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# Natural gas in Polish and European Union's energy sectors

Key words

Natural gas, electricity generation, co-generation

Abstract

Natural gas is widely used both as an energy carrier as well as important material for chemical industry. One of the most prospective directions of natural gas utilisation is its usage for the purpose of electricity generation. The natural gas fired combined heat and power plants (CHP) characterise the high efficiency of chemical energy use. For this reason natural gas has been recently more often used for electricity generation purposes. This is also why the role of natural gas will probably rise in future.

Hard coal and lignite are dominant in Polish sector of electricity generation. The total electricity production in 2002 was 144,1 TW·h and the share of hard coal and lignite was about 96%. Practically the structure of Polish electricity generation has not changed for the recent 20 years. The only, but not very significant, change is that natural gas has just started to be used for co-generation of electricity and heat. It should be mentioned, however, that the rate of electricity produced from natural in Poland is low — 2,1 TW·h (2002), i.e. only 1,5% of the total electricity generation. The biggest combined heat and power plant that in spite of coal uses also natural gas is Lublin Wrotków.

The paper presents short characteristic of the Polish power generation sector with a special stress put on combined heat and power plants based on natural gas. Constrains that prevent from wider scale use of natural gas in the sector are described. The paper demonstrates also the ecological and technical aspects of gas turbines use. It also presents the comparison between structure of electricity production in Poland and in the European Union.

Finally, the paper shows the perspective of the development of energy sector and the role of the natural gas in future structure of primary energy mix for the purpose of electricity production.

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## Introduction

Not less than half a century ago natural gas was commonly considered to be the waste that accompanies the deposits of crude oil. Currently, natural gas finds very broad applications both as the energy carrier, and as a precious raw material for the chemical industry. Its utilization in the electrical power industry is one of prospective directions of gas fuels development.

## 1. Electricity generation structure in Poland and the European Union

Solid fuels definitely dominate in the electricity generation structure in Poland — figure 1b. Out of the total gross production of electricity amounting to 144.1 TW·h, some 96% was generated from coal (2002). Practically, the electricity generation structure in Poland has not changed for the last 20 years. The fact of commencing the utilization of natural gas for electricity and heat generation may be considered such minimal change (currently, the extent to which the natural gas is used in the Polish electrical power industry is very small — in 2002, the electricity generation from the natural gas amounted to 2.1 TW·h, some 1.5% of the total electricity generation). The appearance of new (renewable) sources of electricity generation is the next minimal change. However, the rate of electricity generation from renewable sources is marginal — the most important role is played by hydro-power plants (hydro-power plants generated 2.4 TW·h, wind power plants — 0.061 TW·h, biogas--fired power plants — 0.048 TW·h (Energy Market Agency 2003).

The figure 1b, in its section "remaining" covers all the above mentioned sources of renewable energy, as well as pumped storage power stations (1.6 TW·h) (Energy Market Agency 2003).

At the world scale 18.3% of electricity was produced from natural gas in 2001, however as much as 38.7% was generated from coal (International Energy Agency 2003).

The Polish structure of electricity generation, with a dominant role of coal, results from solid fuels domination in energy raw materials resources, as well as is arises from historical conditions.

While comparing the structure of electricity generation in Poland and in the European Union (comprising 15 countries, i.e. before the EU enlargement of May 1, 2004) (fig. 1a), the following may be noticed:

— the share of coal is much lower in the EU countries than in Poland and is equal to 27%,
— in Poland the nuclear power industry does not exist, while it plays a significant role in the EU countries (34% share),
— the share of electricity generated from renewable sources is marginal in Poland, however, in the EU countries the share constitutes 15% (hydro-power plants are dominating),

— the similar situation may be noticed with regard to hydrocarbons (their share amounts to 24% in the EU countries, while in Poland it approximates to only 1.5%).

The total demand for electricity in the EU countries in 2002 amounted to 2518.3 TW·h. As it can be seen from the figure 1a, the majority of electricity in the EU countries is generated in conventional thermal power stations — some 50% of the total production (the largest rate of electricity being generated from coal), the nuclear power industry provides some third of the total production, while the renewable sources — 15%. This is how the electricity generation structure in the EU countries looks like. The considerable diversification can be seen on the level of particular countries. This diversification arises out above all from:

— historical conditions of development of electrical power industries (e.g. in France as a result of the nuclear power industry program realization, some 80% of energy is generated in nuclear power plants),

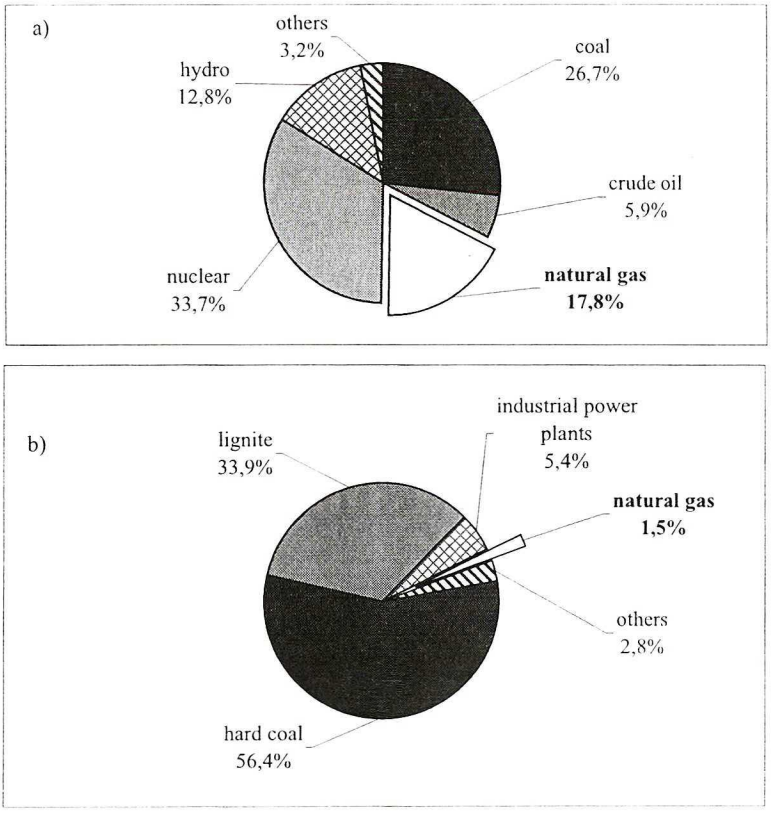


Fig. 1. Electricity generation structure
a — in the EU countries in 2001, b — in Poland in 2002
Source: Energy Market Agency; Biedrzycki, Kozak 2003

Rys. 1. Struktura produkcji energii elektrycznej
a — w krajach Unii Europejskiej w 2001 r., b — w Polsce w 2002 r.

— kind of non-renewable energy resources possession (e.g. Holland possesses considerable resources of natural gas in the North Sea basin and for that reason more than 60% of electricity is generated from natural gas),
— the existence of renewable energy resources potential (e.g. in Austria some 70% of electricity is generated based upon the hydro-power plants).

## 2. Polish heat and power plants fired by natural gas

In last years, the new power plants (or heat and power plants) in Poland have been commenced for operation or extended by adding new facilities utilizing natural gas. As a result of realization of these projects, the successive increase of natural gas utilization in the pRzeszówer industry sector can be seen — figure 2.

As can be seen from the figure, the rate of gas consumed by the electrical power industry increased more than 10 times in the considered period. In 2003, the further growth of natural gas consumption by the power industry sector as compared with the previous year is expected due to, among other things, expected commencement of operation of the gas and steam unit in the Rzeszów Heat and Power Plant.

Generally, the plants fired by natural gas can be divided taking into account as a criterion the electrical power of the units. As a result of such division, the following may be recognized:

— low power co-generation gas-fired systems (usually up to 1 $MW_e$): gas-fired engines, gas-fired turbines;
— heat and power plants (or power plants): gas-fired turbines, gas and steam units.

The table 1 presents more important natural gas fired power plants.

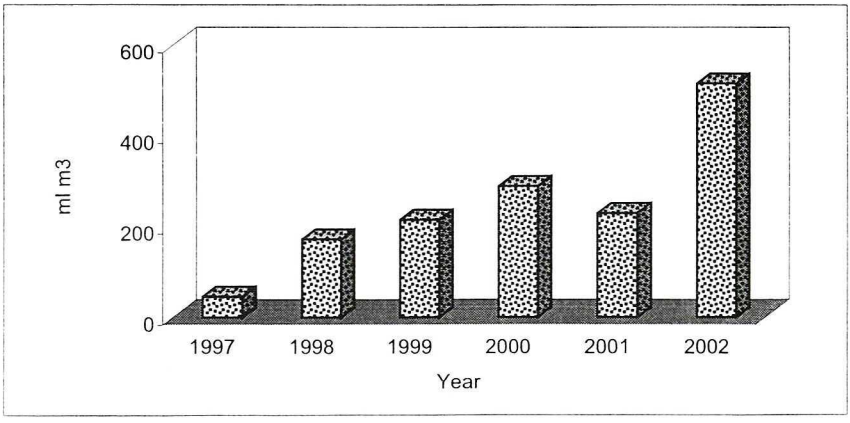


Fig. 2. Rate of consumption of natural gas in the power sector in 1997—2002, ml $m^3$
Source: PGNIG 2003

Rys. 2. Zużycie gazu ziemnego w sektorze elektroenergetycznym w latach 1997—2002, mln $m^3$

TABLE 1

The list operating heat and power plants based on gas

TABELA 1

Lista elektrociepłowni pracujących na gazie ziemnym

| No. | Enterprise name | Heat and power plant type | Electrical power [$MW_e$] |
|---|---|---|---|
| 1. | Gorzów Heat and Power Plant | Gas and steam unit ABB GT8C | 55 |
| 2. | Nowa Sarzyna Heat and Power Plant | Gas and steam unit 2xGE Frame 6B | 116 |
| 3. | Lublin-Wrotków Heat and Power Plant | Gas and steam unit | 235 |
| 4. | Rzeszów Heat and Power Plant | Gas and steam unit | 101 |
| 5. | Władysławowo Heat and Power Plant | Gas-fired turbine Rols — Royce | 12 |
| 6. | Wizów Bolesławiec Heat and Power Plant | Gas-fired turbine Centaur 50 Solar Turbines | 4.14 |
| 7. | Ostrów Wielkopolski Heat and Power Plant | Gas-fired turbine Centrax — Allison CX501 KB7 | 5 |
| 8. | Polar Wrocław Heat and Power Plant | Gas-fired turbine Centaur 50 Solar Turbines | 3.35 |
| 9. | Siedlce Heat and Power Plant | Gas-fired turbine Solar Taurus | 14.6 |
| 10. | Tarnów Heat and Power Plant | Gas-fired turbine | 3.75 |

Source: Kozłow, Badur 2002 and others

As it can be seen, the power of these systems is diversified, from a few megawatts (Tarnów Heat and Power Plant, Ostrów Wielkopolski Heat and Power Plant), through a few dozen megawatts (Gorzów Heat and Power Plant) to more than 100 megawatts (Nowa Sarzyna Heat and Power Plant, Lublin-Wrotków Heat and Power Plant — currently the largest heat and power plant in Poland based on natural gas (Pawlik 2003).

The first enterprise in the country where the gas and steam unit started in January 1999 was The Gorzów Heat and Power Plant. The gas and steam unit comprises:

— the gas fired turbine set, driven by GT8C single-shaft turbine of electrical power 54.5 megawatts and efficiency — 34.6%;
— single pressure exhaust heat boiler, generating 450°C steam with efficiency 83.5 t/h;
— two back pressure turbines of the total power of 11 MW.

The Gorzów Heat and Power Plant uses nitrated natural gas of calorific value 20.2 MJ/m$^3$, delivered from the Cychry field. The annual demand for this gas by this plant is equal to 230 million m$^3$ (the contract for the delivery of natural gas was signed for 20 years, with the option of extension). The start-up of the gas and steam unit allowed replacing four worn out OP-60 coal fired boilers (www.ecg.com.pl; Rejman, Szurlej 2003).

In 2000, the regular operation of the gas and steam unit started up at the Nowa Sarzyna Heat and Power Plant (the unit was commenced in August 1999). The electrical power of the unit system is equal to 116 $MW_e$ and thermal power 40 $MW_t$. The construction of the unit cost million USD 132 (the funds originated chiefly from Bank credits, and are anticipated to be paid off within 14 years). The gas and steam unit comprises:

— two gas turbine sets PG6561(B),
— two waste heat boilers, with additional firing system manufactured by SEFAKO, Sędziszów (Poland),
— one steam turbine set, with one adjustable and one non-adjustable steam outlet,
— reserve steam boilers.

The heat and power plant supplies heat for the Nowa Sarzyna town, while the electricity is sold to the Polskie Sieci Energetyczne SA. (Polish Power Grid Company), and the process steam is supplied to the Organika Sarzyna Chemical Plant. The deliveries of gas are realized based upon the 20-year contract signed with PGNIG S.A. The demand of gas fluctuates between 26 and 28 thousand m$^3$ per hour (180 million m$^3$ per year).

The gas and steam unit at the Lublin-Wrotków Heat and Power Plant was started up in April 2002. The unit comprises (www.ec.lublin.pl; Markowski 2001, Szurlej, Mokrzycki 2003):

— the gas turbine set for electricity production (manufactured by Ansaldo, Italy),
— double pressure waste heat boiler (without afterburning system), using the heat of flue gases from steam production,
— extraction heat and condensation gas turbine set for heat and electricity production in CHP co-generation.

The basic parameters of the gas and steam unit are as follows: electrical power 235 megawatts, thermal power 115 megawatts. The investment outlays for the Lublin-Wrotków Heat and Power Plant development to the gas and steam unit amounted to million USD 127 (at the average rate of exchange from 2000). The sources of funds for financing were as follows:

— chiefly commercial credits,
— own funds of the heat and power plant (about million USD 13.8),
— preference credits from the National and Province Fund of Environmental Protection and Water Economy (about million PLN 17.3).

The table 2 presents the basic technical parameters related to the operation of the heat and power plant based upon the hard coal (2001), as well as on natural gas and coal (2002). Due to the fact that the operation of the gas and steam unit was commenced in April 2002, the year 2002 cannot be adopted for the analysis of characteristics of gas and steam operation on the

entire year scale. According to the estimates, the consumption of coal in the heat and power plant is expected to lower within the entire year from 225 thousand Mg to 66 thousand Mg due to the start-up of the gas and steam unit. The gas and steam unit will consume 345 million $m^3$ of natural gas (of calorific value not less than 33.7 $MJ/m^3$) per year. The heating oil has been anticipated to act as an auxiliary fuel.

TABLE 2

Basic technical parameters of the Lublin-Wrotków Heat and Power Plant

TABELA 2

Podstawowe parametry techniczne Elektrociepłowni Lublin-Wrotków

| Parameter | Unit | Year | |
|---|---|---|---|
| | | 2001 | 2002 |
| Thermal power | MW | 442 | 592 |
| Heat production, in which:<br>from gas and steam block<br>from water boilers | GJ | 4 142 170<br>—<br>— | 3 588 206<br>1 791 782<br>1 796 424 |
| Electricity generation | MW·h | — | 1 342 265 |
| Gas consumption, in which:<br>heat generation<br>electrical energy generation | Thousand $Nm^3$ | —<br>—<br>— | 279 580<br>47 506<br>232 074 |
| Coal consumption | Mg | 218 053 | 91 692 |

Source: www.cc.lublin.pl

In May 2003, the Rzeszów Heat and Power Plant started to operate the gas and steam unit (BGP-100). Following the extension, the heat and power plant has the electrical power of 100 MW (electricity was not produced before the extension), and the heat generation power 332 MW.

The basic subsets of the BGP-100 unit are as follows:

— the gas-fired turbine, consuming natural gas (basic fuel) or diesel oil (emergency fuel),
— double pressure waste gas boiler fed with flue gases from the gas-fired turbine,
— pass-out condensing gas turbine fed with steam from the waste heat boiler,
— air-cooled generator.

The high methane natural gas is the basic fuel for the gas and steam unit. It is estimated that the yearly demand for the gas fuel will be equal to 148 million $m^3$. Prior to the extension, the heat and power plant consumed about 110 000 tons of coal. Now the anticipated fuels share will be: 60% — natural gas, 40% — coal. The gas and steam unit characterizes of high ratios of utilizing the chemical energy of fuel, electricity efficiency at the level of 50% and total efficiency equal to 89% (Rejman, Szurlej 2003; Szurlej, Mokrzycki 2003).

In June 2002, the heat and power plant at Władysławowo started operation using the natural gas being a by-product of crude oil extraction from Baltic-Beta drilling rig, located some 80 km away from the Baltic Sea bank line (to the North of Rozewie). The gas from the platform is delivered by the undersea, polyethylene coated, flexible coiled pipes gas pipeline of the length of 82 km and diameter 150 mm (the longest gas pipeline of this type in the world). Due to the fact that the gas delivered to Władysławowo contains more than 20% of propane and butane, the station of separation and storage for LPG was constructed (this gas is sold to outside companies). Following segregation of the liquefied gas and natural gasoline, the gas, at the rate of 120 000 $m^3$ per day feeds the gas-fired turbines and water boilers. The total cost of the project, including the gas pipeline construction, amounted to million USD 35. The principal equipment of the heat and power plant comprises: two gas-fired turbines, two waste heat boilers, and three peak load water boilers. The total electrical power is equal to 12 megawatts, while the basic thermal power is equal to 18 megawatts, and the peak load power is equal to 15 megawatts. It is estimated that the heat and power plant will operate based upon the gas from the sea deposit by the year of 2015. After the exhaustion of this fuel, the unit will be fed from the national transmission grid (www.energobaltic.com.pl).

## 3. Prospects of utilizing the natural gas in the Polish and European Union power industry

It is expected that the gas fuels utilization will rise in the Polish power industry, the process of increasing the consumption of gas fuels being gradual — by the year of 2010, some 590 megawatts of power are intended to be built in the steam and gas units, and further growth by 2120 megawatts in the similar enterprises is anticipated for the years 2011—2015 (Gajda at al. 2002). However, the solid fuels (hard coal and brown coal) will remain the basic fuel for the Polish power industry.

There are some views with regard to the development of the power supply sector in Poland. Three variants of economic development were presented in the Assumptions of Energy Policy for Poland by 2020 (2000) (the growth of gross national product from 2.3% to 5.5%). According to these extreme variants, the production of electricity anticipated for 2020 is as follows:

— in the least optimistic variant (Survival) — 202 TW·h,

— in the most optimistic variant (Progress) — 236 TW·h.

That governmental document anticipated the national consumption of natural gas in 2020 at the very high level of 26—29 billion $m^3$. Such exaggerated forecast concerning natural gas consumption was, among other things, a result of the assumption that the natural gas would be utilized in power industry on the larger scale.

The table 3 presents the outlook of professor J. Marecki concerning prospects of the electricity generation, with the specification of the shares of particular energy carriers in Poland by 2020.

Based upon this table it can unambiguously be seen that irrespective of the variant adopted (Low or High), the utilization of the energy carrier in the form of natural gas for electricity generation purposes characterizes with the largest growth. According to the forecast, more than 25% of electricity will be produced from gas fuels in 2020. Currently the construction program is underway of building the gas and steam unit at the Zielona Góra Heat and Power Plant (the planned date for completion of the project — half of 2004; electrical power 190 MW, thermal power 95 MW, basic fuel — nitrated natural gas of the minimal calorific value of 28 MJ/m$^3$, approximate annual demand — 370 million m$^3$). KGHM Polska Miedź, wishing to lower the expenditures for purchasing the electricity, intends to construct the gas-fired heat and power plant at Polkowice, as well as in Głogów Copper-Works (the contract was signed with PGNIG S.A. for the purchase of 10 billion m$^3$ of gas within 20 years). In addition, the construction of gas and steam units is planned at the Żarnowiec gas-fired power plant — with power 256.4 $MW_e$ (1000 $MW_e$ after the end of construction), at the Gdańsk refinery — 300 MW, at the Wybrzeże Heat and Power Plants Complex — 200 MW. However, it should be highlighted here that the current announcement of the government, regarding the termination of the long-term contracts for the sale of capacity and electricity, might have adverse impact on the development of the power industry,

TABLE 3

Outlook of electricity generation by energy carriers in Poland by 2020

TABELA 3

Prognozy produkcji energii elektrycznej w Polsce do 2020 roku w podziale na nośniki energii

| Variants | Source of energy | Year | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2000 | | 2010 | | 2020 | |
| | | TW·h | % | TW·h | % | TW·h | % |
| Low | Hard coal | 87 | 61 | 88 | 53 | 95 | 43 |
| | Brown coal | 51 | 36 | 55 | 33 | 55 | 25 |
| | Natural gas | — | — | 17 | 11 | 60 | 27 |
| | Renewable sources of energy | 4 | 3 | 5 | 3 | 10 | 5 |
| | Gross total production | 142 | 100 | 165 | 100 | 220 | 100 |
| High | Hard coal | 87 | 61 | 90 | 49 | 90 | 35 |
| | Brown coal | 51 | 36 | 55 | 30 | 55 | 22 |
| | Natural gas | — | — | 35 | 18 | 75 | 29 |
| | Renewable sources of energy | 4 | 3 | 5 | 3 | 15 | 6 |
| | Nuclear power industry | — | — | — | — | 20 | 8 |
| | Gross total production | 142 | 100 | 185 | 100 | 255 | 100 |

Source: Marecki 2002

in particular, the power industry based on the natural gas. The long-term contracts allowed conveying the costs of purchase of the natural gas into the tariffs for the sales of electricity to the Polish Power Grid Company, as well as tariffs for the sales of heat to the local recipients. Such solution guaranteed the permanent income to the power plants, necessary for paying off the credits. At the same time, the long-term contracts acted as a security and guaranteed the repayment of the investment credits contracted (Kosa 2003).

The table 4 shows the consumption of particular energy carriers for the production of electricity in the EU countries (25 countries — after the EU enlargement of May 1, 2004).

TABLE 4

The outlook of utilizing particular energy carriers in the electrical power industry of the EU by 2030, Mtoe

TABELA 4

Prognoza zużycia poszczególnych nośników energii w elektroenergetyce Unii Europejskiej do roku 2030, Mtoe

| Energy carrier | Year | | | |
|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2030 |
| Hard coal | 132.7 | 103.1 | 133.2 | 195.9 |
| Brown coal | 77.5 | 67.3 | 57.8 | 45.8 |
| Crude oil | 41.8 | 24.7 | 18.8 | 20.8 |
| Natural gas | 112.1 | 186.3 | 243.5 | 255.3 |
| Biomass | 8.0 | 11.6 | 13.0 | 15.1 |
| Waste | 9.7 | 13.8 | 15.2 | 14.5 |
| Nuclear power industry | 237.8 | 245.4 | 213.7 | 185.2 |
| Geothermal sources | 3.0 | 3.4 | 3.6 | 3.9 |
| EU total (25) | 623 | 656 | 699 | 736 |
| Current EU (15) | 541 | 568 | 596 | 625 |
| Candidate countries (10) | 81 | 87 | 103 | 112 |

Source: EC Directorate 2003

The table shows that natural gas will be in 2030 the energy carrier holding the largest share out of all energy carriers in the power industry. It is anticipated that e.g. in the UK some 50% of electricity will be generated in gas-fired power plants as soon as in 2010 (therefore, as early as currently the new directions of imports of this raw material are sought, among other things, in the form of LNG from Qatar). The growing interest in the units utilizing the natural gas can be seen not only in Europe. Taipower from Taiwan is currently constructing the largest gas-fired power plant all over the world, with power 4272 megawatts, and at the cost of billion USD 1.5.

## Summary

The electricity generation sector uses more often the natural gas chiefly due to pro-ecological advantages of this fuel. In addition, the gas units characterize with high ratios of energy efficiency. These are the sources of generation, which may be flexibly controlled, in particular at the peak loads. Characteristic for them is short time necessary for achieving their full power. This provides the gas-fired heat and power plants, as well as power plants, with the better position of the seller on the wholesale market of electricity as compared with the units of the centralized generation.

The dynamic growth of natural gas utilization in the power industry is anticipated in the EU countries. In Poland, the natural gas plays only minor role as the energy carrier in the power industry due to the fact that Poland holds significant resources of solid fuels and the price of natural gas for industry is high — in fact, only a few gas-fired heat and power plants operate. However, in the future, the growth of utilization of the natural gas in electrical power industry may turn out necessary due to the restrictive norms of environmental controls, arising out from the adherence to the EU directives. Also some hope with regard to the increase of the competitiveness of the gas fuels as compared with solid fuels may lie in the liberalization of the natural gas market. However, hard coal and brown coal will remain the basic raw materials for the Polish electrical power industry.

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**GAZ ZIEMNY W ENERGETYCE POLSKIEJ I KRAJÓW UNII EUROPEJSKIEJ**

Słowa kluczowe

Gaz ziemny, wytwarzanie energii elektrycznej, kogeneracja

Streszczenie

Gaz ziemny znajduje szerokie zastosowania zarówno jako nośnik energii, jak i ważny surowiec w przemyśle chemicznym. Jednym z najbardziej obiecujących kierunków użytkowania gazu jest zastosowanie go do produkcji energii elektrycznej. Gazowe elektrociepłownie pracujące w skojarzeniu charakteryzują się wysoką efektywnością przetwarzania energii chemicznej. Z tego powodu gaz jest obecnie coraz częściej używany do wytwarzania energii elektrycznej i można się spodziewać, że jego rola w przyszłości wzrośnie.

Węgiel kamienny i brunatny są surowcami dominującymi w polskim sektorze elektroenergetycznym. Całkowita produkcja energii elektrycznej w roku 2002 wyniosła 144,1 TW·h, a w 96% była ona wytworzona z węgla kamiennego i brunatnego.

Struktura wytwarzania energii elektrycznej w Polsce praktycznie nie zmieniła się w ciągu ostatnich 20 lat. Jedyna, niezbyt znaczącą zmianą jest to, że gaz ziemny zaczął być używany do kogeneracji energii elektrycznej i cieplnej. Wciąż jednak ilość energii elektrycznej wyprodukowanej z gazu jest bardzo niewielka i wynosi 2,1 TW·h (2002), to jest tylko 1,5% całkowitej produkcji. Największą elektrociepłownią, która oprócz węgla używa również gazu jest Lublin-Wrotków.

W artykule przedstawiono krótką charakterystykę polskiego sektora elektroenergetycznego ze szczególnym uwzględnieniem elektrociepłowni pracujących w skojarzeniu w oparciu o gaz ziemny. Opisano powody, dla których nie następuje szersze użytkowanie gazu ziemnego w sektorze. Omówiono również ekologiczne i techniczne aspekty użytkowania turbin gazowych. Dokonano porównania pomiędzy strukturą wytwarzania energii elektrycznej w Polsce i w Unii Europejskiej.

Na koniec przedstawiono perspektywy rozwoju sektora elektroenergetycznego i znaczenie gazu w przyszłej strukturze pierwotnych nośników energii w produkcji energii elektrycznej.