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ENERGY CARRIERS USE IN THE WORLD: NATURAL GAS – CONVENTIONAL AND UNCONVENTIONAL GAS RESOURCES

WYKORZYSTANIE NOŚNIKÓW ENERGII W ŚWIECIE: ZASOBY GAZU ZIEMNEGO W ZŁOŻACH KONWENCJONALNYCH I NIEKONWENCJONALNYCH

This paper discusses forecasts of energy carrier use with particular emphasis on the changing position of natural gas due to global climatic conditions and the increasing role of unconventional natural gas reservoirs. Allocation of natural gas resources in the world are discussed as well as global gas consumption and conditions for development of transport infrastructure and storage. The most important indicators of the energy security of countries are presented. The basic properties of unconventional deposits, and differences in the production/extraction of gas from the conventional and unconventional fields are given. In the paper are also discussed natural gas reserves in Poland, including possible non-conventional resources in the fields and issues of increasing the role of gas as an energy carrier in Poland in the background of the energy changes in Europe and the world.

Keywords: natural gas, conventional, unconventional, resources, technology, energy

W pracy omówiono prognozy energetyczne wykorzystania energii ze szczególnym uwzględnieniem zmieniającej się pozycji gazu ziemnego z uwagi na uwarunkowania klimatyczne oraz wzrastającą role niekonwencjonalnych złóż gazu ziemnego. Omówiono alokację zasobów gazu ziemnego w świecie, zużycie gazu w regionach oraz warunki rozbudowy infrastruktury transportu i magazynowania. Przedstawiono najważniejsze wskaźniki dotyczące bezpieczeństwa energetycznego krajów. Omówiono podstawowe własności złóż niekonwencjonalnych oraz różnice w charakterze wydobycia gazu ze złóż konwencjonalnych i niekonwencjonalnych. Omówiono zasoby gazu w Polsce, w tym możliwe zasoby w złożach niekonwencjonalnych oraz zagadnienia zwiększenia roli gazu jako nośnika energii w Polsce w tle energetycznych zmian Europy i świata.

Słowa kluczowe: gaz ziemny, konwencjonalny, niekonwencjonalny, zasoby, technologia, energia

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1. Introduction

In the current century, natural gas has become the most important fossil energy resource and also the most important energy fuel in general. And this is both due significant resources, especially of unconventional natural gas, and ease of transport or transmission, use but also the level of carbon dioxide emissions from burning natural gas.

Significant increase in gas consumption, in all regions, will be marked in the energy sector. Northern America and Western and Central Europe consume most of the gas on electricity and heat production. The development of gas energy industry in the last decade is caused by (Siemek & Tajdus 2006; Nagy & Siemek 2011; MIT, 2011,):

- introduction, on a large scale, of convenient gas cycle technologies (CCGT, CHP – combination of steam and gas turbines or using of gas engine with the output from a few kW to 3000 MW in case of turbines);
- achievement of high performance cycles – over 50% (the whole 'energy-electricity-heat' cycle – about 90%);
- in comparison with nuclear and hydro-power plants: lower investment and exploitation costs, shorter construction and startup time, less complex design, simpler constructions and installations; unit cost of hydrocarbons (natural gas, crude oil) is higher than coal (in Europe and Asia) and nuclear fuel;
- high degree of social acceptance.

In addition, factors amplifying the expansion of gas industry have emerged:

- the development of liquefied natural gas technology (LNG) and LNG markets means that regional gas trade is beginning to have a global dimension;
- the emergence of gas from unconventional sources, primarily in the US market (gas from shale, gas from deposits of low permeability, gas or methane from coal beds), begins to change trade relations and gas prices. Hence greater ease in obtaining contracts for the supply of gas, including liquefied natural gas, and lowering its prices. The United States are currently the largest consumer of gas;
- unprecedented aspiration for ensuring long-term gas production, its transmission and transport;
- rules governing the operation of gas industry, natural gas markets, are undergoing significant changes at the moment, both on regional as well as international level; comparison or even competition between different regulation systems are becoming a significant element of industry stability in terms of compliance of the supplies with needs, price volatility, investment expenditures and supply security;
- despite weaker or stronger liberalization trends, natural gas remains under strong political influence; it is the only primary energy carrier controlled in almost every link of the gas chain.

The other important factor is relevant to unclear "Future of Nuclear Power after Fukushima" (Tanaka, 2011): "Recent projections for growth in nuclear capacity may now be viewed as optimistic; An increasing number of plants may be retired early due to more stringent safety regulations; Life extensions for older plants may become less common; Investment may be delayed or deferred *Investment to replace the aging fleet in OECD*; *Investment in emerging economies to meet rising base-load demand.* Costs of new nuclear plants may increase. Countries pursuing new nuclear power programs may face difficulties."

The world population is expected to reach 8236 million by the year 2030 and about 9 billion by the year 2050. Energy supply, in those periods for this number of people, can only be assured by a high share of fossil fuels (natural gas, oil, coal). The share of these resources in the profile of primary energy will be around 80% in 2030.

Prognosis relating to the global increase in primary energy consumption and increase in natural gas consumption in the world, according to the International Gas Union (IGU), and (IEA), from now on to the year 2030 r., are shown in Table 1. According to the most probable scenarios of both agencies, gas consumption in 2030 would reach the level of ca. 4,400 billion m^3 (increase in consumption from 1.5 to approximately 1.8% per year). Another approach of both organizations to forecasts was outlined in the conservative scenario by IGU and scenario 450 by IEA.

TABLE 1

Prognosis of natural gas and primary energy demand in the world according to IGU and IEA (IGU, 2009; WEO 2009)

Scenario \ Energy	Shale gas billion m^3/year		Primary energy Mtoe/year	
	2007	2030	2007	2030
IGU – reference scenario	3 000	4 400	12 000	16 500
IGU – conservative scenario	3 000	4 900	12 000	15 000
IEA* – reference scenario	3 049	4 313	12 013	16 790
IEA* – scenario 450	3 049	3 560	12 013	14 389

* 1 toe = 1 210 Sm^3 (15°C, 1 bar, calorific value 34,6 MJ/m^3).

The first one assumes an increase in natural gas consumption at the expense of coal (energy model: natural gas – oil – renewable energy sources). The other assumes limitation of carbon dioxide emissions at all, so that the concentration of greenhouse gases in the atmosphere does not exceed the value of 450 ppm. This scenario assumes the maximum air temperature increase of 2°C, whereas in the reference scenario, this increase is 6°C. The demand for gas is growing in all sectors, but mostly in the energy sector, according to IGU from 1100 billion m^3/year in 2007 to 1,600 billion m^3/year in 2030. A few years ago the main constraint of gas consumption was its price. A clear example here was the U.S.A (Sprunt, 2006). This fact prompted investors and gas companies to seek other energy solutions and other energy carriers, including coal technologies. However, in the U.S.A, the breakthrough came after the turn to unconventional natural gas resources. It is the gas in shale rocks (shale gas), gas in porous rocks with very low permeability (tight gas) and gas from coal beds (coal bed methane). In 2008, gas from such deposits participated in more than 50% (about 360 billion m^3/year) in the profile of natural gases in the U.S.A, including: gas from deposits of low permeability (“tight gas”) ~ 28%, 180 billion m^3/year, methane from coal beds (CBM) ~ 8%, 56 billion m^3/year and gas from shale (“shale gas”) ~ 10.5%, and currently 23% and 137.8 billion m^3/year (according to U.S. Energy Administration Agency, EIA, USA, 2011). Documented unconventional gas resources constitute, for now, only 4% of the total global resources, and extraction is 12% of world extraction (2008). Quite recently, high hopes for the presence of shale gas have been awakened in Poland, with the assessment of resources of approximately 1400 billion m^3, and most recently 5300 billion m^3 (by EIA). Unconventional natural gas may change both the character of trade in liquefied petroleum gas (LNG), the price structure with the tendency towards lower gas prices and energy policy of the world and the European Union. Two factors: unconventional natural gas and energy savings policy may change the image of the global gas markets.

Gas prices are correlated with oil prices, or, to be more precise, they follow oil prices. Hence the high price of oil, did not look promising for consumers not only of liquid fuels, but also natural gas. The role of oil in the world, in Poland, its resources were characterized in an earlier publication AGH (Siemek et al., 2009).

The prognosis, according to data (WEO, 2009) of various energy carrier consumption in the year 2030 is shown below, in %:

	2007	2030
Coal	26,5	29,1
Oil	34,1	29,8
Gas	20,9	21,2
Nuclear Energy	5,9	5,7
Hydropower	2,2	2,4
Biomass and waste	9,8	9,6
Other RES	0,6	2,2

A slight decrease in the share of crude oil can be noted as well as a nonetheless stable, even slightly increasing position of coal, and also natural gas. When it comes to coal, technologies of underground and above-ground gasification come to notice.

During last years (2009-2011) IEA has changed their scenario structure in every report (WEO, 2009, 2010, 2011):

Scenarios in WEO 2009:

1) Reference – unchanged policy
2) 550 ppm –a projection with moderate climate and energy policy changes (level 550 ppm CO_2 in 2035);
3) 450 ppm – projection with significant changes in climate and energy policy (level 450 ppm CO_2 in 2035)

Scenarios in WEO 2010:

1) Current policy – the new-name of “reference“ scenario
2) New Policy –the 550 ppm scenario has been dropped as climate science clearly
3) 450 ppm – as above

Scenarios in WEO 2011:

1) Current policy – important: renewable energy (RE) projections have been increased.
2) New Policy – remarkably low the (Carbon capture and storage) CCS – only 1% of the total fossil fuel power plants with CCS by 2035).
3) 450 ppm – projection close to WEO 2010
4) Low Nuclear case – assume of nuclear significant delays in new nuclear power plant projects.

In view of the economic and financial crisis in the period from 2008 to 2010, the IEA (WEO 2011) developed a scenario ‘2035 New Policies Scenario WEO-2010’, and the next scenario ‘Scenario GAS 2035’. The latter, considered the most reliable, the assumes the following:

– significant increase in energy consumption, particularly of natural gas in China, to about 620 billion m^3/year in 2035
– reduction of investment (by about 10%) in nuclear energy,

– CO_2 and greenhouse gases emissions remain at the level of 650 ppm (in comparison with the 450 ppm scenario from 2009). As a consequence, atmospheric temperature increases by 3.5° C in a sufficiently long time.
– increase in the use of unconventional gases (by about 40% in 2035).

The picture below (Fig. 1) (WEO, 2011), shows how energy prognosis changed.
Table 2 according to WEO (2011) shows the results of prognostic calculations for 2 scenarios

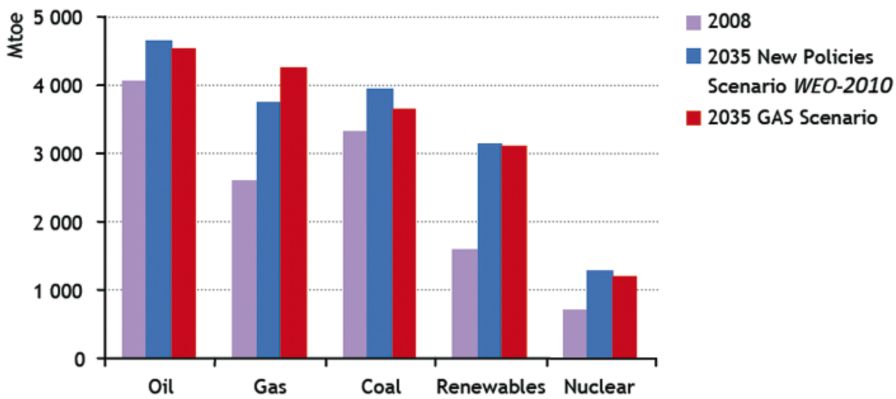

Fig. 1. World primary Energy demand by fuel and scenario (WEO, 2011)

(2010 and 2011). One can notice an increase in the share of gas from 21% to 25% (Table 1a) in world power consumption. One can also notice that major changes occurred in the assessment of global energy consumption in 2035 compared to 2035 (Table 1a). Hence the conclusion about stabilization of growth in world energy demand.

TABLE 2

Prognosis of global energy demand according to 2 scenarios – 2010 and 2011 (WEO, 2011)

			GAS Scenario		New Policies Scenario *WEO-2010*	
	2008 Demand (Mtoe)	**2008 Share in energy balance**	**2035 Demand (Mtoe)**	**2035 Share in energy balance**	**2035 Demand (Mtoe)**	**2035 Share in energy ba-lance**
Coal	3 315	27%	3 666	22%	3 934	23%
Oil	4 059	33%	4 543	27%	4 662	28%
Gas	2 596	21%	4 244	25%	3 748	22%
Nuclear energy	712	6%	1 196	7%	1 273	8%
Hydropower	276	2%	477	3%	476	3%
Biomass	1 225	10%	1 944	12%	1 957	12%
Other RES	89	1%	697	4%	699	4%
Total	**12 271**		**16 765**		**16 748**	

When it comes to natural gas, an increase in consumption is projected as follows (table 3): (in billion m^3/year).

TABLE 3

Increase in consumption in the world (IGU, 2009)

	2018	2020	2030	2035	
World	3149	4019	4778	5132	**↑ 1,8% yearly**
UE	536	587	621	636	**↑ 0,6% yearly**

The largest increase in natural gas consumption will be noticed in the energy sector (more than 2000 billion m^3/year in 2035). The values relating to the year 2030 fall within the range of forecasts by IGU (Table 1).

Because of the position of the United States in the consumption of natural gas, and because of the impact the country on trade and gas (and oil) prices in the world, forecast graphs relating to the gas industry in the U.S.A, according to (OPGR 2011) are presented below. In 2008, the U.S.A. consumed 662 billion m^3/year and in 2030 they will be consuming around 741 billion m^3 in 2035 786 billion m^3/year, according to WEO (2011).

Prognosis of conventional and unconventional natural gas extraction in the USA in Tcf/year and in % (OPGR 2011) is presented in the fig. 2

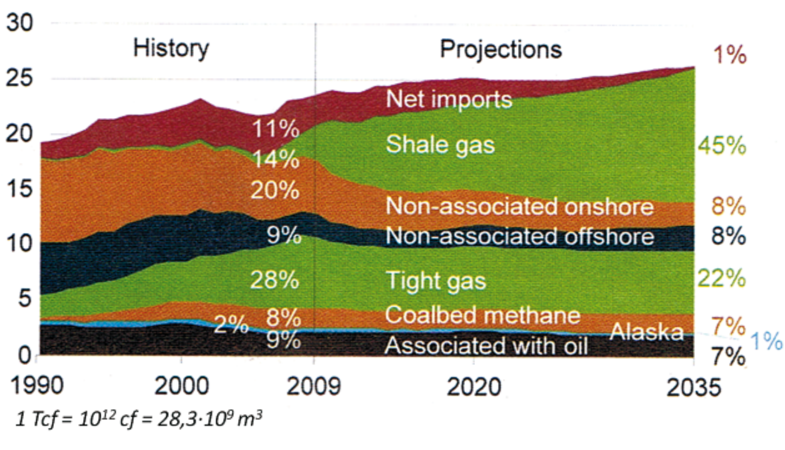

Fig. 2. Forecast of conventional and unconventional natural gas extraction in the USA in Tcf/year and in % (OPGR, 2011 after AEI, 2011)

Share of individual energy carriers in electric power generation in the U.S.A in [10^{12} kWh/year] in [%] (OPGR 2011) is presented in fig. 3 and estimated emissions of carbon dioxide (CO_2) and greenhouse gases according to CO_2 are visible in fig. 4 (OPGR 2011). Forecast of oil prices in the years 1980-2035 in [USD/barrel] in 2009 are shown in fig. 5.

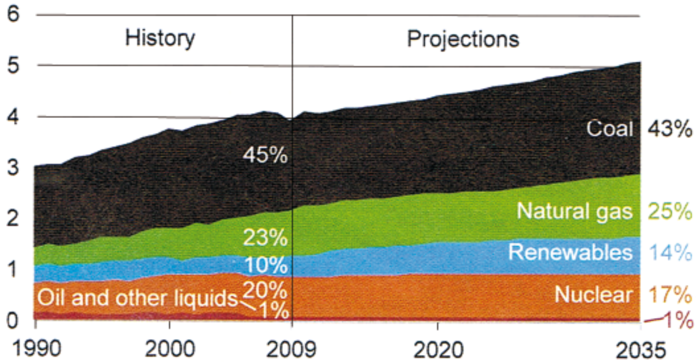

Fig. 3. Forecast energy demand in the USA in Tcf/year and in % (OPGR, 2011)

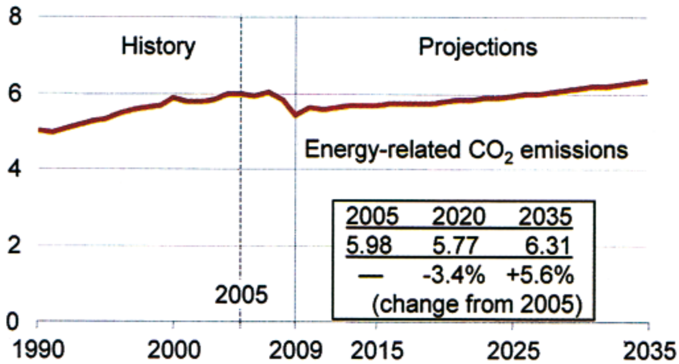

Fig. 4. Emissions of carbon dioxide (CO_2) and greenhouse gases according to CO_2 equivalent in [10^9] (OPGR, 2011 after AEO, 2011). CO_2 emissions in the world – ca. 30 Gt (10^9 tons) in 2010

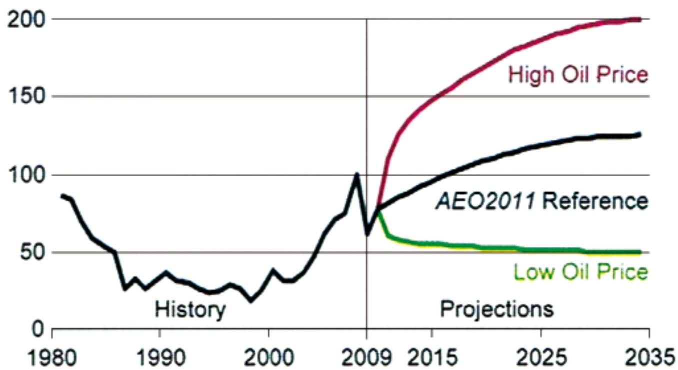

Fig. 5. Forecast of oil prices in the years 1980-2035 in [USD / barrel] in 2009 (OPGR, 2011 after AEO, 2011)

The conclusions from these predictions are as follows:
- the role of shale gas in the U.S.A is increasing (up to 45% of extraction in 2035) and gas from deposits of low permeability (tight gas – 22%)
- gas imports to the U.S.A will cease in 2035
- coal will still have a significant and dominant role in electricity generation.

The strong position of coal is similar to its position in Poland. The U.S.A. control the extraction and use of energy carriers very reasonably.
- CO_2 emissions until 2035 will remain constant at around $6 \cdot 10^9$ tons (ie. about 17% of global emissions).
- price of oil barrel (bbl) will increase but rather moderately, and according to reference scenario (AEO 2011) in 2035, it will be ca. $ 125/bbl (according to 2009 prices). Increase in relation to the current price (around 75 USD / bbl), would be about 65%.

According to WEO (2011) gas prices, compared to 2009, will increase in 2030 by about 36%, and in 2035, about 47%, and follow the rise in oil prices.

2. Gas resources allocation and natural gas production

Location of natural gas resources in the world and in the regions adjacent with the European Continent and the European Union have been well described in the publication (Siemek et al., 2009), because in this passage section is restricted to citing the most recent estimates and predictions. They were also used and confronted reports IGU, IEA and BP. According to BP (2009) updated at the end of 2008 natural gas reserves amounts (in 10^{12} m^3) (table 4).

Natural gas production in 2008 year – according to BP (2008) amounted (Table 5).

TABLE 4

Location of natural gas resources and sufficiency BP (2009)

		Percentage	Sufficiency (in years)
World	185,02		60,4
European Union	2,87	1,6	15,1
Russian Federation	43,30	23,4	72
Russia and the former republics	57,00	30,8	71,8

TABLE 5

Natural gas production in 2008 r. according to BP (2009)

	Mtoe	Percentage	in billion m^3
World	2 768		3 045,6
European Union	171,3	6,2	190,3
Russian Federation	541,5	19,6	601,7
Russia and the former republics	714,3	25,8	793,7
Norway	89,3	3,2	99,2

Note: Data in BP are related to m^3 at (15°C, 1 atm) and the heat of combustion 37,7 MJ/m^3 (heat of combustion of gas 40 MJ/m^3), 1Mtoe = $1{,}151 \cdot 10^9$ m^3

All previously reported numerical characteristics relate to the conventional natural gas resources. The size of conventional resources is determined by the International Energy Agency (IEA) in two categories: as documented resources and as prospective resources (yieldable). About their sizes directs figures reported in Table 6.

TABLE 6

Allocation of conventional natural gas resources in different regions of the world – WEO (2009)

	Documented resources (tcm)	Share in global resources (%)	Recoverable Resources (tcm)	Extracted till now (tcm)	Other resources in deposit (tcm)	Share in global reserves (%)
Middle East	75,2	41,2	134,8	2,3	132,5	32,8
Eurasia	54,9	30,1	151,8	15,2	136,5	33,8
Asia Pacific	15,2	8,3	33,9	3,1	30,8	7,6
Africa	14,7	8,1	29,9	1,2	28,7	7,1
North America	9,5	5,2	68,8	36,6	32,2	8,0
Latin America	7,5	4,1	24,5	2,1	22,4	5,5
Europe	5,4	3,0	27	5,7	21,3	5,3
World	**182,4**	**100**	**470,7**	**66,1**	**404,5**	**100**

1tcm = 10^{12} m^3

Prospective resources are more than two times bigger than resources in a well recognized and documented natural gas beds. By the consumption of gas in the world, averaged about 3 018 billion m^3 in 2008, the amount of documented gas beds would be enough for over 60 years, however prospective resources prolong this period to well over 120 years. Therefore, it can be concluded that the primal energy carrier will dominate in the XXI century. Natural gas extraction technologies and its transmission, both from terrestrial and undersea deposits, have achieved a high level of development and now allow the exploitation of remote gas beds in difficult geological conditions.

Expected natural gas production both conventional and unconventional in long years 2035 in [billion m^3/rok], according to WEO (2011), shown below in Table 7:

TABLE 7

Expected natural gas production (WEO, 2011)

	2008	2020	2030	2035
World	3167	4019	4778	5132
EU	216	165	113	93
Norway	102	114	128	127
Russia	662	720	842	881

Fig. 6 & 7 show forecasting of gas production of the conventional and unconventional gas till the year 2035, according to WEO (2011).

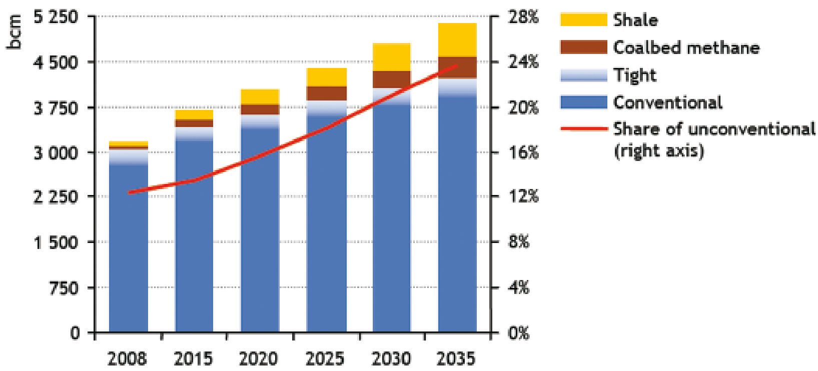

Fig. 6. Production of natural gas according to beds classification (WEO, 2011)

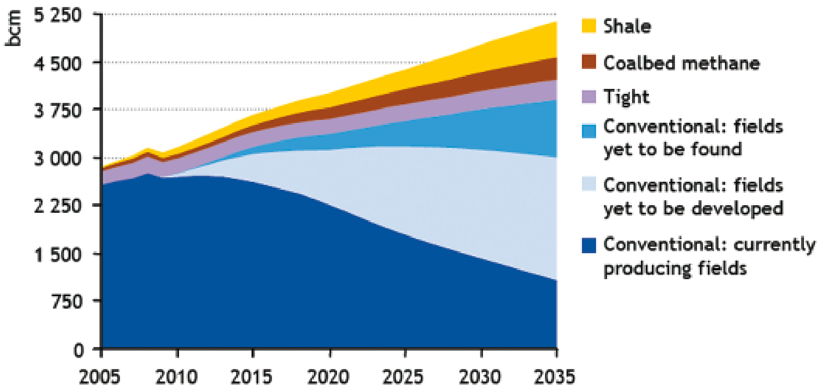

Fig. 7. Forecast of gas production from different deposits (WEO, 2011)

Both diagrams show that the share of unconventional gas in 2035 will not be outnumbered 24% in the profile of the world gas economy. And only the part of it (around 10%) has shale gas. Still, according to forecasts, principle value has conventional gas and its beds.

Natural gas resources is a key element of the expanding gas industry, but not the only one. The global dimension of natural gas as primary energy carrier, is conditioned by transport and storage infrastructure. Transmission and trade of natural gas can be lead up by:

- Gas-mains reaching the length of 4,000 km
- Application of liquefied natural gas technology (LNG) and transport over long distances by sea
- Expansion of gas systems with underground gas storages able to store sufficient amounts of gas – up to 25% of yearly domestic consumption

In the years 2010-2030 the industrial pipeline network will keep developing. Fig. 8 shows, according to Tubb (2011), the length of transportation pipelines of natural gas and petroleum, planned or already under construction in different parts of the world.

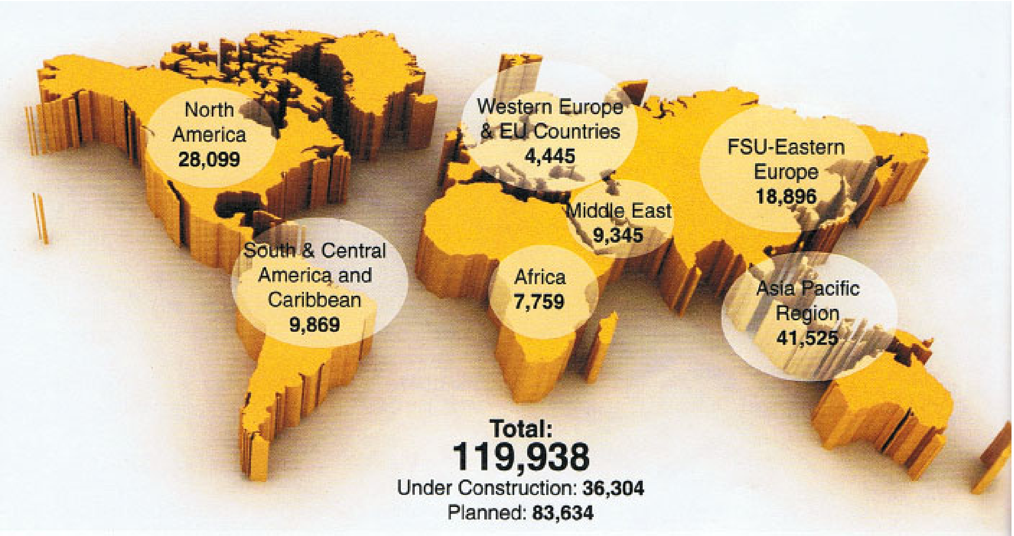

Fig. 8. Total length of pipelines (in miles) under construction and currently planned in different parts of the Word (**1 mile = 1609,34 m**) (OPGR, 2011 after Tub, 2011)

Evident is the supremacy of North America (United States, Canada), Russia and the Asian republics and countries of Eastern Europe, but mainly Asia-Pacific region. Only 4% of the world length of pipelines refers to the transportation of petroleum and other liquid raw materials (in North America – 8%), other pipelines are designed to transport the natural gas. The report (Tubb, 2011) notes also that in the United States and Canada alone natural gas pipelines reach the length from 28,900 to 61,600 miles (46,500 to 99114 km) in years after 2030. In the Asia Pacific region, the leader in the gas pipelines construction is China, especially their national concern – China National Petroleum Company (CNPC). Currently, in various phases of accomplishment, there are natural gas pipelines projects with a total length to 20,000 km. In Europe, the most visible, currently ending investment, is the Nord Stream – Fig. 9 (Tubb, 2011). The pipeline runs from the town of Vyborg (Russia) to the port city of Greiswald in the Federal Republic of Germany. The pipeline is being built by the Nord Stream AG company and will be the double pipeline. The first line of the pipeline with a capacity of 27.5 billion m^3/year is started in 2011, while the second line, boosting the productivity up to 55 billion m^3/year, is to be launched in 2012. This amount of gas is also to provide energy for 26 million households. The cost of the pipeline is approximately 7.4 billion EUR.

Several gas concerns: Gazprom, Ruhrgas E. (BASF), Winteshall (Germany) and Gasunie (Netherlands) committed their efforts to the construction of the North Stream. Other planned pipelines which are of interest of Europe (mostly European Union) are: the South Stream (30 billion m^3/year), Nabucco, AGRI – Azerbaijan – Georgia – Romania with a transport in liquefied form by tankers across the Black Sea (7 billion m^3/year). Their proposed locations of Nabucco and South Stream are shown in the Fig. 10. The future of constructing Nabucco pipeline is still unclear after signing several agreements between Russia and other states supporting South Stream conception.

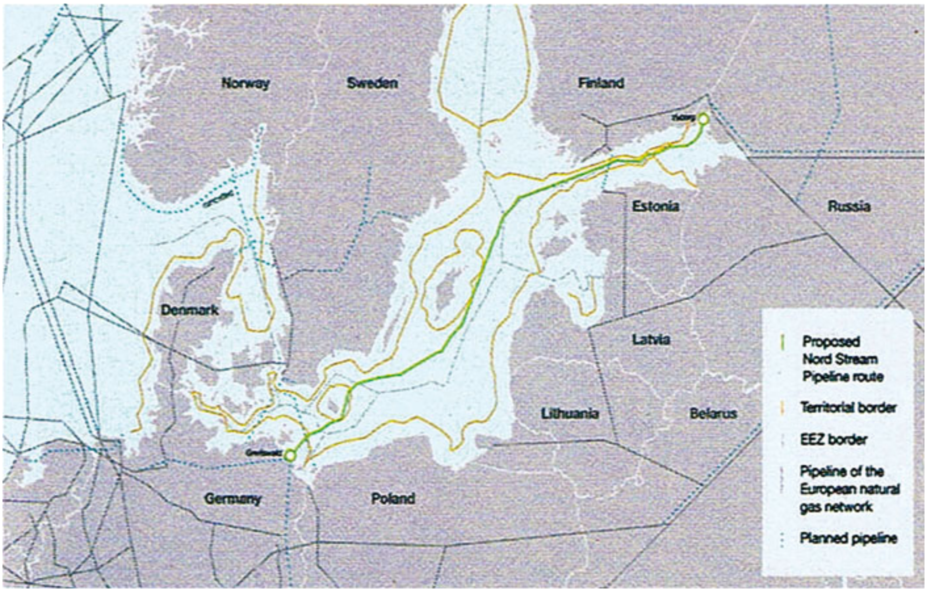

Fig. 9. Location of Nord Stream with territorial maritime borders of states and exclusive economic zones (OPGR, 2011 after Tub, 2011)

Fig. 10. Proposed South Stream and Nabucco gas pipelines, according to Nabucco, ENI Siemek at al. 2009)

It cannot be omitted the description of the another ambitious project, known as the Trans-Saharan Gas Pipeline (TSGP) projected by the Nigerian National Petroleum Company and the Algerian Sanatrach. The three African countries: Algeria, Nigeria and Niger have signed an agreement to launch the designing of this pipeline. Gazprom, the French gas company Total and the European Union, have shown an interest in the project. The characteristics of this project are as follows: length of the pipeline from the Niger River delta to the coast of Algeria – 4127 km, the transmission efficiency – about 20 billion m^3/year, estimated costs of the project – about USD 10 billion, plus USD 3 billion for the development of gas beds in Nigeria.

The European Union, despite having its own natural gas resources, will has to import in 2030, almost 75 to 80% of gas consumed. The main directions for import are Norway (North Sea), Russia, Algeria and in smaller quantities Nigeria (LNG), Egypt, Middle East, and Azerbaijan. Natural gas demand for Europe.

Deliveries, or natural gas trade, is conducted with increasing intensity by using the technology of LNG (Liquefied Natural Gas). Facts and the future of LNG is described below (IGU, 2009):

- Till 2008 the LNG production, during the preceding 5 years, had increased by 50%, and then decreased as a result of the global crisis. In 2010 this production should have remained at the level of 380 billion m^3/year;
- High prices of steel, engineering construction, capabilities of technical personnel, have caused the increase of costs of LNG, to about USD 1,000/ton/year;
- The expected production of LNG is going to increase from about 400 billion m^3/year in 2015 to 750 billion m^3/year in 2030 (17% of global natural gas consumption);
- The efficiency of re-gasification terminals will be increased in relation to installations liquefying two-fold. It will enable greater liquidity and growth of competitiveness of the LNG.
- Quatar is becoming a leading country in the production and transportation of LNG. First liquefying terminals are being built by Norway and Russia (Sachalin).
- Medium distances in maritime transport of LNG, amounted 7100 km in 2008, and may reach 8000 – 8500 km in 2010; one tanker takes from 125000 m^3 to 250000 m^3 of LNG (100000 m^3 LNG = 60 million m^3 of gas).
- Long-term delivery contracts of LNG will dominate. It is not expected to increase "spot"-types deliveries, but short-term contracts (few years) will be increasing.
- Gas streams in inter-regional trade will depend (and currently depend) on gas prices. It becomes the strong competition between LNG and shale gas and sedimentary rock gas in the USA.

European countries, in 2007, imported 51 billion m^3 (approximately 22% of world trade in LNG) of liquefied natural gas (LNG) (IGU 2009). Re-gasification abilities of European LNG terminals are as follows (in billion m^3/year):

active terminals before 2010	120
terminals under construction	70
terminals planned	98
terminals planned in the future	112
terminals open after 2010	191

In western European countries LNG terminals play only the complementary and the regional role in relation to gas pipeline transport. Only in Spain they are the primary source of gas supply. The re-gasification terminal utilization in Europe in 2007 was 56%, while the LNG storage capacity (in the "on import") was 16%.

Important elements of the gas system are underground natural gas storages. They are made in: derived or partially derived deposits of natural gas, petroleum, hydrated layers, salt and rock caverns, even in abandoned coal mines (Belgium, USA). The primary objective of the underground natural gas storages is to store up the congested gas in periods of reduced or low consumption (summer period) and giving back in periods of excessive consumption (winter period, low temperatures), as well as receiving imported gas. Magazines are also built for strategic aims – to store gas reserves as a guarantee of energy security. Schematic types of underground natural gas storages are illustrated in the fig. 11. Currently in the world there are more than 600 active underground natural gas storages (40% in the U.S. and Canada, 25% in Europe and 31% in the Russian Federation and the Asian republics. The total capacity is about 270 billion m^3 (2003). Underground natural gas storage individual capacity fluctuates from a few dozen million m^3 of gas to several billion m^3 of gas. Poland has six natural gas storages with a total capacity of 1.6 billion m^3 of gas in one separated in salt caverns, the rest are exploited deposits of natural gas. Receiving abilities of all underground natural gas storages in Poland amounts to 33 million m^3/day.

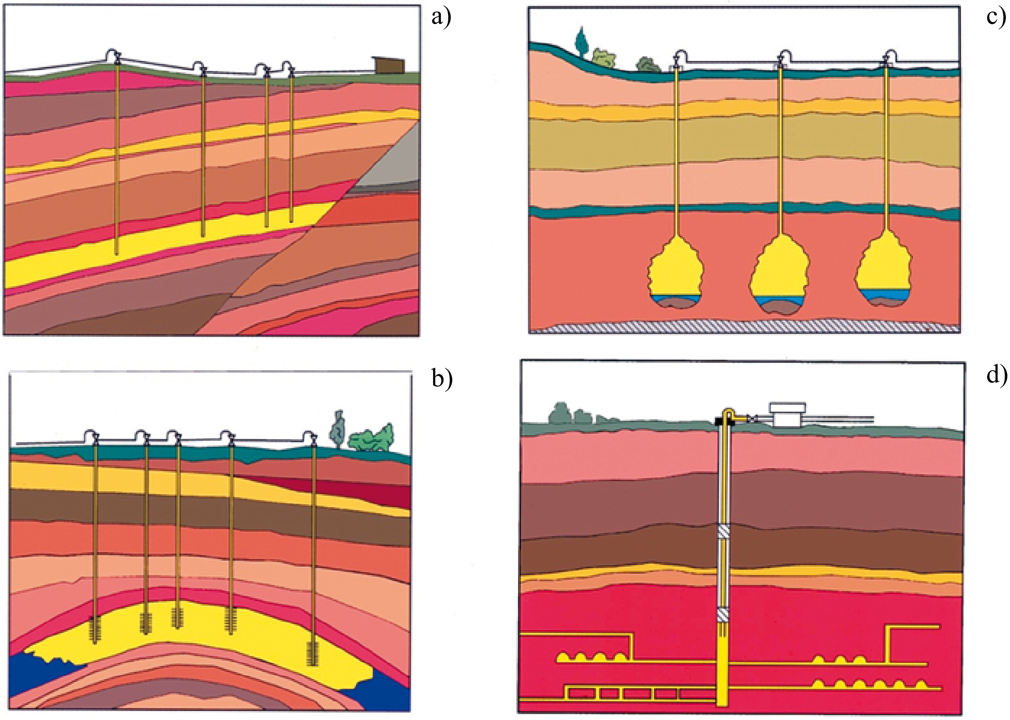

Fig. 11. Types of underground natural gas storages (Nagy & Siemek, 2010 after Kretzmar, 2007): a) underground natural gas storage in porous media; b) salt cavern gas storage; c) ugs in aquifers; d) ugs in abandoned coal mines or in other mining workings

A very important element of energy security is the certainty of energy supply, in this case natural gas supplies coming from private sources or from other countries or regions. And here it appears a problem of multidirections of gas import or its diversification. Neither too much dispersion of gas suppliers, or the concentration of imports from one direction is not advantageous. To assess the concentration (a measure of concentration) introduced two indicators. The first is the Herfindahl-Hirschman Index (HHI Index) defined as (adapted by Sikora (2010) after Hirschman 1964):

$$HHI = \sum_{i=1}^{n} U_i^2$$

where:

U_i — share in supply of gas for the country or region from *i*-source, but without own country

n — number of import directions.

This indicator can undergo decomposition in order to obtain a binomial formula compound of a relative concentration (inequality feature) as well as an absolute, depending on the number of market suppliers in particular of natural gas. Decomposition can be used to make dynamics evaluations in economy and gas trade (Kryzia, 2010) and the concentration of gas resources, the concentration of extraction, the concentration of consumption, the concentration of export of gas and concentration of import of natural gas. The HHI can fluctuate from a value of $1/n$ with n sources of gas to 1 with only one source (the highest concentration degree). If U_i shares are expressed as a percentage of the $10000/n <$ HHI <10000. The European Union accepts as satisfactory value of HHI which is not greater than 2000. According to Sikora (2010), Europe's highest HHI values for gas imports -10000, reached: Bulgaria, Finland, Ireland, Lithuania, Romania, Serbia, Slovakia, Estonia, Latvia, Bosnia and Herzegovina and Macedonia. Poland holds the HHI equal to 6405 (domestic production, mainly importing from Russia). The lowest HHI have: France, Italy, Spain, Belgium, Germany and Holland – all within or below the 3000. HHI does not include the domestic extraction.

Another measure of concentration is the Shannon-Wiener index (SWI) and its modification (SWIm). They are expressed in equations (Sikora, 2010):

$$SWI = -\sum_{i=1}^{n} (U_i x_i \ln U_i)$$

or

$$SWIm = -\sum_{i=1}^{n} (b_i U_i \ln U_i)(1 + g_i)$$

Where b_i means the certainty of suppliers factor ($b_i = 1$ for a very reliable supplier) and g_i – the share of domestic production of gas in the national economy. This time $SWIm \geq 1$ is a high certainty of gas supply, $0.5 \leq SWIm <$ a moderate stability, and $SWIm < 0.5$ strongly unfavorable situation. For example, set of *SWIm* summarized for several European countries [8]:

the Netherlands – 3,44
Great Britain – 2,11
France – 1,77
Germany – 1,33
Austria – 0,91

Poland	–	0,61
the Czech Republic	–	0,56
Slovakia	–	0,0
Finland	–	0,0

In the Polish energy situation significant resources of coal and the good functioning of the "coal-gas" energy model must be noted, dominating until the second half of the twenty-first century for certain.

3. Resources of unconventional natural gas reservoirs

The essence of the classification of natural gas as conventional or unconventional has been well recognized in Figure 12 (by Holditch (2006) and Masters (1979), according to the WEA (2009)).

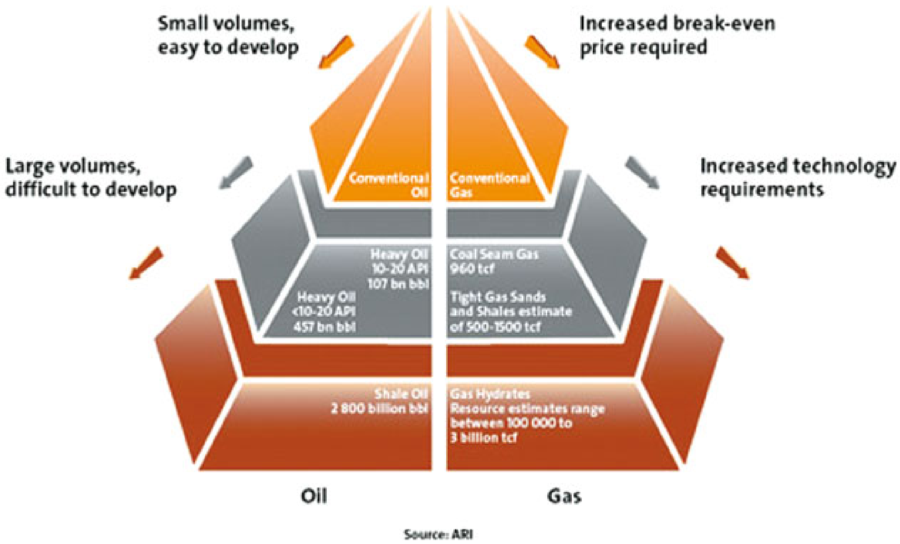

Fig. 12. Classification of natural gas sources (Masters (1979), Holditch et al. (2006), WEO (2011))

Unconventional natural gas deposits far outweigh conventional and may constitute an important energy reserve for humanity, taking into account the addition of over 2.5 times less carbon dioxide emissions in relation to CO_2 emissions when burned by the coal, brown coal, oil and its derivatives industry.

Unconventional natural gas resources are:

– gas in reservoirs with low permeability (from < 0.1 mD to < 0.001 mD) contained in pores with limited connections between them (so-called tight gas);
– gas (methane) in coalbeds, both in the free form in the cracks, as well as in the form of adsorbed (coal bed methane – CBM);

– gas in the clayey-mud rocks (shale gas). The basic substance constituting the organic layer generating the gas and oil, is kerogen. Gas remains in the bedrock, does not migrate into other layers.
– gas bound in the form of hydrates. So far, despite considerable efforts and developments in research, engineers have been unable to work out plans for effective technologies of capturing the gas.

The deposits have different capacities for accumulation of gas, as shown in Table 8. Quantities relating to natural gas hydrates draw attention. Locations of unconventional gas reservoir are shown in fig. 13.

TABLE 8

Storage capacities of natural gas

The natural gas reservoir (Φ = 30%, depth 1500 m)	**10-20 m^3 gas/m^3 deposit**
Hydrates	50 (water-bearing layers 70-160, clean hydrate 160-180) m^3 gas/m^3 (reservoir)
Coalbed methane(CBM)	8-16 m^3 gas/m^3 (reservoir)
Tight gas (sandstones of low permeability	5-10 m^3 gas/m^3 (reservoir)
Shale gas (Devonian shales (USA))	1,5-5 m^3 gas/m^3 (reservoir)

However small amounts of gas contained in a unit of volume unit of the layer of Devonian shale impose relatively dense network of wells deployment to sustain gas production (apart from the very low permeability that restricts the flow of gas, drilling a smaller range). Deposits of unconventional gas "in situ" in tcm as shown in Table 9.

TABLE 9

Unconventional gas resources (WEA, 2009)

Region	Deposits of low permeability	Methane in coalbed	Gas in organic clayey rocks	Total
Middle East and North Africa	23	0	72	95
Sub-Saharan Africa	22	1	8	31
FSU	25	112	18	155
Asia – Pacific	51	49	174	274
Central Asia and China	10	34	100	144
OECD Pacific	20	13	65	99
South Asia	6	1	0	7
Far East – Pacific	16	0	9	24
N. America	39	85	109	233
Latin America	37	1	60	98
Europe	12	8	16	35
Central and Eastern Europe	2	3	1 (underrated)	7
Western Europe	10	4	14	29
World	**210**	**256**	**456**	**921**

1tcm = $10^{12}m^3$

Total non-conventional gas resources are substantially greater than conventional (almost 5-fold), among them the dominant role is played by the gas contained in shale bedrock.

The table does not specify the resources present in the form of gas hydrates. Natural gas hydrates occur in the northern, Arctic areas, and undersea deposits. Hydrates were the cause of a failed rescue operation of an outflow of oil in the Gulf of Mexico after the collapse of an off-shore platform operated by the British Petroleum (2010). Estimates indicate that the gas resources bound in the form of hydrates range from $1\ 000 \cdot 10^{12}$ to $5\ 000 \cdot 10^{12}$ m^3, and so outweight the combined resources of all other natural gases.

Only part of unconventional resources can be extracted. Table 10 shows the amount that can be extracted with the currently used methods and prices. Resources possible to extract are comparable to conventional gas resources.

TABLE 10

Deposits of extractable natural gas and costs of extraction, 2010 (WEA 2011), in [tcm]

	Conventional gas		Deposits of low permeability		Shale gas		Coalbed methane	
	tcm	USD/ MBtu	tcm	USD/ MBtu	tcm	USD/ MBtu	tcm	USD/ MBtu
E. Europe and Eurasia	136	2-6	11	3-7			83	3-6
Middle East	116	2-7	9	4-8	14			
Asia/Pacific	33	4-8	20	4-8	51		12	3-8
OECD N. America	45	3-9	16	3-7	55	3-7	21	3-8
Latin America	23	3-8	15	3-7	35			
Africa	28	3-7	9		29			
OECD Europe	22	4-9			16			
World	**404**	**2-9**	**84**	**3-8**	**204**	**3-7**	**118**	**3-8**

1MBtu = 28,3 m^3 (acc. to British Petroleum)

4. Shale Gas Reservoirs Properties

Technological capabilities of shale gas production have been and still are the subject of intensive research in the U.S. and in Europe. United States today, receive about 10% (60 billion m3) of gas consumed in the country from the shale deposits, and this at a lower cost than the cost of natural gas imports through pipelines or liquefied form (LNG), or exploiting deposits of conventional gas. The involvement of U.S. companies in the exploration and exploitation of gas deposits in the Devonian shales (Barnett Shale, Fort Worth basin, central Texas), are reported with data relating to the number of drilling carried out since 1981. In the 15 years period 300 vertical wells were realized, and in 2002-2006, up to 2,000 horizontal wells (Devon Energy company). Currently, horizontal wells reach a few thousand meters in length – the record length is about 11000 m (Maersk Oil, Denmark).

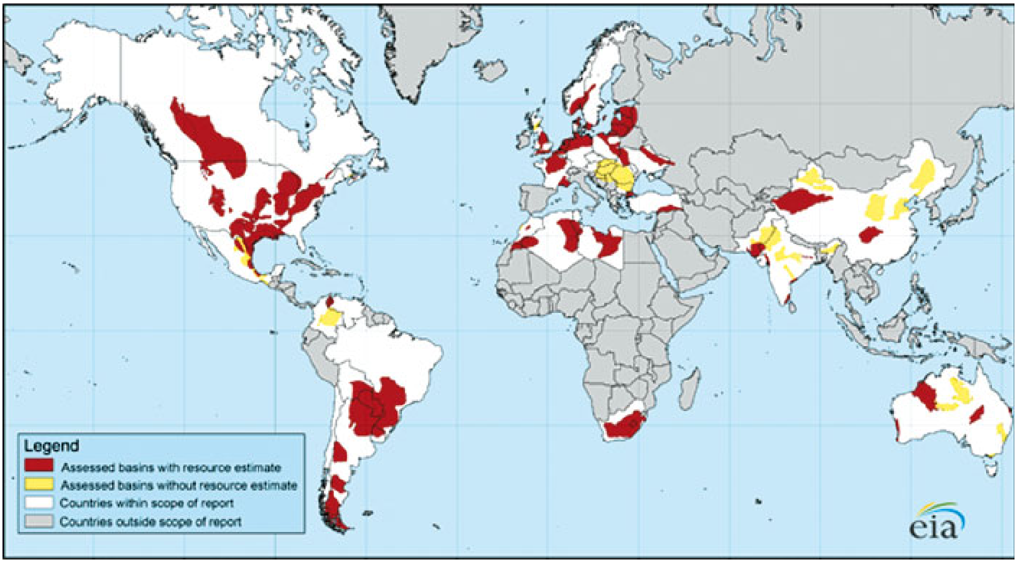

Fig. 13. Location of unconventional resources in the World (EIA, 2011)

Shale deposits containing gas are characterized as follows Boyer et al. (2006):
- large regional extent and thickness;
- lack of clearly developed layers and structural traps;
- lack of a clear contour of the gas-water relation, although water may be present up to 75-80% saturation;
- natural fissures system ;
- the estimated ultimate recovery EUR is much lower than for conventional deposits and amounts approximately 20%-40% > 40% occasionally;
- very low permeability of rock matrix.

Currently, in addition to the Barnett Shale deposits gas is mined in the United States from deposits on the border between Louisiana and Texas, in Arkansas and from deposits located in the northeastern part of the country. The characteristics of seven fields:

Basins area (km^2)	11 000 to 250 000
– Barnett shale (km^2)	13 000
Depth of deposit (m)	300 to 4 100
– Barnett shale (m)	2000 to 2800
thickness (m)	15 to 300
– Barnett shale (m)	50 to 200
Total organic carbon content (%)	0,5 to 14
– Barnett shale (%)	3,8 to 8,0
Gas in deposit (bln m^3/km^2)	0,2 to 3,2
– Barnett shale (bln m^3/km^2)	0,5 to 3,0

Density of drilling 1.5-3.5 boreholes/km^2. From one place on the surface there may be up to 32 boreholes. The latest trends in development of drilling technology is presented in paper of King (2012).

Organic matter generating hydrocarbons (petroleum, natural gas), also changing over to coal is Kerogen. Kerogen is an insoluble organic matter. The ability to generate hydrocarbons depends on:

- ratio of oxygen to carbon in kerogen;
- ratio of hydrogen to carbon.

Most preferred values refer to the so-called Kerogen III, partially Kerogen II in the area, where natural gas is produced. Other, very important nonetheless, but derived from shale bedrock properties are: total organic matter content (TOC) and the coefficients of vitrinite reflexivity (kerogen component) R_o. In determining the organic matter content (TOC) susceptibility of shale (kerogen) to generate gas can be classified (Boyer et al., 2006):

TOC % weight	**Kerogene quality**
< 0,5	very low
0,5 to 1	low
1 to 2	satisfactory
2 to 4	good
4 to 12	very good
> 12	Perfect

TOC content is measured using the pyrolytic method of the French Oil Institute. Gas, in the bedrock, is present in free form in the pores and crevices (silica) and as adsorbed on the active surfaces of the system of nanopores and pores in general. The amount of gas adsorbed σ is determined by the laboratory methods and is consistent with the Langmuir isotherm:

$$\sigma = \frac{V_l p}{(p + p_l)}$$

where:

V_l — Langmuire capacity (σ where $p \rightarrow \infty$)

p_l — Langmuire pressure (adsorbed gas capacity is equal $V_l/2$) and $\frac{\partial \sigma}{\partial p} = \frac{V_l p_l}{(p + p_l)^2}$.

During operation in the initial phase, at a high pressure a small amount of gas is desorbed, to grow in the final stage. Using the methodology of the TRA analysis (Schlumberger, Salt Lake City, USA), previously used in rocks with low permeability, the spectrum of physical and mechanical properties of shale rocks that make up the potential for gas or hydrocarbon potential can also be determine, that is the ability to generate hydrocarbons. The other important phenomena related do adsorption and capillary condensation of rich gas is discussed in Nagy (2002). Adsorption is also discussed in several papers: Clarkson (2010), Ambrose et al. (2011), Rajtar (2010).

The collection of values of the physical properties of shale rocks, positively promising for the potential for the volumes of gas, is as follows (based on the U.S. sources):

porosity	> 4%
water saturation	< 45%

oil saturation	< 5%
permeability	> 100 nanodarcy (1 nD = 10^{-21} m^2)
TOC	> 2%
R_o (vitrinite reflexivity coefficient)	> 1,3-1,5%

In modeling or simulation of exploitation of shale gas a variety of computer programs are used, including quite often used the program called ECLIPSE (Gas Shale module). This is a program whose algorithm is based on the method of finite differences. The program enables optimum design of wells, vertical and horizontal (currently the most commonly performed for the exploitation of shale gas), design of stimulation treatments (fracturing of deposits) and configuration of deployment of well on the field. Economic evaluations of technology projects are also included in the simulation procedure. In assessing the cost effectiveness of extraction projects the ratio of economically viable recoverable resources (ERR) to the technically recoverable resource reserves (TRR) is taken into account. It is in the U.S. about 60% and depends on the cost of field development, drilling costs and gas prices (Holditch & Madani, 2010). In relation to the primary (initial) resources in the bed TRR ≈ 75% and ERR ≈ 30-40%. Illustration of a horizontal well showing the water lifecycle in hydraulic fracturing is presented in fig. 14 (EPA, 2010)

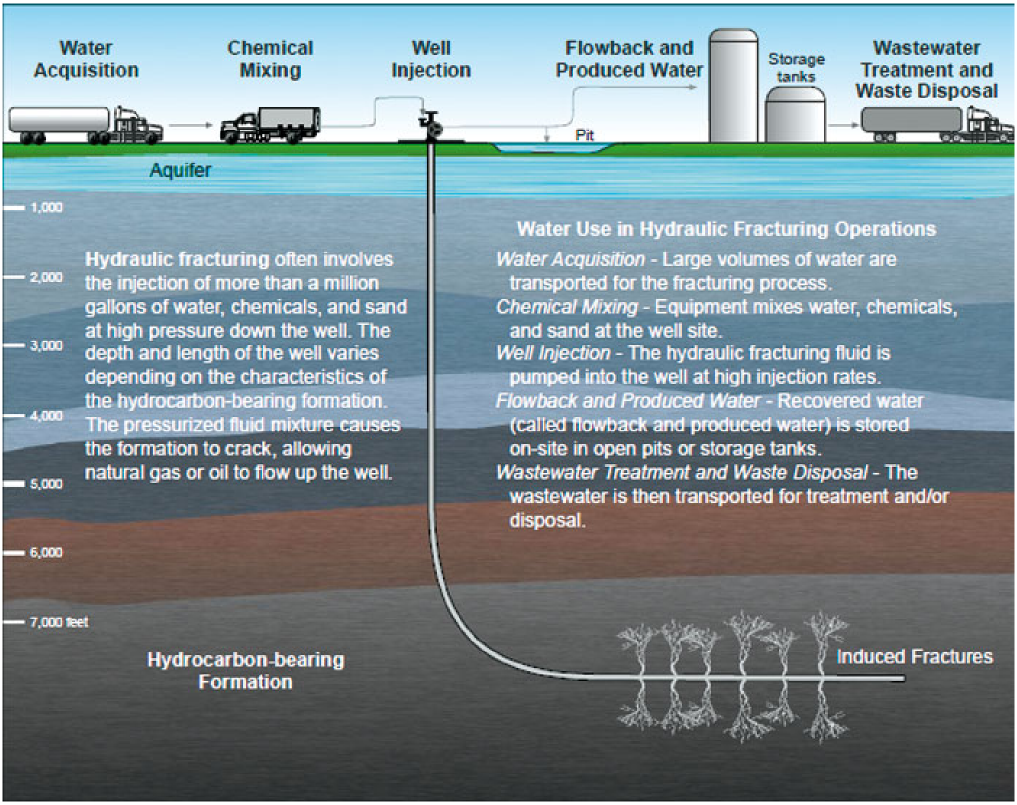

Fig. 14. Illustration of a horizontal well showing the water lifecycle in hydraulic fracturing (EPA, 2010)

One of the most important, if not the key element in the shale gas extraction technology is the stimulation of shale layer. Stimulation in the form of hydraulic fracturing is aimed at increasing very low permeability of the rock matrix. Horizontal wells are generally run in a perpendicular direction to the direction of maximum horizontal stresses. This creates a greater likelihood of cracks. Fracturing additionally generates cracks allocated along the borehole, increasing surface contact with the shale and thus intensifying the flow of gas. Fracturing process consists of pumping under high pressure a narrow stream of low-viscosity water-based liquid. After pumping water a gel is injected. Created cracks penetrate to a distance of several hundred meters (300 meters) from the borehole. Along with the fracturing liquid a granular sand or granules of ceramic materials (so-called „proppant“) is pumped aimed at preventing the closure of the crack edges. The technological problem is transportation and maintenance of „proppant“ in cracks. For this purpose, special fracturing fluids are used, devoid of the gel, and having the organic-like components (Fitzer liquid FRAC), which may be after a certain period of time able to dissolve, increasing the flow in the cracks. Factor stimulating the formation of cracks in the clayey rocks silica, or carbonates. These are springy, springy-elastic rocks, in which cracks can be physically created.

Fracturing consumes large quantities of water, 10 000 to 20 000 m^3 per 1 well. A single fracture treatment is 2 000 m^3 at 5-30 fractures per 1 well. This involves considerable environmental problems. Recent reports regarding technological change point to the development of clean, high-efficiency natural gas extraction technology opportunities for the exploitation of deposits of over 55% recovery, which seems to be an excellent result in comparison to the technology of the 80‘s last century (1% recovery) (King, 2012). Example of Heynesville shale production well history after fracturing (Chesapeake, 2009) is presented in fig. 15.

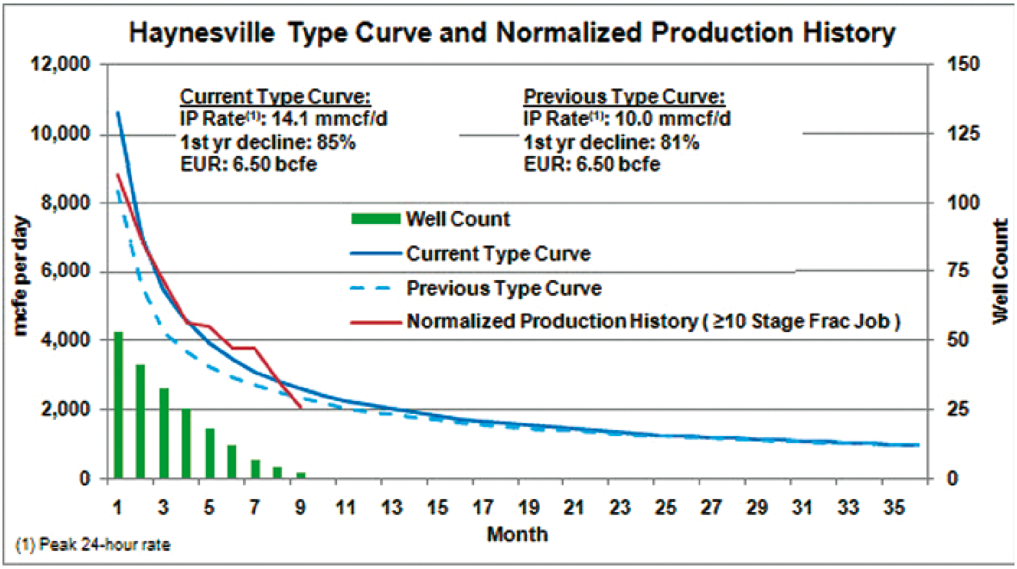

Fig. 15. Efficiency of Haynesville shale production history after fracturing (example) (Chesapeake, 2009)

The flow of gas in the shale rocks takes place in the network of nanopores connected to microspores. Phenomena of gas desorption and diffusion in kerogene to the area of contact with nanopores are observed. The area of nanopore desorption is inversely proportional to the diameter of the d nanopore: $\left(S \sim \frac{4}{d}\right)$.

According to Javadpour et. Al (2007) the scale of phenomena associated with gas drilling from clayey rocks can be classified as follows

- macroscale → flow of gas to the borehole;
- mezoscale → flow in microspores, bigger pores i microcracks;
- microscale → flow in nanopores with constant diffusion coefficient;
- nanoscale → desorption of gas from the nanopore structure;
- molecular scale → diffusion of gas in the native organic matter (kerogene).

Flow in the micropores and the pores is described by equation of Navier-Stokes, and more specifically by Darcy's law which is also a variation of the equations of motion. However in nanopores, the gas flow „with skid“ on the facets of nanopores and the molecular flow occurs. This is a completely different boundary condition than the one appearing in Navier-Stokes problems, i.e. the velocity of fluid particles on the walls is not zero. The type of flow is determined by the Knudsen number:

$$K_n = \frac{\lambda}{d}$$

where:

λ — is defined as the average free path of gas molecules (derived from the Boltzman's statisctics);

d — nanopores diameter. Parameter $\lambda \sim \frac{1}{p}$, p – gas pressure.

If Knudsen Diffusion Number $K_n < 0{,}001$ „continuum" fluid flow occurs following the Darcy's law, d from 1 to 50 μm, and if K_n: $0{,}001 < K_n < 1$ flow „with slip", d from 10 to 300 nm. (1 nm = 10^{-9} m).

One may notice that only to a certain extent, the flow of methane in coal seams is similar to the flow of gas in shale deposits. The same phrase applies to the gas flow in deposits with low permeability (tight gas). Laboratory methods for determining the amount of gas adsorbed in coal can be especially used in case of gas contained in shale rocks.

Given the nature of various environmental concerns, several countries have taken decisions on the moratorium (indefinite or temporary) for the extraction, or management of shale gas deposits (Nagy & Siemek, 2011).

5. Unconventional gas resources in Poland

Polish natural gas resources, allocated by nature, are within four regions: the Carpathians, in the foothills of the Carpathians, the Polish Lowland and the Baltic Sea Shelf. The largest gas production comes from the Polish Lowlands (67%) and the foothills of the Carpathians (32%). Extractable resources by the state of the data as of 31.12.2008 amounted to 93.3 billion m^3 in the on-shore fields and 4.9 billion m^3 in the Baltic deposits. Natural gas production in 2008 amounted to 4.1 billion m^3, while consumption 13.9 billion m^3 (Rychlicki : Siemek, 2009; Zawisza & Nagy, 2008). However prognostic resources estimated by various institutions (AGH, Oil and Gas Institute, PGI) range from 890 to 2 670 billion m^3 (Jezierski, 2010). These are very optimistic estimates, not proven by any examination or studies. It must be emphasized that these resources relate to the so-called conventional natural gas resources (porous rock layers). Unconventional natural gas resources is methane contained in coal seams, gas in reservoirs with very low permeability, or partially closed in the rocks („tight gas“) and the gas in the shales (clayey-mud rocks, kerogen).

Methane in coal seams is found in three coal basins: the Upper Silesian (USCB), Lower Silesian (LSCB) and Lublin (LCB). Due to the coalbed the USCB is the largest reservoir of methane. Prospective methane reservoirs are assessed at 254 billion m^3, including the extracted resources at approximately 150 billion m^3. Extraction of methane (demethanation technology of mines) is rather small and fluctuates around 250-270 million m^3/y, in comparison to the amount of about 160 million m^3 for local purposes (GIG, 2009). Attempts of industrial exploitation of resources, since the early 90' of the last Century by various national and foreign companies, have not produced satisfactory results. This does not mean that extracting methane from coal deposits should be abandoned (Siemek et al., 2009). Shale gas in large quantities can be located on Polish territory in the basins of the Baltic and the Lublin-Podlasie. It is gas from geological formations (shales of the lower Paleozoic) extending from the eastern part of Polish Baltic seashore, diagonally to the Podlasie and Lublin up to the eastern Polish border, at a depth of 1 500 to 4000 m (lower Paleozoic shales.)

Shale gas resources, according to U.S. sources, are assessed in the amount of 1400 billion m^3 to 3000 and even 5300 billion m^3 (Poprawa, 2010). During conferences and symposia the number of 8000 billion m^3 of gas is sometimes quoted. All these data should be approached very cautiously and critically.

So far there is no research basis for a credible and full assessment of resources, and differences in their prognosis is very large (see also Kaliski at al., 2012). Technically recoverable resource of shale gas in Poland according PGI (2012) are extremely low in comparison with previous (2009, 2011) estimation. It seems that assumption related to Estimated Ultimate Recovery are very unrealistic – based on unclear statistics taken from USGS. Polish Geological Institute (2012) has provided official evaluations – the Institutes estimation is 340-780 billion m^3 of gas. The projection of PGI is questionable because of methodology of estimation and lack of important data. Location of polish shale gas resources is presented in fig. 16. The main parameters of these deposit are presented in table 11.

Serious interest in shale gas is currently manifested by prestigious and large U.S. companies like Exxon Mobile, Conoco Phillips, Chevron and Marathon Oil, and more recently by European companies (Total, Statoil, Shell). In 2011, the number of concessions granted for exploration of unconventional gas is around 85. It should be noted that although in the U.S. currently about 15% of consumed gas is shale gas, the extraction technology is complicated and not always effective. It is expected to further increase production in order to reduce the import of gas (e.g. liquefied LNG).

Horizontal wells must be drilled relatively densely. They have a high initial but rapidly diminishing efficiency. Furthermore extraction from shales requires hydraulic fracturing to increase permeability of shale layers and deposits for gas flow to the borehole. Large amounts

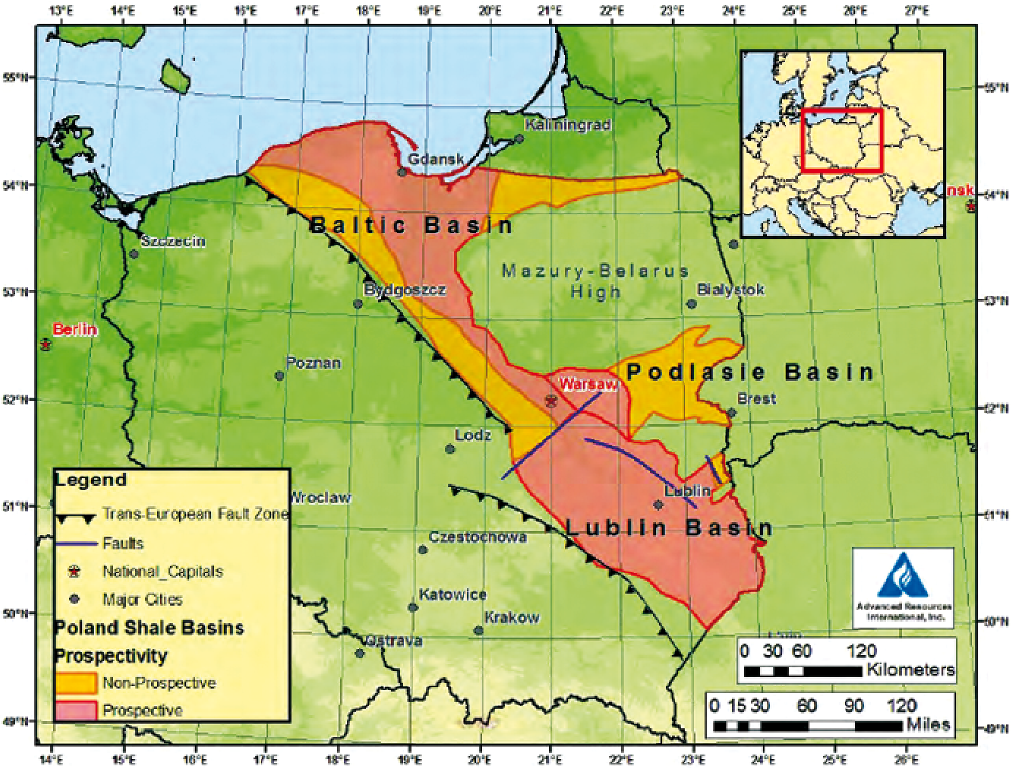

Fig. 16. Major shale gas basin in Poland (WEO 2011)

of water are needed to carry out such procedures, what may result in ecological problems. In general, the mechanism of transport of gas from shale is a complex, yet not quite well in terms of physics explored. There are gas desorption phenomena, Knudsen's nanopores flow, microspores flow (Darcy's law), finally the flows in the cracks and the bore-hole itself. Potential of an industrial scale shale gas production in Poland, is in a fairly distant time horizon of at least ten, if not several years.

Poland has large, unconventional natural gas resources in the form of methane in coal seams and natural gas in shale formations of the lower Paleozoic. While the gas production from shale deposits can be expected after documentation of resources in the perspective of the 20' of the current Century, abandoned were the attempts to extract coalbed methane in the Upper Silesian Coal Basin. But the resources of both gases (including natural gas from deposits of unfavorable petrophysical properties) may constitute a substantial margin of energy security of the country and in the decade of the twenties may participate in the energy economics of the country. They may lead to the reduction of carbon dioxide emissions from the Polish territory to the atmosphere.

TABLE 11

Polish shale gas basin parameters (ARI/US EIA, 2011)

		Baltic Basin	Lublin Basin	Polasie Basin
Basic data	Shale formation	Lower Silurian	Lower Silurian	Lower Silurian
	Geological Age	Llandovery	Wenlock	Llandovery
	Area [km^2]	22901	30186	3430
Thickness	Interval min [m]	100	100	110
	Interval max [m]	250	340	220
	Organically Rich	175	125	165
	Net	96	70	90
Depth	Interval min [m]	2500	2000	1750
	Interval max [m]	5000	4100	3500
	Average	3750	3050	2600
Reservoir data	Reservoir pressure	Overpressured	Overpressured	Overpressured
	Average TOC (wt. %)	4	1.5	6
	Thermal Maturity (% Ro)	1.75	1.35	1.25
	Clay Content	Medium	Medium	Medium
Resources	GIP concentration (Bcm/km^2)	10.7	5.8	10.6
	Risked GIP (Tcm)	14.7	6.3	1.6
	Risked Recoverable (Tcm)	3.7	1.3	0.4

6. Conventional natural gas resources in Poland

Ministry of Economy in 2009 accepted the estimate of fuel and energy consumption over the horizon to 2030 (Ministerstwo Gospodarki, 2009) "Demand for fuels and energy forecast until 2030". According to this forecast, which is somewhat Polish energy action plan, gas consumption in each period will be shaped as follows:

TABLE 12

Demand for fuels and energy forecast until 2030 (Ministerstwo Gospodarki, 2009)

Years	2006	2010	2015	2020	2025	2030
in Mtoe	12,3	12,0	13,0	14,5	16,1	17,2
in bn m3	14,5	14,1	15,4	17,1	19,0	20,2

This forecast may be quite unfortunate in light of new low-carbon policies in case of rejection of "Carbon Capture Storage" (CCS) technology and unclear of nuclear energy development (after "Fokushima case") in Poland (Nagy & Siemek, 2011).

The amounts relate to the gas of high calorific value equal to 35.5 MJ/m^3. This gas is considered as one of the primary energy carriers. By 2015, an increase of gas consumption is small, and in the years 2015 to 2030 only a little larger. In 20 years (2010-2030) the total increase in gas consumption, compared to 2010, is "only" 5.7 billion m^3 of gas, or about 40%. The problem may be the credibility of the forecasts, one should take into account the fact that subsequent forecasts of energy, constructed over the years 2000-2009, give out numbers differing by up to 30%.

However, it seems that the latest version of the program is well justified and documented, at least in the version relating to the demand for natural gas and oil. In the structure of primary energy consumption natural gas contributes to the amount of approximately 12.8% (2009). This is not a high rate, especially in relation to the average value in the European Union equal to about 24% (Siemek at al., 2009). The increase in gas consumption would because of the individual customers mainly in the municipal and household sector and also in electricity generation sector. Program to increase participation of gas in electricity production and heat production in cogeneration systems is shown below (Ministerstwo Gospodarki, 2009). The presented forecast of natural gas demand in Poland has to be updated soon because of change in global and European energy policy.

TABLE 13

Demand for natural gas forecast until 2030 (Ministerstwo Gospodarki, 2009)

Years	2006	2010	2015	2020	2025	2030
Natural gas bn m^3	1,133	1,143	1,289	1,913	2,490	2,900

This would be a significant increase, up by about 150% in 2030, of the share of gas in the electro-energy industry. It is very important that during the combustion of natural gas in opposition to coal more than twice as less carbon dioxide is emitted. Still, gas electric power would only constitute approximately 6.6% of net electricity generation capacity (in the structure of fuels used for energy). For comparison, the share of natural gas in electricity generation in the European Union in 2030, according to the reference scenario, will amount to about 25%, while according to the scenario 450 – about 18% and always exceed share of coal and brown coal together (WEA, 2009). Similar scenarios, but with shifts in the direction of growth of the share of natural gas to 30% in 2030, are provided by the forecasts of the International Gas Union (IGU, 2009).

Other gas-related economy projects are:

- gas imports from the Russian Federation in the years 2010-2037 in the amount of 10.3 billion m^3/y;
- construction of the LNG terminal to receive liquefied natural gas (LNG) in Swinoujscie; planned imports amounting to 2.5-3.0 billion m^3/y may be, after extension increased to 5.0 billion m^3/y and even up to 7 billion m^3/y;
- construction of pipeline network connections with Germany, Czech Republic, possibly with the Austrian Baumgarten gas hub;
- expansion of underground gas storage facilities with a capacity of around 1.6 billion m^3 now (6 stores) for about 3.2 billion m^3 in 2015 (5 in the tapped into or partially tapped into deposits of natural gas and one in salt caverns). This allows the creation of a large strategic reserve of natural gas (about 30% of annual gas consumption in Poland) (Nagy & Siemek, 2010)
- extension of exploration of Polish shale gas deposits, development of shale gas plays, development of natural gas surface infrastructure.

These projects aim to improve the security of gas supplies to Poland and to create sufficient reserves in case of different weather perturbations, technical and finally political. Lack of notice may be noted among Polish authorities in relation to the "North Stream" and "South Stream" transcontinental gas pipelines and even projected "Nabucco gas pipeline". They will, within the next 20-30 years, serve as the gas mains to the European Union.

7. Conclusions relevant to Polish energy policy

Poland is dependent on large imports of raw hydrocarbons (natural gas and petroleum), hence it is important to ensure continuity of supply and creation of such technical infrastructure of reception and storage of gas and oil. Completely opposite is the situation of the country's gas and oil deposits. Not only prognostic but also documented gas resources are considerable and there are opportunities to increase its production from domestic deposits similar hopes for crude oil are low. The characteristics of the demand for both of these hydrocarbon raw materials are also divergent. Natural gas is primarily used in municipal and household sector (much less energetic), but also in the industrial sector, while crude oil is mainly used in the transport and refinery sector and to a lesser extent in other areas of use. Finally, different is the degree of security of supply of both raw materials. There were no major problems with imports of crude oil. Detailed proposals are as follows:

- Increase in gas consumption by 40% over a 20-year-old period, slight enough to be easily offset by growth in import and additional extraction of domestic deposits. The measures taken by the government are reasonable and can ensure, during this period, full coverage of Polish demand for natural gas. Again, the necessity of active and rational to engagement in politics and the multi-energy projects of the European Union must be emphasized. The objective is to achieve the level of security such as in the European Union. Economic criterion of supply must play one of the primary roles.
- The Polish energy sector in the upcoming future will very much resemble "coal-gas" model. In 2030, 67.3% of electricity and heat, will be derived from burning coal, lignite and natural gas. Also while in 2030 the share of these energy sources will be at 53.7%. Hence the important role of coal and natural gas in energetics and importance of high-performance technology of burning coal and gas.
- Poland has a large, unconventional natural gas resources in the form of methane in the reservoirs of coal and natural gas in shale formations of the lower Paleozoic. The development of shale gas extraction in Poland may lead to the reduction of carbon dioxide emissions from the Polish territory to the atmosphere.

Poland may be in a much better energy position than many other European countries. It has its own coal deposits and active mines, its own natural gas and oil deposits and a positive prognosis for the future (unconventional natural gas resources). The condition is a consistent, reasonable energy policy within the European Union, but also as an individual country, creating gas systems connections with neighboring countries – west and southward expansion of underground gas storage systems, adaptation and development of gas extraction technology from unconventional deposits, further exploration of conventional hydrocarbon reserves.

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