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# INNOVATIVE SOLUTIONS IN NATURAL GAS ENGINEERING**

## 1. INTRODUCTION

Technological innovations should not be presented as simple laboratory activities aimed at finding new tools, solutions or processes for gas sector. The novel solutions are focused on linking new technologies with business models to help achieve business goals quicker and more efficiently, and at the final stage offer a better product. Technology increases innovativeness and reputation of a company putting emphasis on own cognitive potential through supporting strategic visions for the future.

With the dynamic development of natural gas sector all over the World the industrial base started its transformation by using natural gas. Natural gas can be also perceived as an important link with other alternative energy sources coming from environmentally friendly fuels. A dynamic development of gas engineering has been recently observed.

## 2. ENERGY PRODUCTION FROM NATURAL GAS

The first area in which gas sector has been observed to significantly develop is power industry. Owing to a low $CO_2$ emission, natural gas is an ecological fuel and its role in the global energy mix keeps on increasing. The present participation of natural gas in primary energy production totals to about 24% (Fig. 1), though according to the OPEC estimations, after 2040 natural gas may be dominating fuel for energy production on World's scale with the average annual growth dynamics of 2.4% (Fig. 2).

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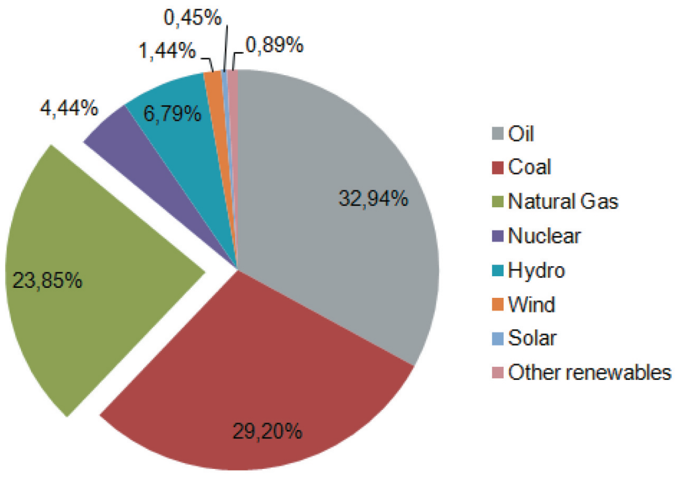


**Fig. 1.** Global Energy Mix by source in 2015 [1, 2]

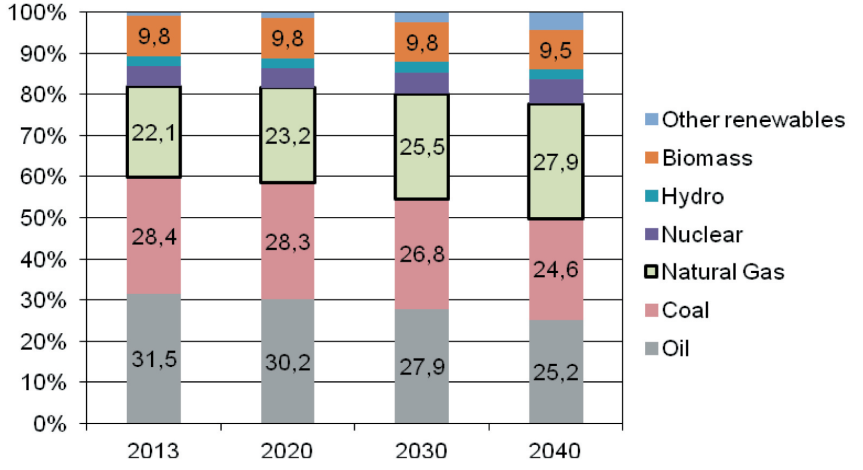


**Fig. 2.** Forecasts of percentage shares of energy sources in global energy mix to 2040 (including biomass) [2, 3]

## 3. DEVELOPMENT OF ALTERNATIVE FUELS TECHNOLOGIES IN TRANSPORT

At present vehicles are powered nearly exclusively by oil-based fuels. With the increase of fuels consumption the qualitative parameters become more and more strict to minimize the environmental impact. At the same time attempts are made at working out and implementing alternative fuels in the place of the traditional ones. The search for alternatives for gasoline and Diesel oil stems from the need to: increase the efficiency of vehicles and limit the environmental impact, lower emission of greenhouse gases and protect the vanishing oil resources. Natural gas is the most important fuel in the environmental campaign. It may take the compressed (CNG) and liquid (LNG) forms. Natural gas is also used for hydrogen production with the steam reforming method [4]. Hydrogen can be used as an input substance in chemical industry, in refinery processes, and also as a source of fuel in car transport.

Considerable developments were made in working out alternative fuels, e.g. methanol, ethanol, natural gas (CNG/LNG), LPG, dimethyl ether (DME) and biodiesel. The World's major car producers conduct works on introducing to the market electrical vehicles and cars powered by fuel cells.

Optimum, as far as emissions generated by vehicles are concerned, is Liquefied Petroleum Gas (LPG). The LPG production is intrinsically connected with the production and processing of oil and gas, constituting a small percentage of them. The potential of this alternative for traditional fuels is proportionately limited. The use of LPG in transport has increased over last years (Fig. 3). Attention should be paid to the fact that about 50% of LPG used in transport is covered by 5 countries (Turkey, Russia, Poland, Korea and Italy). Almost all vehicles powered by LPG can be converted to CNG, where the conversion does not require dismounting of the existing installation.

Owing to their reliability, ecology and efficiency, the CNG buses and vehicles are nowadays a frequent option in the city transport in the U.S.A. Their is assessed to over 120,000. In Poland this type of vehicles also grow in popularity in big agglomerations and also in small towns, where public communication is available.

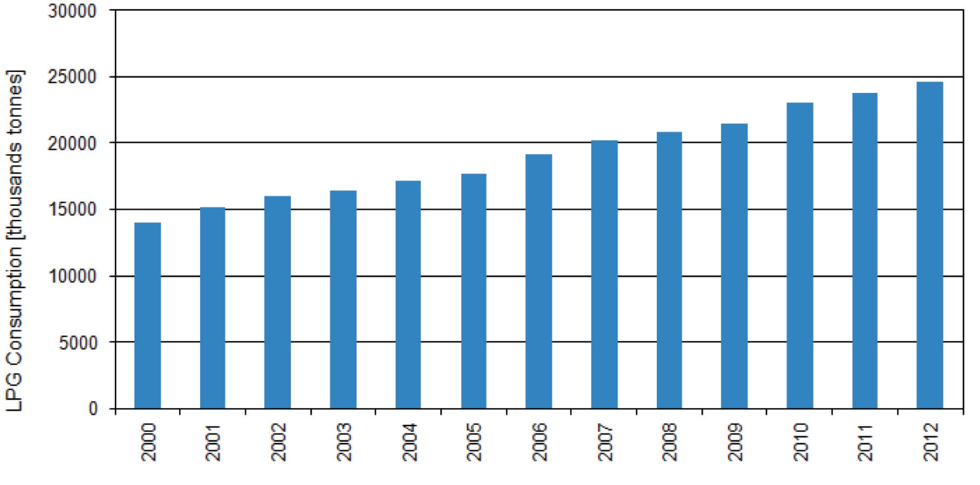


**Fig. 3.** World LPG consumption in transport [5]

From the environmental point of view, the hydrocarbons and carbon oxide emission of Natural Gas Vehicles (NGV) is lower by 40–90% as compared to LPG. Vehicles powered by natural gas do not emit soot. This type of engines emit to atmosphere about 10% less carbon dioxide than LPG, which is their main advantage as far as environmental issues are concerned. Besides the cost of car exploitation is lower than LPG because of the lower wearing of the engine. Considering the present fuel prices, gas-powered engines belong to the most economic (Fig. 4).

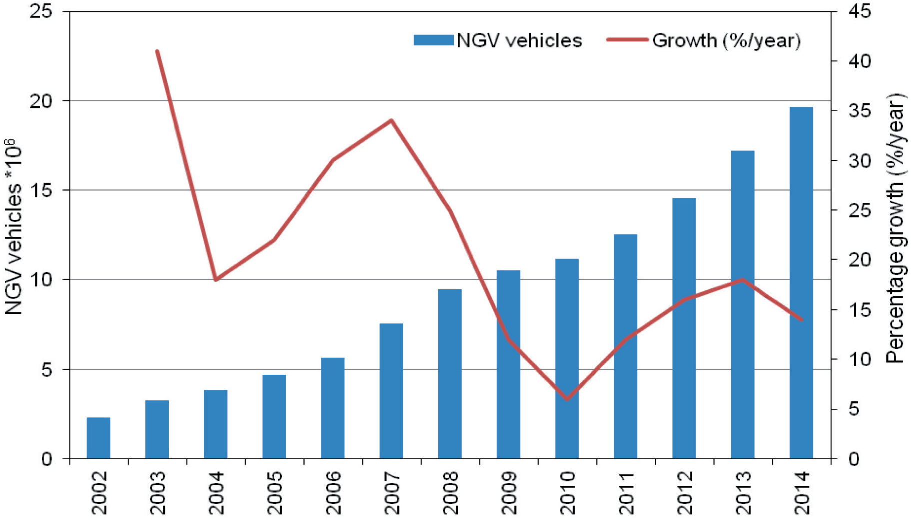


**Fig. 4.** Total Natural Gas Vehicles number around the World [6]


**Fig. 5.** Truck vehicle with LNG fuel [own materials]

Liquefied Natural Gas (LNG), a clean, low-emission and efficient energy source, is used for powering cars, trucks and buses (Fig. 5); it is also used in railway and marine transport. As a fuel for cars, it is distributed at LNG stations. LNG is bunkered on the ships from stationary LNG stations, cisterns or bunkers.

Biogas may be a very good fuel for powering cars, though it undergoes the same regimes as ethanol. The same production process and materials are involved in both cases.

## 4. COMPRESSED NATURAL GAS (CNG)

Natural gas can be compressed as CNG. This is a perfect compromise between costs and availability of a given technology, which has been verified and which can be relatively easy to implement in many branches of car sector. For these reasons CNG grows a considerable interest in it as a fuel all over the World (Tab. 1).

**Table 1**

Number of cars powered with natural gas in EU [item] [6]

| No. | Country | NGV | | |
|---|---|---|---|---|
| | | 2007 | 2013 | 2015 |
| 1. | Italy | 432 900 | 823 000 | 885 300 |
| 2. | Germany | 60 000 | 96 349 | 98 172 |
| 3. | Bulgaria | 25 225 | 61 623 | 61 320 |
| 4. | Sweden | 11 515 | 44 322 | 46 715 |
| 5. | France | 10 150 | 13 538 | 13 550 |
| 6. | Spain | 1 526 | 3 781 | 3 990 |
| 7. | Poland | 1 400 | 3 392 | 3 590 |
| 8. | Austria | 1 022 | 7 717 | 8 332 |
| 9. | Czechia | 903 | 7 050 | 8 817 |
| 10. | Holland | 858 | 6 680 | 7 573 |

Compressed Natural Gas (CNG) is compressed and sometimes additionally cooled (though not liquefied). It has a high octane number of ca. 130. It is compressed to maximum 25 MPa, in ambient temperature, thanks to which its volume is lowered and density of transported energy increased [4, 7].

CNG is a verified and known technology used onland and in marine transport. Since 2000, marine transport of CNG was considered to be a real alternative for LNG transport and pipelines. Ships transporting CNG are actually floating pipelines. On land technological objects and installations required for loading and unloading of transported CNG consist of relatively simple constructions, the cost of which is minimum as compared to LNG installations.

Marine transport of CNG can be considered to be a new generation of high efficiency CNG tanks which considerably lowered the cost of transport. The realization of CNG deliveries may open new gas markets and provide energy for the already developed energy markets.

## 5. LIQUEFIED NATURAL GAS (LNG)

Among the advantages of liquefied natural gas are the smaller storage volume and larger range of vehicles powered with this fuel. Much bigger quantities of gaseous fuel are obtained in volatile phase from a relatively small volume of LNG, acquired through regasification in the installation, before it is directed to the combustion chamber. The same volume of LNG may comprise about 2.5 times more gas than CNG. It is assessed that from 1 cubic meter of LNG one can obtain ca. 600 cubic meters of gaseous fuel, which means almost 600 times bigger compression. Although the output seems great, there remains a problem with temperature which has to be maintained very low (–162°C) in the storage tank; this necessitates the use of specialist cryogenic systems [8].

The development of modern designs, development in technology and integration bring about higher energy efficiency of World's industrial LNG infrastructure. The potential of small and moderate installations starts to significantly grow in significance influencing the development of LNG industry and initiating new technological directions.

The industrial development is connected with the growing demand for electrical energy. A considerable number of countries all over the World visualize LNG market through the perspective of lowering the cost of electrical energy production and power. This gives a spur to work out new projects and technologies to reduce these costs. Among new options to be considered attention should be paid to systems which may improve the efficiency of regasification of liquefied natural gas, making use of LNG as a source of cold for increasing power of the cogeneration process [9]. Electrical energy can be produced with the use of LNG as a cold radiator in the combined cycle, to increase the efficiency. Integration with a power plant, employing the Rankine cycle, Brayton cycle or combined cycle may be a natural process of development of LNG regasification technology, which would help limit the total cost of the installation and increase its overall thermal efficiency. The LNG evaporation system making use of water and Rankine power generator as a source of heat, are presented in Figure 6.

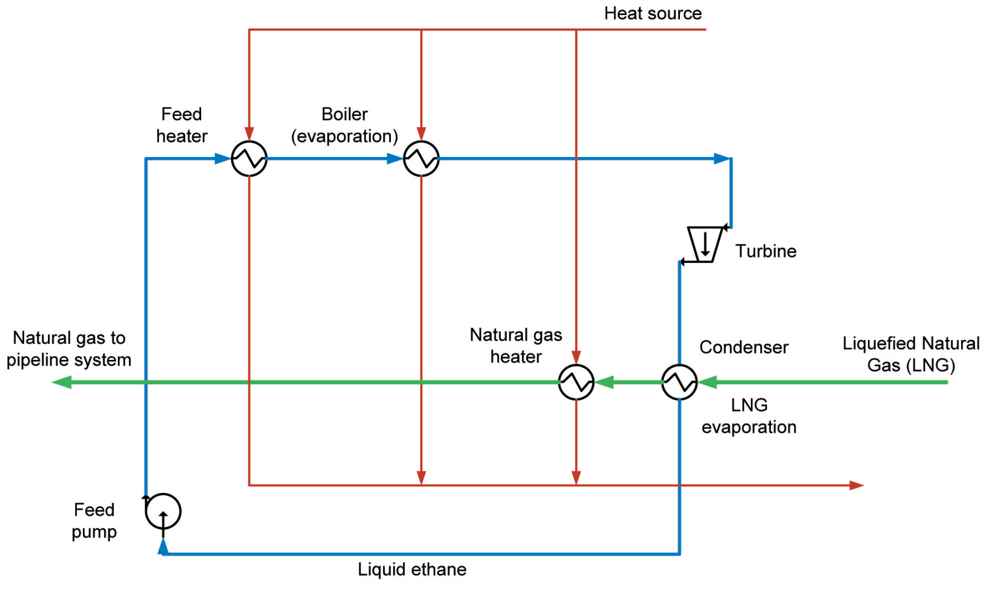


**Fig. 6.** LNG evaportation system using water as heat source with Rankine power generator

Cold energy of LNG is also applicable in food industry (cold rooms) for the production of dry ice and desalination of sea water, in air condensers and for condensation of BOG vapors BOG, for the reduction of high temperature of magnets in magnetogasdynamic generators, in medicine, and also at low-temperature fractionation of gaseous hydrocarbons. The use of LNG also creates possibility of delivering natural gas to areas, where no suitable infrastructure and also no connection with the transmission network are available because of technical or economic reasons. This allows for better functioning of the gas network and undisturbed gas deliveries in temporary high demand situations (local peak installations). In the periods of low consumption of network gas its excess is liquefied (40–100 tons LNG daily) and stored. In the period of increased demand, the liquefied natural gas is evaporated and introduced to the network.

Floating LNG (FLNG) is one of the new technologies relating to the production and to some extent import. This technology allows for the exploitation of coastal small gas fields, whose development and onland transport through the pipelines turned out to be unprofitable with the available methods. This method links undersea extraction methods with production from platforms – LNG-Floating-Production-Storage-Offloading (LNG-FPSO). The FLNG system consists of an offshore platform LNG FPSO for the production (condensation) of gas – LNG carrier – Floating-Storage-Regasification-Unit (FSRU) berthed on the sea or in the coastal area, where LNG is stored, regasified and then transported on land with undersea pipes. The FSRU system can play the role of a floating LNG terminal and cooperate with LNG Articulated Tug and Barge (LNG ATB), and so with the use of tugboats and barges adjusted to LNG storage and transport LNG. The latter technologies can be used only on a small scale and only for small LNG projects. Over the last decade the participation of FLNG systems has rapidly increased on the background of World's regasification energy; in 2006 it was only 0.8% to increase to 10.02% in 2016 (Fig. 7).

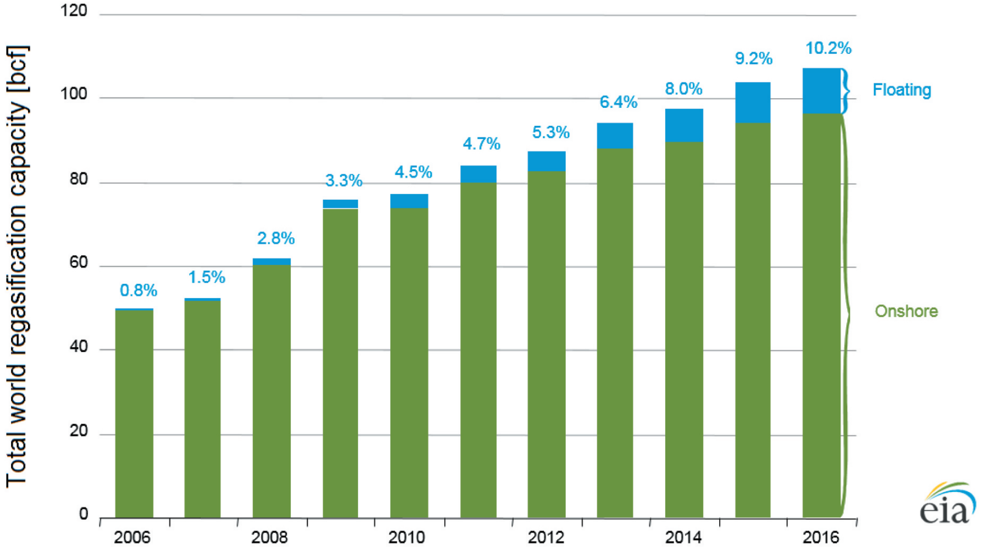


**Fig. 7.** Total world regasification capacity with floating LNG share [2]

The largest producer of LNG is Qatar, which held a 31% global market share in 2014. Qatar has seen a massive expansion of its capacity, up more than 63 bcm since early 2009 to reach 105 bcm. Indonesia, Malaysia, Australia and Algeria are also significant LNG exporters [2].

## 6. GAS TO LIQUIDS (GTL)

The main alternative for pipeline transport is liquefied natural gas (LNG), to some extent compressed natural gas (CNG), and also chemical conversion of gas to liquid fuels defined as Gas to Liquids (GTL). The GTL industry has quickly changed over the last years and with alcohols grows in significance.

Alcohols, i.e. methanol and ethanol create an ideal fuel for engines with spark ignition. They have high anti-knock qualities, which define them as a 10% additive to unleaded petrol and relative cleanness of the generated exhaust gases.

Natural gas cannot be directly transformed into liquid fuel, though a number of such solutions have been presented in scientific literature. The transition through the half--product stage has been inevitable so far. One of the best verified solutions lies in the conversion to methanol, which may be subjected to further transformation, as a result of which dimethyl ether (DME) is obtained – variant proposed by H.Topsoe AS as a replacement for Diesel oil or processed to gasoline (MTG, MethanoToGasoline by Exxon and TIGAS by H. Topsoe A.S. technologies) or olefins (MTO, MethanoToOlefins (ethylene and propylene by UOP and by Lurgi) for petrochemical sector. Methanol employing natural gas as a raw material requires costly and complex production processes.

## 7. ADSORBED NATURAL GAS (ANG)

ANG is one of the new technologies of gas storage and transport through the adsorption of gas particles on various adsorption materials. The ANG technology allows for storing large quantities of gas at relatively low pressure (40–60 bar), at room temperature, in a relatively thin-walled tank filled with adsorbent [10]. This pressure level allows for loading the tank with simple and cheap equipment or sometimes tanking directly from the pipelines. Active carbon of higher natural gas storing potential at a pressure to 34 bar is available now. Carbons are both highly efficient and also tend to have high density. Therefore the very dense carbons will occupy less space in the tank. The storing capacity of activated carbon as compared to CNG technology is presented in Figure 8.

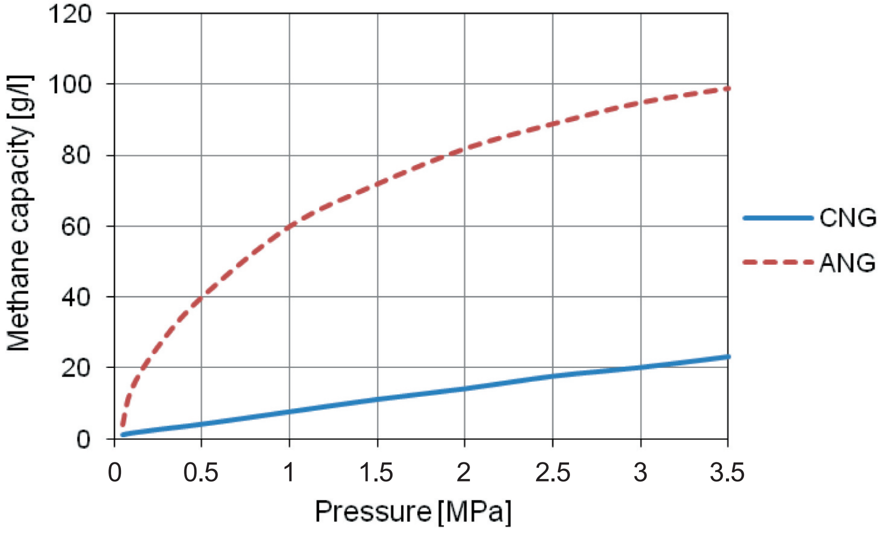


**Fig. 8.** Comparison of methane capacity in CNG and ANG technologies [10]

## 8. ARTIFICIAL GASEOUS MIXTURES SUPPORTING NATURAL GAS SUPPLY NETWORKS

The economic analyses prove that providing exchangeability of gaseous fuels would bring about better economic results than increasing the passability of gaseous pipelines for delivering the same quantities of natural gas. The risk of threatened gas deliveries in peak demand periods is associated with the necessity to provide gaseous mixtures which do not affect the quality of gas and which are safe for the users. The replaceability of gases is associated with the need to add a certain amount of a natural gas-substitute to natural gas to provide uninterrupted gas deliveries [11]. Such solutions are applied in many countries all over the World. In this solution gas networks do not need to be recalibrated at the design stage or further reconstruction to increase the flow capacity. Among gases which can be used for mixing and replacement are mainly LPG, landfill gases (LFG) or biogases, and in some cases dimethyl ether (DME). The peak demand for natural gas is most frequently covered by introducing a mixture of 75% of natural gas and 25% of synthetic natural gas (SNG), being a mixture of evaporated natural gas and air, commonly ca. 45% of air and ca. 55% LPG. The SNG systems and installations can be viewed as improving the safety and flexibility of gas deliveries.

## 9. HYDROGEN

Conversion of natural gas to hydrogen is a commonly applied technique used at lower scale flows. Hydrogen is treated as an input chemical material for further industrial processing (e.g. for synthesis of ammonia and methanol), refinery industry or as engine fuel. Hydrogen is considered to be a super clean fuel, because only water is produced in the course of its combustion. It is a basic fuel for high capacity vehicles for zero-emission fuel cells. Despite the advancements and technological development, the cost of hydrogen production remains immense. The cost of hydrogen transport and distribution are still unknown.

Hydrogen from clean sources, i.e. solar energy or wind is viewed as a transport fuel of the future. The cost of production of hydrogen from such sources remains very high and is unprofitable because of price of the generated electrical energy. Hydrogen is an energy carrier which can be used for storing energy excess in the periods of lower energy demand. Hydrogen can be stored for the regeneration of electrical energy in local network where deficiency of energy is observed. In decentralized energy markets such a renewable hydrogen system can provide a balance between supply and demand. With the technological development hydrogen and methane are planned to be produced from the excess of electrical energy (power-to-gas technologies).

The participation of renewable energy which covers about 30–40% of home demand for electrical energy may bring about considerable energy surplus which should be accounted for in the energy system of a given country. The participation exceeding the demand by 60–80% or more, may generate tens of TWh of extra electrical energy each year in such countries as, e.g. Germany, Holland, Spain and Great Britain. This problem can be solved by storing electrical energy in the form of hydrogen. In this way the efficiency of energy production is increased, the management of production and transport are improved, the quality of energy is better and the renewable energy sources are used more effectively (periodical or local excess of electrical energy from renewable energy sources).

Considering the localization of potential hydrogen storages with respect to the sources of its acquisition, pipeline transport should be taken into account. The issue of hydrogen transport should be analyzed in view of the technological and material aspects [12]. The radius of hydrogen atom is sufficiently small to penetrate the crystalline structure of steel from which the pipeline has been made. Moreover, hydrogen can react with carbon enclosed in steel. These are hydrogen diffusion and corrosion phenomena, which have to be dealt with at the stage of selecting materials. Technologically, hydrogen per unit of volume contains a small quantity of energy (the energy value of hydrogen per unit of mass is very high though hydrogen is the lightest of all gases). Owing to its small mass, hydrogen can be transported at greater distances than natural gas. One should consider the possibility of adding small amounts of hydrogen to the stream of natural gas to improve the conditions of transport through the pipelines, with strictly maintained calorific value [12].

Hydrogen is also introduced as a vehicle fuel, though the growth of hydrocarbon participation as a fuel is hindered by the development of CNG technologies and the considerable difference in the cost.

## 10. CONSTRUCTION AND EXPLOITATION OF NATURAL GAS STATIONS

The increased working pressures necessitates using higher strength parameters of steel pipes. Low-alloy fine grain steel pipes of plastic boundary over 450 MPa or higher are frequently used. Higher strength standards also have to be met by other elements used for other construction elements, e.g. profiles or other pipeline equipment. The development of this domain resulted in the development of new materials and technologies of pipeline construction, especially as far as strength and resistance to corrosion is concerned (e.g. systems of composite pipes Flexpipes, X200™ or other). For instance, a complex system of pipes known as X200™ consists of composite pipes made of laminated glued steel bands. It offers a new and cheap technology of pipes production for gas pipelines and gas pipelines in various configurations. Construction material, i.e. type of steel, special alloy or reinforced thermoplastic layer can be defined by the user and adjusted to the transported medium. Pipes are stronger and are much lighter than the conventional ones; their maximum working pressure may reach up to 10 MPa.

Technological advancements allow for increasing the safety of pipelines exploitation and for quicker reaction to failure situation [15]. Of special interest are leakage and integrity detection methods based on sensor optical fiber cables. Three areas can be distinguished for optical fiber application to the monitoring of gas pipelines and technological objects: detection of possible leakages, monitoring of pipeline integrity (change of the state of stress in the pipeline) and detection of activity of third parties in automated objects or stations and automatic generation of alarm signals.

The use of optical fibers for the detection purposes is connected with their resistance to the operation in difficult conditions, i.e. vibrations, dusting, high temperatures, high pressure or electromagnetic interference. An additional advantage of the optical fiber sensors lies in their high sensitivity, broad range of measurement and no electrical conductivity. They can be safely installed in zones threatened with explosions.

Another way of controlling gas pipelines is, mainly transmission pipelines, is laser method for detecting methane and gas leakages. The IR spectral analysis is used for recognizing and determining methane or other aliphatic hydrocarbons in a given medium. This process is determined as absorption spectroscopy. It is performed from the air with, e.g. a drone or helicopter.

The basic object of each gaseous network is a gas station. Modern control systems provide as full control of the reduction/measurement stations [14]. The use of data transmission and visual monitoring systems as well as integrated electronic managing system of the station, digital intelligent control units allow for optimizing operation of the station, and so adjusting the station to the expected changes of gas reception conditions.

## 11. CONCLUSIONS

This paper is an outline of development of technologies increasing the innovativeness in the gas sector. A great number of gas sources and their types, localizations and markets require using diversified technological options. A fast technological development in natural gas sector resulted in increasing gas consumption over last years. Newer applications of natural gas also increased the demand for gaseous technologies. New technologies should not be treated as an alternative but as additional possibilities enriching the increasing World's demand for energy in a more flexible and sustainable way.

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