The Role of Hydrogen Connected to the Existing Natural Gas Infrastructure in the Hungarian Energy Transition

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***Abstract* - Electricity from renewable energy sources aimed at promoting a carbon-free economy can be one of the pillars of the European Union's climate policy ambitions. In this, green hydrogen is a fundamental element of an integrated energy system and a hydrogen economy. In its hydrogen strategy, the European Commission recognised that underground hydrogen storage is needed to strike a balance between future energy systems that rely heavily on renewable energy sources in order to ensure security of supply. REPowerEU also quantified this in its announcement, aiming to achieve 20 million tons of green hydrogen supply in its member states by 2030. On the demand side, it is necessary to comply with higher peaks in electricity demand created by residual load. After a general overview of hydrogen strategies of Europe and Hungary the authors determined possibilities for replacing natural gas demand with hydrogen depending on potential green hydrogen production capacities of the country.**

***Index Terms* - Energy Transition, Hungary, Hydrogen, Infrastructure, Natural Gas**

I. Introduction

The requirements for hydrogen storage are determined by the evolution of supply and demand for hydrogen, as well as by interactions with other sectors (energy, transport, heating, cooling) and other flexibility instruments in the sectors (batteries, heat and cold storage, pumped hydropower, etc.). Therefore, both storage capacities and operational profiles need to be analysed. In relation to hydrogen, the development of dedicated hydrogen infrastructure can be mentioned as a long-term goal, but as a short-term solution, the blending of hydrogen into the natural gas network is also proving promising.

However, the question is whether the current gas infrastructure can operate safely with natural gas mixed with hydrogen. Research into this is currently underway around the world. The findings are valid for all EU member states, including Hungary. However, the method of implementation is different, as they have different existing energy infrastructure and geological conditions. Hungary has a very well-developed natural gas network infrastructure and a significant underground storage capacity of around 60% compared to its annual natural gas consumption.ng.

For accurate economic analyses, it is necessary to quantify the quantities of hydrogen produced from renewable sources now and in the future, as well as its rates for storage. This must be compared with existing underground storage capacities for natural gas and the limits at which renewable hydrogen will represent an economically competitive storage alternative.

The operating costs of the existing natural gas network infrastructure must also be taken into account, which can be used to demonstrate the inputs at which climate-neutral green hydrogen can be stored and converted back into electricity. The system is undoubtedly useful from the point of view of energy independence, from a technical point of view quite a few questions are still open, but economic issues should not be forgotten either.

II. Hydrogen strategies

Hydrogen is a strategic supporter of the energy transition and an instigator of a new industrial revolution that brings positive returns for economic growth, employment and energy security. In its REPowerEU communication, the European Commission acknowledged the central role of hydrogen in the green transition and aims to reach 20 million tonnes of green hydrogen supply by 2030. [11] Over the last few months, the European institutions have worked hard to help the sector to flourish by interfering in simplifying the regulatory framework and providing new financing instruments.

The European Hydrogen Strategy for a climate-neutral Europe plans to introduce hydrogen technologies in three phases. In the period 2020-24, the aim is to green the current hydrogen production capacity and boost the demand for hydrogen. In the second phase of 2025-30, hydrogen can become an integral part of the integrated energy system and a European hydrogen market can be created. According to the plans, the hydrogen production technology will be at such a stage that green hydrogen can become competitive in some sectors (transport, steel production), but it is already intended to play an active role in the regulation of the electrical system. The third phase after 2030 assigns a fundamental role for hydrogen in the European energy system; green hydrogen production technologies will become marketable and will also play a major role in the industrial segment to decarbonize.

In May 2021, Government of Hungary published the National Hydrogen Strategy in order to support the achievement of the energy and climate goals already outlined with another possible route. The development of the European hydrogen economy is a long process, in which Hungary wants to play an active role. The strategy is based on four pillars: low- and zero-carbon hydrogen production, decarbonising industrial energy use partly with hydrogen, greening transport and exploiting the supporting background of electricity and gas infrastructure.

Energy policy objectives are best determined by the availability and capacity of electricity and natural gas infrastructure. Of the two, the most critical operation is shown by the electrical network, since it does not have buffer capacities, i.e. consumer needs appear almost immediately on the production side. The increasing share of renewable energy makes buffer opportunities even more important. The interconnection of electricity and natural gas networks offers a solution for this. If there is a surplus in the electrical system, for example, due to intensive renewable power generation, then hydrogen can be produced with the excess energy. It is already in a gaseous state, which can be stored. The existing Hungarian natural gas infrastructure, which still has plenty of spare capacities, can be suitable for receiving, transmitting and storing the gas produced. This synergy can be one of the solutions for balancing the electrical system.

It follows from the above that the EU's objective of achieving 100% decarbonisation of the energy sector by 2050 will also have a significant impact on the gas industry, especially in the EU, where both gas transport and storage have a significant role within the industry. The most obvious decarbonisation pathways in the gas sector include the interconnection of the gas and electricity sectors and the increasing production of renewable gases, including biogas and other alternative energy gases. Renewable hydrogen can fully replace current hydrogen production, which is currently 95% fossil fuel-based. In recent years, significant investments have been made at EU level to support the construction of gas infrastructure to establish the foundations for security of supply and to develop a well-functioning gas market at EU level. [5, 7]

III. Hydrogen Demand

Global hydrogen demand exceeded 94 million tonnes in 2021, which represents a 5% increase compared to the previous year. The larges part of the increase was related to the use of hydrogen in traditional applications, especially in the chemical industry, with nearly 3 million tonnes. New uses have emerged in heavy industry, transport, energy production and construction, as well as the production of hydrogen fuels. The demand for hydrogen in these areas was very low in 2021, approximately 40 thousand tons of hydrogen, which accounted for about 0.04% of global hydrogen demand. This was mainly road transport, which showed significant growth, reflecting the faster spread of fuel cell vehicle, especially for heavy goods vehicles. China is the largest consumer in the world, the United States is second and the Middle East is third in the ranking. Demand in Europe increased by 8% in 2021, representing 8 million tonnes overall. [6]

The demand for hydrogen is met almost entirely from fossil fuels. In 2021, total global production was 94 million tons of hydrogen, coupled with more than 900 million tons of carbon dioxide emissions associated production. Hydrogen is also produced in refineries as a by-product of hydrocarbon reforming (18%) and then used for other processes (e.g. hydrocracking, desulphurisation). Hydrogen production from coal accounted for 19% of total production in 2021, mainly in China. A limited amount (less than 1%) of oil was also used to produce hydrogen. Low-emission hydrogen production in 2021 was less than 1 million tons (0.7%), almost all from fossil fuels. Using electricity, splitting water, only 35 thousand tons of hydrogen got into the economy. The amount of hydrogen produced during water electrolysis, although very small, has increased by almost 20% compared to 2020. This reflects the increasing use of water electrolysers. [6]

IV. Costs of Hydrogen Production

Hydrogen production costs vary by technology and process, with fossil fuels currently dominating the market. Blue hydrogen from fossil fuels can be an economically competitive, carbon-neutral alternative to conventional fuels used in the electricity, industrial and transport sectors. Currently, coal gasification without carbon capture is the most cost-effective conventional production process, as shown in Figure 1. [12]

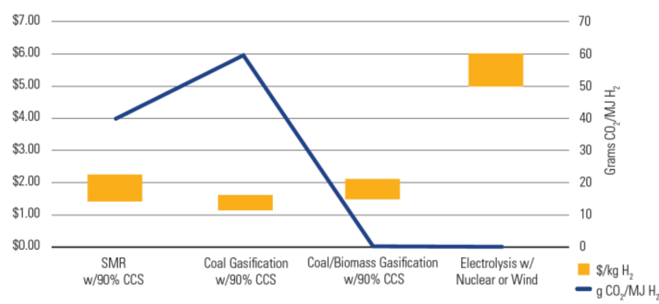

Figure 1. Costs and carbon intensity of hydrogen production by technology in 2020 [12]

The costs of natural gas steam reforming range from 1.43 to 2.27 USD/kg with carbon capture and storage, this largely depends on the price of the transported natural gas. Several studies report that the cost of hydrogen from gasification varies between USD 1.16-1.63/kg for coal and USD 1.31-2.06/kg for coal/biomass/plastic waste raw material using carbon capture and storage. These processes also largely depend on the price of raw materials. The cost of hydrogen production from nuclear or wind sources is between USD 5.0 and USD 6.0/kg of water decomposition. This hydrogen is 2.5-4.0 times more expensive than hydrogen from carbon-neutral or net-negative carbon fossil resources.

V. TECHNOLOGY OF HYDROGEN STORAGE

Hydrogen can be stored and transported on a small scale in pure gaseous and liquid states, as well as by adsorption and absorption methods. At the moment, the legislative framework sees the production of hydrogen as a chemical process on a large-enterprise scale. However, with the technologies expected for the future, this statement will no longer hold water. Therefore, in order to be stored in large quantities, an excellent alternative is to use the existing natural gas network infrastructure. It can be mixed directly into the distribution network for smaller capacities, or into the natural gas transmission system and, through it, into underground gas storage facilities. The legal framework for this is not yet available in Hungary; certain conclusions can only be drawn on the basis of the regulations on natural gas. Research is currently underway on several lines to determine the "hydrogen tolerant" limits of existing infrastructures. In any case, it can be stated that the supply of hydrogen to the natural gas network needs to be addressed.

VI. NATURAL GAS CONSUMPTION STATISTICS

During the research, the potential of replacing natural gas consumption in Hungary with hydrogen was analysed on the basis of the latest available statistical data. Based on the statistical data published by the Hungarian Energy Authority, Table 1 presents the annual quantities of natural gas delivered to end-users by natural gas traders and universal service providers to end-users over the past 6 years, expressed in units of volume, in thousands of m^3 units in relation to the average annual gross calorific value (GCV) of natural gas, in a reference state of combustion and measurement of 15/15 °C. [8]

TABLE I. ANNUAL NATURAL GAS CONSUMPTION IN HUNGARY

Year	**Domestic Natural Gas Sales** *thousand m^3at 15 °C*	**Average Gross Calorific Value of Natural Gas** *kWh/m^3*
2016	8 545 831	10.520
2017	9 053 522	10.525
2018	8 517 508	10.559
2019	8 700 951	10.613
2020	8 871 286	10.608
2021	9 667 239	10.672

Based on the data in the table, it can be concluded that the amount of natural gas delivered to Hungarian users during the period under review varied between 8.5 and 9.6 billion gas technical normal m^3. Among non-residential users, the largest amount was sold to industrial and power plant customers above 500 m^3/h.

VII. THEORETICAL AMOUNT OF HYDROGEN NEEDED TO REPLACE NATURAL GAS

It was investigated how much theoretical hydrogen would be needed to replace the previously presented quantities of natural gas to a certain extent. The study did not take into account that the elements of the natural gas transmission system are not designed and scaled for hydrogen with a density nearly eight times lower, nor the as yet unknown effect of hydrogen on the materials of the system. Not to mention the leakage risk due to the molecular size of hydrogen and the widening ignition concentration range (~4.0-77.0 V/V%) compared to natural gas (~4.4-15.5 V/V%).

TABLE II. QUANTITIES OF HYDROGEN NEEDED TO REPLACE HUNGARIAN NATURAL GAS CONSUMPTION

Year	**Needed Domestic Hydrogen Sales to Replace Natural Gas in 100%** *thousand m^3at 15 °C*	**Average Gross Calorific Value of Hydrogen** *kWh/m^3*
2016	26 740 600	3.362
2017	28 343 344	3.362
2018	26 749 996	3.362
2019	27 467 104	3.362
2020	27 990 116	3.362
2021	30 687 577	3.362

Table 2 shows that the energy content of the annually used domestic natural gas quantities could have been completely replaced by hydrogen by producing 26.7-30.7 billion m^3 of hydrogen between 2016 and 2021. If a smaller proportion of hydrogen is used, we should obviously take the percentage of these values. For example, replacing 20% of the amount of natural gas used requires one fifth of the quantities of hydrogen indicated in the previous table.

VIII. HUNGARIAN GAS STORAGE INFRASTRUCTURE AND HYDROGEN CAPACITY

The question arises as to whether the current Hungarian natural gas system is capable of receiving, storing and transmitting such large quantities of hydrogen. Today's Hungarian natural gas system solves the annual transport of 14-16 billion m^3 of natural gas, together with the transit quantities transported through the country [9]. As a result, it can be said that the Hungarian natural gas system has a capacity of up to 50% of the amount of hydrogen to be transported theoretically. Of course, the issue cannot be simplified to such an extent, since increasing the current transmission line pressures and permissible flow rates may result in further capacity increases, but the technical parameters of the system will be the limit.

The domestic underground gas storage capacity is currently 6.3 billion m^3 [4]. Research is still being carried out today in the direction of how hydrogen can affect the structure of storage, surface technologies. Exact proportions are not yet available. In any case, the fact that, if the entire storage capacity were filled with hydrogen, only 30% of the amount of energy currently stored in them could be used, which cannot be undertaken from the national energy security point of view, without mentioning further possible operational problems, speaks for itself. One thing is clearly visible from the above, the current natural gas infrastructure as a whole will only allow mixing natural gas with a certain amount of hydrogen.

IX. THEORETICAL AMOUNT OF HYDROGEN THAT CAN BE PRODUCED FROM A GREEN SOURCE

It is also worth examining the issue from another point of view, namely, how much natural gas the currently operating domestic renewable energy power plants would be able to replace if we produced green hydrogen entirely from the electricity produced.

To determine the theoretical amount of green hydrogen, small power plants with electricity generation licenses actually operating in 2022 based on renewable energy were listed. It is important to emphasize that the maximum theoretical hydrogen potential is likely to be significantly reduced to the actual amount of hydrogen that can be used, since a significant part of the electricity produced by the power plants is used. Table 3 contains the data extracted from the official database [10].

TABLE III. SMALL POWER PLANTS WITH ELECTRICITY GENERATION LICENSES IN HUNGARY

Energy Source	**Installed Electric Capacity** *MW*
Biogas	71.654
Biomass	108.140
Water	48.186
Wind	327.250
Sun	2021.322
Geothermal Energy	2.700
Landfill Gas	11.555
Total	**2590.807**

For the calculation, only those power plants that operate on renewable-based fuels and energy sources, which belong to the categories of biogas, biomass, landfill gas, water, wind, geothermal, and solar energy, were selected. Based on official data in September 2022, 239 photovoltaic power plants were in operation in Hungary, with a total installed capacity of 2021.3 MW, of which the smallest power plant is 0.54 MW and the largest is 49.92 MW. There were 58 biogas, 10 biomass and 12 landfill gas plants with a total installed capacity of 191.3 MW. In addition, 11 hydroelectric power plants with a capacity of 48.2 MW, 46 wind power plants with an installed capacity of 327.3 MW, as well as a geothermal power plant with a capacity of 2.7 MW were in operation. By September 2022, Hungary had a total of 2590.8 MW of renewable-based installed capacity. A significant part of this, 78.02%, was photovoltaic, 12.63% wind, 2.77% biogas, 0.45% landfill gas-based, 1.86% hydro and 0.10% geothermal power plant capacity. The following basic data from the literature were used to determine the theoretical hydrogen potential on a renewable basis:

- A 20 MW of installed capacity is capable of generating an average of 21 GWh of electricity per year;
- To produce 1 kg of hydrogen, about 50 kWh of electricity is required. The exact amount of this varies depending on the type of electrolyser. The theoretical hydrogen quantities that could be produced were calculated separately for each type of electrolyser. Based on them, the electricity requirement for alkaline electrolysis is 50-51 kWh that of the PEM electrolyser is 55-58 kWh, while for the SOE electrolyser there is a need for electricity of 40-41 kWh during the production of 1 kg of hydrogen. For the calculation, average values were taken into account from them. It is 50 kWh/kg during alkaline electrolysis, 56 kWh/kg during PEM electrolysis and 40 kWh/kg during SOE electrolysis.
- a volume of 1 kg of hydrogen of 11,89 m^3 in the normal gaseous state (at a temperature of 15 °C and a pressure of 1,01325 bar);
- density of hydrogen 0,0841 kg/m^3 in the gaseous normal state (at 15 °C and 1,01325 bar). [1, 2, 3]

Based on the calculations, it can be said that the installed renewable electricity capacity available in 2021 would have allowed the production and feeding of approximately 48-68 million kg of hydrogen in Hungary, i.e. 577-808 million m3 of hydrogen in the normal state of gas technology, depending on the type of electrolyser used. It should be added that all this theoretical amount could have covered only 1.9-2.6% of the total annual natural gas consumption in Hungary in 2021, if in fact all the electricity produced was used exclusively for hydrogen production.

X. CONCLUSION

The possibility of replacing natural gas with 100% hydrogen is currently far from reality in Hungary. To replace the energy content of the entire annual end-user natural gas quantity with hydrogen, it would be necessary to produce about 27 - 30 billion standard m3 of hydrogen, taking into account the statistics of natural gas in recent years. The total renewable capacity installed could only cover about 2% of our annual natural gas consumption. The replacement of natural gas with 100% hydrogen is a theoretical value; this requires a natural gas system and gas appliance technology that operates in an island operation. It has not been tested, but a problem is expected during the appearance of hydrogen with the material of the fittings of the natural gas system, capacities, pressures and, most importantly, the safe operation of gas appliances. Another fact is that gas-consuming appliances with the largest number of units, the widest range of types, as well as age, occur in the residential and communal sectors. It follows from all this that, when examining the share of hydrogen supplied through the natural gas network, special attention must be paid to the residential and communal sectors in terms of end-user equipment. All things considered, however, hydrogen, as a clean and environmentally friendly energy carrier, must be a priority for the energy of the future.

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