Prior to the pressing process, the seeds are crushed and properly conditioned. In effect raw oil and pressing is received. Unlike the classical technology, the hot pressing technology is pro-ecological, and fodder values of pressing are definitely bigger (higher soluble protein content, higher energy value, lack of residual solvent) [37,38].

Very small mills with a production capacity of 1-15 Mg per day are called mini mills. Applying the cold forming technology and followed by the one-or two-stage process after a partially crushing and heating the seed to a temperature no higher than 45°C [37].

The process for receiving rapeseed oil as a raw material for the production of esters, consists of three basic technological operations: rapeseed crushing, the extraction of oil, and filtration. These treatments can be carried out in small mills with small production capacity of 0.1-0.5 Mg of seed per hour, as well as in the industrial mills with a large production capacity of 50, 000 Mg per year. In the oil plants with a large production capacity the process of obtaining oil from the seed is enriched with additional processes: extraction, bleaching, and filtration [38].

In Poland the process of trans esterification is usually carried out with methanol and an alkaline catalyst [8].

Production of bioethanol in Poland

The distillery traditions in Poland date back to the sixteenth century. In 2000 Poland had about 900 distilleries, but their number have dropped to about 150. The majority of alcoholic products are produced in the agricultural distilleries located in areas with a large production of potatoes. The production capacity of all distilleries in Poland is around 400 million dm^3 of alcohol per year. However, the demand for alcohol consumption and industry does not exceed 250 million dm^3. Thus, there are reasons to apply it as an additive to motor gasoline [39,40].

The use of bioethanol on a mass scale in gasoline, was initiated in Poland at the end of 1993. Adding ethanol in quantities not exceeding 5% v/v enabled the introduction of new standards for fuel stations PN92 C-96025. Since 1999, the amended regulations were obtained in accordance with EU standards (BS EN228). The total production capacity of the dewatering ethanol plants in Poland amounts to 700 million dm^3. Currently in Poland the largest bioethanol production plants are located in Starogard, Oborniki, and Wroclaw. The largest producer of biodiesel is Rafineria Trzebinia SA, and factories in Surochów, Tychy and Malbork Figure 4.

The city, which first introduced the bioethanol as a fuel for city buses, was Slupsk, in 2011 [41].

Harnessing Biogas in Poland

The biogas technology in Poland has developed well in recent years–March 2013 there were 196 biogas plants in Poland with a combined total electric capacity of about 112 MW. Since the mid-90*s* of the last century biogas plants were created close to the wastewater treatment plants and landfills. In the years 2008-2013, 30 agricultural biogas plants were established [42,44].

Poland as an agricultural country has huge biogas potential. In Poland the biogas obtained from sewage sludge in medium and large wastewater treatment plants is profitable. The technical potential of biogas from sewage sludge is about 25 million m^3. The amount of municipal waste generated from households and public utility buildings in Poland is about 12 Tg, more than half of this waste is biodegradable. Assuming that the technological potential is 15% of the theoretical potential, then the possible amount of biogas that could be produced from municipal waste is about 80 million m^3. Poland has a wide range of gamma substrates for the production of agricultural biogas: animal excrement, agricultural waste or food waste. In Poland there are 5.7 million head of cattle, 15.2 million pigs, and 155 million chickens. Management of manure would raise about 1800 million m^3 of biogas.

Biogas plants close to wastewater treatment plants

In Poland there are about 1700 industrial wastewater treatment plants and about 1500 municipal sewage treatment plants, only 2% of the treatment waste manages to result in biogas. For technological reasons, not all buildings are suitable for the production of biogas, but the remaining part is suitable for modernization [46].

An example of functioning solutions in fermented sludge treatment is a wastewater treatment plant in Tychy Figure 4. The yearly sewage flow is 12 million m^3. Initial sediment is directed through a heat exchanger to separate sludge digesters. Excessive sludge, after the mechanical compaction, moves to the fermentation chambers where it is subjected to the process of methane fermentation. Biogas produced in the closed fermentation chambers is collected in the common collector before being put through dehydration, than it is directed to the desulphurization reactor using morass ore. After dehydration and desulphurization biogas is introduced into the flexible storage tank, which protects and storages 6 hours of biogas production. Until April 2006, at the wastewater treatment plant in Tychy, biogas was combusted in coke boilers that were adapted for combustion of biogas and provided

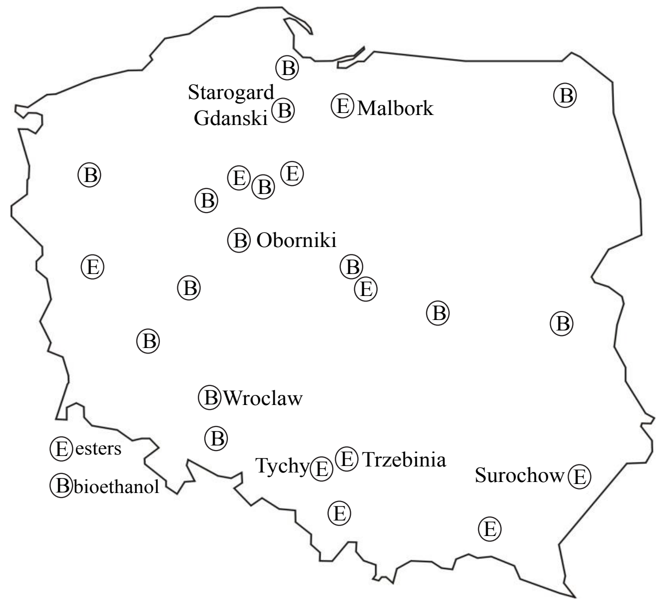

Figure 4: Producers of biofuels and bio components in Poland (development personally).

fuel for production of heat to support technological processes and heating purposes. In 2006, a modern, low-temperature hot water boiler was installed with a capacity of 895 kWc equipped with an oil gas dual-purpose burner. The boiler is a backup device–for production of needed heat for technological processes along with heating buildings, produced in cogeneration unit. Digested sludge is directed to the gravity thickener, and then is fed into the sludge drainage system: centrifuges and belt presses. Stabilized and dehydrated sludge is collected for temporary dehydrated sludge storage and used for land reclamation [47].

The wastewater treatment plant in *Zamość* Figure 4 has been functioning since 1995, where sludge fermentation is carried out in two fermentation chambers. The fermentation process is done at a temperature of around 34°C. During powering the chambers by concentrated sludge, the digested sludge is pushed out from the bottom of the chamber through a tube derived to the top of the tank. The sludge from the fermentation chambers is discharged into an open pool; equipped with a sludge supernatant system and a stirrer in which the second step of fermentation is carried out. The dehydrated sludge is subjected to hygienization by quicklime, and after a few days of ripening the sludge in the storage yard is used by farmers as a fertilizer. Obtained biogas is stored in unpressurised fabric tanks, which power the local gas boilers [48].

Another example of a treatment that applies anaerobic digestion process is a wastewater treatment plant in *Toruń* Figure 5, which produces about 80-90 Mg of sewage per day. Originally this was deposited in the landfill, but with such a large number of it further populating landfills was irrational. To prevent this decision was made to dispose of it in the treatment area. Sewage is currently fermented, and then prepared for agricultural utilization. Obtained biogas in fermentation chambers is in the amount of 200-250 m^3/hr., it is subject to desulphurization, and then used to produce electricity and heat. This energy satisfies 60% of the electricity needed for heating. Working generators have a significant impact on reducing the cost of the plant functioning [48].

As a result of wastewater treatment at the *Gdańsk*-East treatment plant in *Gdansk* Figure 5 is sewage sludge, which is fed to fermentation chambers, where a deposit methane fermentation process takes place. The biogas obtained during the fermentation process is purified and used for energy purposes (burned in local oil-gas boiler rooms). As a result of carrying out the process of anaerobic sludge stabilization; about 3 million Nm^3 of biogas is produced annually with the calorific value of 23 MJ/Nm^3, of which 1.6 million Nm^3 is needed for the treatment plant. The dehydrated sludge is not subject to further processing and it is passed for the reclamation purposes; for plant cultivation that is not for consumption purposes but for the production of fodder [49].

The location of biogas plants working near wastewater treatment plants in Poland is shown in Figure 5.

The biogas plants in landfills

Biogas plants employed for degassing of municipal waste landfills are a factor in reducing the threat to people and the environment. The main ingredient of this mixture is a methane-gas, which is flammable and explosive, has had a very big impact on advancing the greenhouse effect along with the destruction of the ozone layer. From the point of view of counteracting threats, an effective way to avoid them is retrieval of biogas and its use for energy purposes. It will be implemented actively, by using the negative pressure in the deposit. By appropriately selected parameters of the burning process it is possible to virtually process all organic compounds into carbon dioxide and obtain combustion products that contain very small amounts of pollutants such as: carbon monoxide, nitrogen oxides, and sulfur dioxide [50,51].

The biogas plant in Toruń is still functioning and it is one of the first biogas plants in Poland Figure 6. In 1997 it started the exploitation of gas deposits, in December of 1999 additional work was completed and permission to operate was obtained. In 2001 nominal technical-exploitation parameters were achieved. Gas extraction covered 11 hectares of the landfill. During the period of 1997-1999 there were 40 fifty meters gas wells built and gas network cables was laid. The installation is technically equipped for biogas suction (pumping-regulating module MPR-1), with an internal gas combustion engine (generator AP-1) producing the electrical capacity of 550 kWe and thermal capacity of 770 kW, working at high-speed cogeneration. The CHP plant was at-

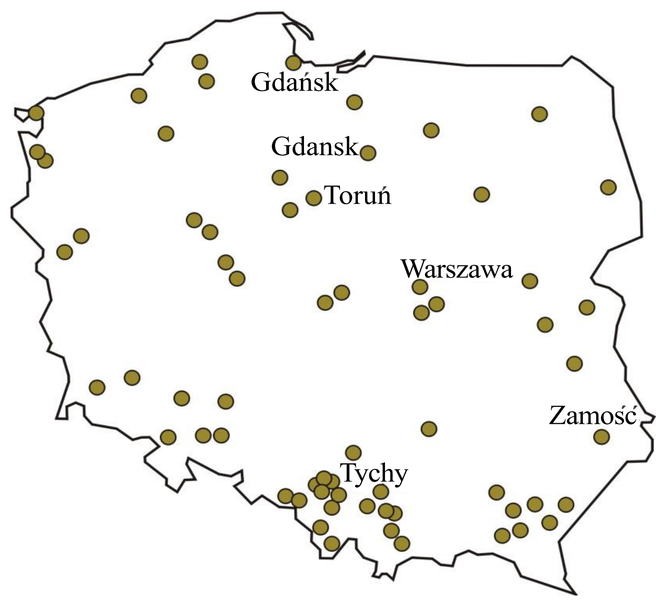

Figure 5: Biogas plants near wastewater treatment plants in Poland, as of April 2013 (developed personally).

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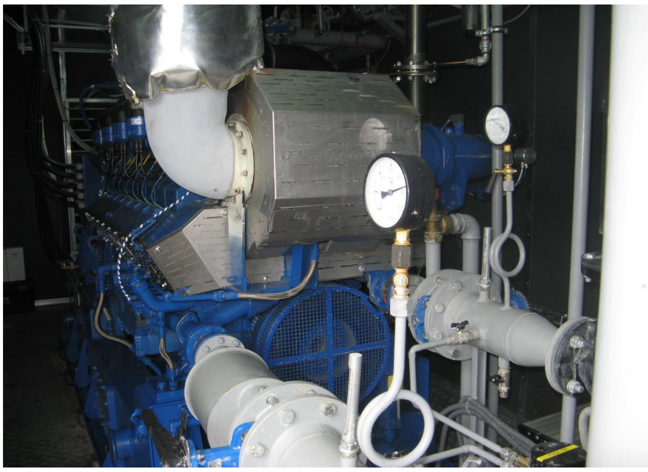

Figure 6: The biogas plant generator set in Franki *(Picture B. Igliński).*

tached to the power grid and district heating. In April 2002, another 12 wells were built and engaged into the system [50].

In January 2004 the second generator (AP-2) MDE brand with the electrical capacity of 324 kWe was launched, and thus was completed the first stage of development of the installation for acquisition and utilization of landfill biogas, which included the above-mentioned construction of 12 wells, 3 km gas pipeline, transformer station, NN cable line, and the purchase of AP-2 [50].

From March 1st 2004, the biogas plant instillation has an electrical capacity of 698 kWe and a thermal capacity of 770 kW - utilizes 440 Nm3 / h of landfill biogas. Additional biogas wells built in: August 2007 (17 wells), December 2009 (5 wells), and December 2010 (20 wells). In the meantime, a total of 12 inactive or ineffective biogas wells were closed. At the end of 2012, 82 biogas wells were being used distributed in a heap with an area of about 14 ha and an average height of 18 m. The produced electricity and heat supplies the residents of Torun through local network operators: Energa-Operator SA (electricity), Toruńska Cergia Społka Akcyjna (heat) [50].

Another example is the biogas plant on the landfill in Franki Figure 6. Degassing installation of municipal waste, also for the production of electricity and heat from biogas captured for the targeted electrical capacity of about 1 MW. Biogas is captured from deposits using degassing wells, then through collectors with a 63 mm diameter is sent to the station, where it is dried (dehydrated), and delivered to the central collector with a diameter of 150 mm-312 mm. At the accumulation station every shot (well) is regulated manually or through automatically regulated valves, and biogas composition from each well is measured by a gas analyzer. This allows for an optimal exploitation of the deposit. From the accumulation station biogas is transported using main collectors with a diameter of 150 mm, through an anti-explosive nozzle and gas-meter for biogas powering (generator), along the way is further dehydrated. In the event of a generator failure or repair, biogas is burned in flare. Produced electricity is delivered through a container transformer station 0.4/15 kv to the existing medium-voltage overhead line (15 kV) and sold to the electric industry. Eventually, the heat is managed by installing heat accumulators, construction of the dryer, or used for the need of the landfill [51,52].

The most important and the most expensive device in the installation of landfill gas utilization is the engine room–biogas fueled generator along with instrumentation. The biogas plant in Franki currently exploits a German generator made by MWM, type-TCG 2016 V16 C (formerly DEUTZ) with a nominal electric capacity of 716 kWe [51,52].

Agricultural biogas plants

After World War II mini-biogas plants began to form in Poland. For example, in the village of Tworóg near Katowice operates a biogas plant, at which 5 m^3 of liquid manure were processed a day harnessing about 70 m^3 of biogas. At the time mini-biogas plants went bankrupt pretty quickly. Frequent downtime resulting from errors on the stage of construction and carrying out methane fermentation meant that they were not viable economically. Since 2005, modern agricultural biogas plants are being built in Poland; the first biogas plant in Pawlowek.

In Poland, as well as throughout Europe, mainly used is mesophilic fermentation process (temp 32 °C -42), only in Mełno, the agricultural biogas plant is fueled Figure 6 through thermophile fermentation (57-50 °C). In Poland heat and electricity are obtained from biogas– in cogeneration units, used for cogeneration of electricity and heat, which is the most common (and virtually only) method for biogas energy [54].

Agricultural biogas plants in Poland are usually close to large animal farms, using as a substrate the burdensome waste like slurry and manure. The application of these wastes as substrates in agricultural biogas plants is a much better alternative to the commonly used method of disposing of this waste (in Poland, slurry and manure are poured directly into the field). As a result of this process sanitation occurs, this prevents the risk of groundwater contamination. In addition electricity and heat are obtained, and the post-fermentation remains are used as fertilizer [42].

Capital expenditures of the first centralized agricultural biogas plant in Poland in Pawłówek have amounted to 8 million PLN. The biogas plant in Pawłówek uses a liquid manure as a substrate for the production of biogas, which comes from nearby farms in Pawłówek and Dobrzyń (about 29 Gg / year), maize silage and waste from the nearby meat processing plants (3.5 Gg / year) which is previously subject to the process of hygienization at 70 ° C and glycerin (1 Gg / year). In Pawłówek, the installation consists of two fermentation tanks, a mixing tank (initial), two post-fermentation tanks, and hygienizer of waste. The residue from the fermentation process is discharged into airtight containers and used as organic fertilizer. The obtained electricity from combustion of biogas is used for personal purposes (mixer, room lighting) as well as it is sent to the electricity grid - the biogas plant satisfies the energy needs of 1800 individual farms. The obtained heat from the cogeneration process is used to heating farm and offices [55].

The two largest agricultural biogas plants in Poland are settled in Koczale and Liszków. The installation in Koczale, which was established near a farm with 8 thousand sows, processes 58 Gg of slurry and 32 Gg of corn silage each year in the fermentation process. The substrates in appropriate proportions are put into the mixer, and then they are directed to three fermentation chambers. The fermented biomass moves to the two post-fermentation tanks where it is stored until its agricultural application. After removal of sulfur compounds by a biological filter, the biogas is sent to the cogeneration system. Electricity and heat are used for personal purposes: in the biogas plants, in feed mills, on the farms, and the excess energy is sold. The biogas plant in Liszkowo exploits broad-spectrum substrates:

- Distillery broth: 100 Gg/year.
- Onion: 10-12 Gg/year

- Vegetable wastes: 6 Gg/year
- Potato pulp: 2-3 Gg/year
- Glycerol 2 Gg/year
- Waste from processing of apples: 300 Mg/year,
- The sediment from oil cleanup: 60 Mg/year
- Beet pulp: 15 Mg/year [56].

In a biogas plant in *Liszków* an organic matter that could still be a source of biogas is recycled for re-processing. The effect is using about 95% of organic matter in the process. In this solution there is also no need for water intake after the fermentation process, because it is contained in a distillery broth, which is used as a substrate. Water losses are supplemented by returning water processing technology from the settler. In *Liszków*, the column method is applied for the desulfurization of biogas, otherwise known as dry or biological desulfurization. The biogas pumped into the lower part of the column moves up. Then it passes through the deposit filled with granules of iron oxide, whose function is to block the precipitation of sulfur. As a result of this reaction is water or water vapor. Simultaneously with the process of desulfurization occurs regeneration of deposits by adding the compressed air. Due to the possibility of air forming an explosive mixture of biogas, the dose of added air is used on the minimum level. The advantage of regeneration is the fact that this process is exothermic. Thanks to this the formation of steam condensation is made impossible [56].

Nacław is currently constructing a heat distribution network with a length of 1.5 km, which connects the biogas plant with six apartment buildings, a common room, and a primary school. The biogas plant covers heat demand for hundreds of residents. This allows the exclusion of two old boiler houses that used coal and fuel oil, and will provide the residents with stable supply of heat throughout the year [42].

The distillery and the biogas plant in Mełno cooperate closely together. The heat generated from the combustion of biogas in cogeneration Figure 7, 8 is used for the production of ethanol in distilleries. The fundamental substrate for methane fermentation in biogas plant is distillery broth Table 2 [57].

Poland also erected small agricultural biogas plants. In the biogas plant in Szewni 50 kg of agricultural commodities or their waste (beets, corn, straw, leaves) are added to fermentation chamber once a day. From such a quantity is produced about 1 m^3 of biogas per hour. Studzionka biogas plant uses bird droppings (690 Mg/year), liquid swine manure (320 Mg/year), maize and grass silage (365 Mg / year) and small amounts of residues from agricultural production and household. The obtained electricity is currently utilized for the biogas plants and agricultural industry. The heat is used to heat residential buildings and livestock buildings containing piglets. The fermented liquid manure is applied to fertilize the fields [42].

Summary

Poland as an agricultural country will develop technologies based on biomass. In Poland, potential investors still deter; high initial investment costs of renewable energy technologies, the high cost of preparing the project in relation to the operating costs. Also includes the lack of well defined economic and tax mechanisms in the state budget, financial policies, strategies, along with programs and schedule of expenditure from the ecological funds [54].

In terms of biofuel exploitation, Poland occupies first place among new EU member states (8th place in the EU-27). The main component in country wide regulation is the result of the Act of August 25, 2006 on bio components and liquid biofuels, which introduces EU Directive 2003/30/EC into Polish law. Since 2004 Poland has recorded growth in biofuel consumption by 0.5 to 1.5 percentage points per year. The national market for biofuels consumed in transport is mainly based on the addition of bioethanol and biodiesel into ethyl gasoline. The share of energy from renewable sources in final gross energy consumption was determined for EU members in the Directive 2009/28/EC of the European Parliament and of the Council of April 23, 2009. This promotional directive endorses energy from renewable sources, which also amended and subsequently repealed Directives 2001/77/EC and 2003/30/EC. In 2020, Poland's share of energy from renewable sources in final gross energy consumption is projected to be 15% [55].

The European Parliament, the Council, and the Commission have taken appropriate measures to establish mandatory national targets. These are consistent with a 20% share of energy from renewable sourc-

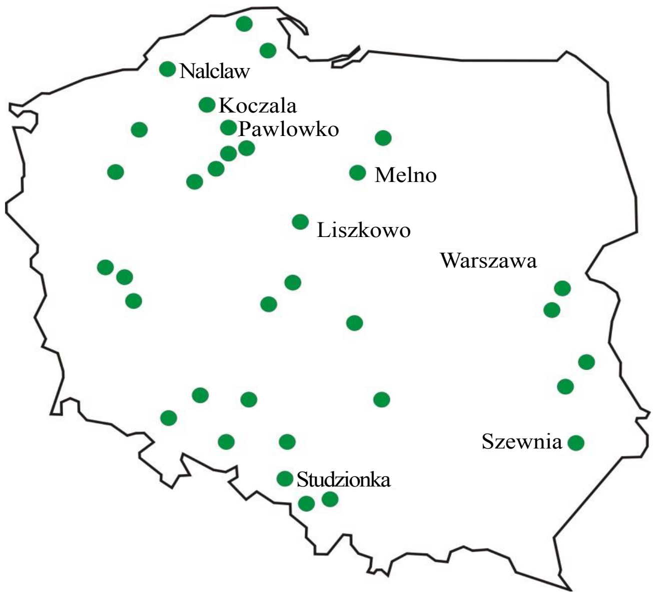

Figure 7: Location of agricultural biogas plants in Poland-current to April 2013 (Developed personally).

Figure 8: Cogeneration systems in Mełno (fot. B. Igliński).

Lp.	Substrate name	Total [Gg/rok]	Monthly availability	Dry matter content [s.m.]	Temperature [°C]
1.	Pig manure	6	January- December	6%	local
2.	Distillery broth	41	January-December	10%	86°C
3.	Beet pulp	to 25	January-December	22%	local
4.	Onion husk	7	September-May	23%	local
5.	Fruit and vegetable waste	2	July-October	16%	local

Table 2: Input material/substrates for installation [57].

es and a 10% share of energy from renewable sources in transport in Community energy consumption by 2020 [55].

The control of European energy consumption, amplified exploit of energy from renewable sources, along with energy conservation and increased energy efficiency, all play an important part in measures required to reduce greenhouse gas emissions, also complying with the Kyoto Protocol formed by the United Nations Framework Convention on Climate Change and with continued community and international commitments for reduction of greenhouse gas emission beyond 2012. All these measures play an important part in promoting reduction of greenhouse gas emission through security of energy supply, technological development, and innovation while providing employment opportunities and regional development especially in rural and isolated areas [55].

Priority access and guaranteed access to electricity produced from renewable energy sources are key for integrating renewable energy sources into the internal electricity market, in accordance with article 11(2) and article 11(3) of Directive 2003/54/EC. Reliability and safety requirements relating to grid up keep and the dispatching may differ from textbook secure and national grid operation. Priority access to the grid pledges reliability to connected electrical generators using renewable energy sources. This ensures the ability to sell and transmit the electricity produced from renewable energy sources in agreement with connection law and regulation at all times, as soon as the source becomes available. In case of spot market integration of electricity from renewable energy sources, guaranteed access entails that all electricity sold and supported will be granted access to the grid. This will ensure maximum consumption of electricity from renewable energy sources utilizing installations connected to the grid. It is important to note that no obligations are implied on the part of Member States to support or introduce purchase obligations for energy from renewable sources. Other systems employ a fixed price for electricity produced using renewable energy sources; usually this includes a purchase obligation for the system operator. Priority access in such an event has already been given [55].

The volume of petroleum fuels consumed in road transport in the EU decreased 3.5% between 2008 and 2010, while the volume of *biofuels* consumption increased by 39%. About 75% of the biofuels in 2010 utilized in the EU consisted of; 22% bio-diesel (mainly methyl esters), 21% bio gasoline (mainly bioethanol), and about 4% recorded using other liquid biofuels [57]. Germany consumed 22% of all EU biofuels in 2010 which made it the largest consumer market in the EU; other large consumers were France, United Kingdom, Italy and Spain. The German consumption of biofuel decreased in 2008, but soon recovered in 2009 and once again increased in 2010. In 2010 the French market came to a stop. The Latvian market between 2008-2010 experienced the strongest percentage growth (more than tenfold), even with such growth its overall market is still very small. Poland also experienced significant growth. Followed by consistent low growth, Danish biofuels consumption seems to have halted completely in 2010. Consumption levels in Malta and Estonia are still of no significance [55-57].

Development of renewable energy has a great importance for the Polish energy policy until 2030 [3]. The increased use of these sources carries a greater degree of independence from imported supplies. Promoting renewable energy allows increasing the degree of diversification of supply sources and to create conditions for the development of energy on locally available raw materials. The renewable energy usually consists of small generator units located close to the receiver, which allows growth of local energy security and reducing transmission losses. Energy production from renewable sources is characterized by low or zero pollution emission, which provides positive environmental effects. Development of renewable energy also contributes to the development of less developed regions (eastern and northern Poland what are rich in renewable energy resources).

According to the Polish energy policy until the year 2030 in the nearest future the most energy efficient solutions will be implemented, including gasification of biomass and waste. It is assumed that in the near future building will begin new biogas plants mainly on landfills and agricultural biogas plants [3].

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References

1. Soliński J (2012) Energy sector of the world and Poland: Beginnings, development, present state. Instytut Gospodarki Surowcami Mineralnymii Energią PAN, Kraków.
2. Młynarski T (2011) Bezpieczeństwo Energetyczne w pierwszej dekadzie XXI wieku. Mozaika interesów igeostrategii.Wydawnictwo Uniwersytetu Jagiellońskiego, Kraków.
3. Rada Ministrów (2009) Polity kaenergetyczna Polski do 2030 r. Warszawa.
4. http://www.ure.gov.pl/uremapoze/mapa.html.
5. Strupczewski A and Radovic U (2006) Koszty Zewnętrzne Wytwarzania Energii Elektrycznej w Polsce. Biuletyn Miesięczny Informacji Publicznej, 1:14-29.
6. PietraszewskiA (2011) Polskie Górnictwo Węgla Brunatnego – 2010 rok. Węgiel Brunatny 1, 74:15-22.
7. Igliński B, Iglińska A, Kujawski W, Buczkowski R, Cichosz M (2011) Bioenergy in Poland. Renew Sust Energ Rev, 15: 2099-3007.
8. Pigan M, Raport o, stanielasów w, Polsce(2009) Centrum Informacyjne Lasów Państwowych. Warszawa .
9. Szlachta J (2001) Energetyczne aspekty wykorzystania biomasy, Akademia Rolnicza we Wrocławiu, Dolnośląski Wojewódzki Ośrodek Doradztwa Rolniczego z/s w Świdnicy, Świdnica.
10. Ratajczak E, Szostak A, Bidzińska G (2003) Drewno poużytkowe w Polsce. Wydawbictwo Instytutu Technologii Drewna, Poznań.
11. Buczkowski R, Igliński B, Cichosz M, Ojczyk G, Stańczak M, Piechota G (2012) Biomasa w energetyce. Wydawnictwo Uniwersytetu Mikołaja Kopernika, Poland, Toruń.
12. SzymańskaD, Chodkowska-Miszczuk J (2011) Endogenous resources utilization of rural areas in shaping sustainable development in Poland. Renew SustEnerg Rev, 15:1497-1501.
13. Shastri YN, Rodriguez LF, Hansen AC, Ting KC (2012) Impact of distributed

storage and pre-processing on Miscanthus production and provision systems. Biofuel BioprodBior, 6:21-31.

14. Grzybek A, Gradziuk P, Kowalczyk K (2001) Słoma – energetyczne paliwo, Wydawnictwo Polskie Towarzystwo Biomasy PolBiom, Warszawa.
15. Gradziuk P (2006) Ekonomiczne i ekologiczne aspekty wykorzystania słomy nacele energetyczne w lokalnych systemach grzewczych. Acta Agroph 8:591-601.
16. Poślednik H (2005) Ciepłownie w Piszu – rokdoświadczeń. CzystaEnergia 2:22-26.
17. Sołowiej P, Nalepa K,Neugebauer M (2008) Analiza energetyczno- ekonomiczna produkcji energii cieplnej w kotłownia na zrębki drewna. Inż Rol 2:263-267.
18. Denisiuk H, Piechocki J (2005) Techniczne i ekologicznea spekty wykorzystania słomyna cele energetyczne. Wydawnic two Uniwersytetu Warmińsko-Mazurkiego, Olsztyn.
19. Lipski R, Orliński S, Tokarski M (2006) Energetyczne wykorzystanie biomasy na przykładzie kotłowni opalanej słomą we Fromborku. MOTROL 8:202-209.
20. Sławińska M, Kowalczyk-JuśkoA(2011) Efekt środowiskowyi ekonomiczny zamiany nośnikaenergii cieplnej w wybranym przedsiębiorstwie materiały konferencyjne: Przedsiębiorstwa wobec zmian klimatu, Warszawa.
21. Igliński B, Iglińska A, Kujawski W, Buczkowski R, Cichosz M (2010) Renewable energy in kujawsko-pomorskie voivodeship (Poland). Renew SustEnerg Rev 14:1336-1441.
22. Sekret R, Nowak W (2005) Energetyczne technologie wykorzystania biomasy z możliwością utylizacji odpadów komunalnych. (red. R. Buczkowski), Wydawnic two Uniwersytetu Mikołaja Kopernika, Poaland, Toruń: 281-308.
23. http://www.ppik.pl/pl/node/103.
24. http://scc.com.pl/konferencje/prezentacje/FTEB_27-20-2011/09%20W.Wisniewski.pdf.
25. http://zepak.com.pl/pl/ekologia/inwestycje/budowa-kotla-opalanego-biomasa.html.
26. http://ebiomasa.pl/index.php?option=com_k2&view=item&id=84:elektrownia-kozienice-wsp%C3%B3%C5%82spalanie-biomasy&Itemid=279.
27. http://www.ekonews.com.pl/pl/0,284,9170,elektrownia_kozienice_spala_coraz_wiecej_biomasy.html
28. http://www.polcoaldex.pl/index.php?option=com_content&view=article&id=229%3Awspospalanie-biomasy-wci-popularne-w-polskich-elektrowniach-i-elektrociepowniach&catid=69%3Apolska&Itemid=67&lang=pl.
29. Radzimski D (2009) Wykorzystanie paliw alternatywnych w produkcji cement. pracamagisterska, UMK, Poland, Toruń.
30. Walendziewski J, Kułażyński M, Surma A (2007) Określenie potencjału odpadówi ich rodzajów do produkcji stałych paliw alternatywnych Opracowanie dlasiecinaukowo-gospodarczej Energia, Wrocław.
31. http://polskicement.pl/5/zdjecia_org/826.pdf
32. Ustawa z dnia (2006) o'biokomponentach i biopaliwach ciekłych, Dziennik Ustaw z. Nr 169: 1199.
33. Dam J, Faaij APC, Lewandowski I, van Zeebroeck B (2009) Options of biofuels trade from Central and Eastern to Western European countries. Biomass Bioenerg 33:728-744.
34. Tys J, Piekarski W, Jackowska I, Kaczor A, Zając G, Starobrat P (2003) Technologiei ekonomiczne uwarunkowania produkcji biopaliwa z rzepaku, Rozprawyi Monografie, InstytutAgrofizykiim. Bohdana Dobrzańskiego PAN, Poland, Lublin.
35. KrzymańskiJ (2009) Olejrzepakowy – nowysurowiec, nowaprawda.PolskieStowarzyszenieProducentówOleju, Warszawa.
36. Jarosz L (2004) Rynekbioetanolu w Polsce, ZeszytyNaukowe. PolitechnikaŁódzka 125:243-246.
37. Inorowicz J (2008)Widmobankructwanadalwisiałonadgorzelniamirolniczymi. PrzemysłSpirytusowy 1:54-55.
38. 38.http://www.autoflesz.pl/artykuly/490,Bioetanol_pierwsze_autobusy_w_Polsce_dla_Slupska.html
39. Igliński B, Buczkowski R, Iglińska, Cichosz M, Piechota G, KujawskiW (2012) Agricultural biogas plants in Poland: investment process, economical and environmental aspects, biogas potential. Renew SustEnerg Rev 16 :4890-4900.
40. Budzianowski WM(2012) Benefits of biogas upgrading to biomethane by high-pressure reactive solvent scrubbing. Biofuels BioprodBior 6:12-20.
41. Piechota G, Igliński B, Buczkowski R (2013) Development of measurement techniques for determination main and hazardous components in biogas utilized for energy purposes. Energ Convers Manage 68:219-226.
42. GłównyUrządStatystyczny (2012) Rocznikstatystycznyrolnictwa 2012. Warszawa, Poalnd.
43. Krzak J (2009) Biogazownie w Polsce – niedocenioneźródłoenergii. INFOS 4:1-4.
44. http://www.rcgw.pl.
45. http://www.peosa.pl .
46. http://www.giwk.pl/files/4/167/160/3_rozdzial.pdf .
47. Igliński B, Sobólski J (2011) Bioenergy production in the Toruń biogas plant (Poland). Linköping University Electronic Press: 33-40.
48. Piechota G, Hagmann M, Buczkowski R (2012) Removal and determination of trimethylsilanol from the landfill gas. BioresourceTechnol 103:16-20.
49. DębskaP (2010) Czynniki wpływające na efektywność pozyskiwania biogazuna skład owisku odpadów komunalnych Franki, pracamagisterska, Polska, Toruń.
50. Brodowicz K (1983) Biogaz, znaczeniegospodarcze, wytwarzanie. Biuletyn Informacyjny Instytutu Techniki Cieplnej Politechniki, Warszawskiej 64:3-33.
51. Oniszk-Popławska A, Zowsik M, Wiśniewski G (2003) Produkcja I Wykorzystanie Biogazu Rolniczego. Wydawnictwo EC BREC/IBMER, Poland, Warszawa.
52. Cukrowski A, Oniszk-Popławska A, Mroczkowski P, Owsik M, Wiśniewski G (2011) Przewodnik dla inwestorów zainteresowanych budową biogazowni rolniczych, Instytut Energety ki Odnawialnej, Poland, Warszawa.
53. Kocińska K (2010) Pozyskiwanie Biogazu z materiału roślinnego w biogazowni Liszkowo.Praca Magisterska, UMK, Poland, Toruń.
54. Buczkowski R, Igliński B, Cichosz M, Piechota G (2011) Technologieproe kologiczne w przemyśl eienergetyce – znaczenie dla gospodarki i środowiska. Wyd, UMK, Poland, Toruń.
55. European Parliament And Of The Council (2009)On the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives : 2001/77/EC, 2003/30/EC.
56. Report for the European Commission (2012) Renewable energy progress and biofuels sustainability.
57. Report from the Comission to the European Parliament and Council (2013) Renewable energy progress report, Brussels.