THE ROLE OF HYDROGEN SOLUTIONS IN THE ENERGY TRANSITION PHASE IN ROMANIA

ROLUL SOLUȚIILOR DE HIDROGEN ÎN FAZA DE TRANZIȚIE ENERGETICĂ ÎN ROMÂNIA

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Abstract: *Concerns about reaching the target of decarbonisind of energy systems by 2050 have led to hydrogen coming to the attention of energy specialists as a primary source of energy both as fuel in power plants and as input into fuel cells, taking into account that the emissions are minimal when used. Of the current methods of producing „clean" hydrogen, only the use of electrolysers powered by electricity from photoelectric, wind, hydro and nuclear sources is considered by the future. The paper analyzes the possibilities of producing „clean" hydrogen, the problems related to its transport and the prices at which it can be achieved.*

Keywords: hydrogen, renewable sources, hydrogen transport, hydrogen price.

***Rezumat**: Preocupările privind atingerea ţintei de decarbonare a sistemelor de energie până în anul 2050 a determinat ca hidrogenul să intre în atenţia specialiştilor energeticieni ca o sursă primară de energie atât ca combustibil în centralele electrice cât şi ca element de intrare în celulele cu combustibil, având în vedere că la utilizarea acestuia emisiile poluante sunt minime. Dintre metodele actuale de producere a hidrogenului „curat" este considerată de viitor doar utilizarea electrolizoarelor alimentate cu energie electrică din surse fotoelectrice, eoliene, hidro şi nucleare. În cadrul lucrării sunt analizate posibilităţile de producere a hidrogenului „curat", problemele legate de transportul acestuia şi preţurile la care poate fi achiţionat acesta.*

Cuvinte cheie: hidrogen, surse regenerabile, transport hidrogen, preţul hidrogenului.

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1. Introduction

Achieving the zero-carbon net target during the transition period by 2050 requires the development of energy specialists' concerns on three main directions:

– increasing the efficiency in the use of electricity;

– decarbonising of fuels used for the generation of electricity;

– carbon capture and storage.

The paper focuses on the fuel decarbinising solution using hydrogen. The decarbinising actions aim to increase the share of hydrogen for the production of electricity through use as fuel and as fuel cell supply.

Hydrogen is an important element in achieving the net zero carbon target by 2050. In this regard, many countries in the world have developed strategies for the production, transport and use of hydrogen during the energy transition phase. In this respect, in Romania, the Hydrogen Strategy is being developed with the EU target that in 2050, 12% of the final energy used in the country be covered by the use of hydrogen or its derivatives [1].

Although hydrogen can be produced by different processes, only „clean" hydrogen obtained by electrolysis of water or by reforming methane gas with carbon storage is taken into account in decarbonising analyzes.

The use of hydrogen in power plants for the production of energy will play an increasingly important role, and by 2050 it will completely replace natural gas as the primary source of energy. (table 1) [2].

Although the production of hydrogen by electrolysis of water is a known and easily accessible process, reducing the costs of the resulting hydrogen will be essential in increasing its share in the energy field. It is considered that the most efficient solution for powering electrolyzers consists in using the energy produced in excess by unpredictable energy sources (solar, wind). Considering also the possible cost reduction in an electrolyser plant, it is possible that, in the long term, hydrogen will become competitive as a primary energy source.

Of course, there is the question of what needs to be done so that the use of hydrogen can lead, in the short term, to significant contributions to reducing the carbon footprint. The lack of necessary infrastructure, the lack of demand, the lack of supply, but also the problems related to the use of hydrogen as well as the lack of specialists in the field, determine that, by 2030, the contribution of the use of hydrogen to the decarbonising of energy systems will have a relatively low share and practical uses will be only at pilot level [3].

Table 1. **The perspective of fuels used for power plants** *)

Step	Year	Power plants	Emission level gCO_2/kWh
0	2020 – present	Many power plants based on coal (lignite)	~1300
1	2025	Switching from coal fuel to natural gas. Mixed cycle plants using natural gas and prepared for hydrogen mixture	250-280
2	2030	Increasing hydrogen production. Power plants with an increasing share of hydrogen.	~ 100
3	2050	Natural gas will be completely replaced by hydrogen	0

*) To cover the electricity needs, high efficiency mixed cycle, wind and solar installations will have an important share

2. Hydrogen generation

Depending on the energy source used and the technology used to produce hydrogen, colors are sometimes used to characterize it from a carbon footprint point of view (Table 2). However, this classification is disputed, with a focus on carbon equivalence, costs, new methods of producing and using hydrogen.

Green hydrogen and blue hydrogen solutions, commonly referred to as „clean" hydrogen production solutions, can play an important role in the transition period. It is considered that in the case of „blue" hydrogen there is a very low emission of methane and the carbon is completely captured and stored.

It is considered that in the year 2050, globally, according to the 1.5°C scenario, about 409 million tons of „clean" hydrogen will be used, a large part of which will be obtained through the electrolysis of water [1], which will require that about 30% from the electricity production to be used to power the electrolyzers.

It is estimated that in 2050, for the production of the 409 Mt H_2, the electricity for the supply of the electrolyzers will be 21000 TWh (51,4 kWh/kg H_2) [1]. To produce 1 Mt H_2/year requires a 10 GW electrolyzer to operate constantly about 60% of the year [1].

Table 2. **Types of hydrogen and carbon footprint**

Energy source	**Terminology**	**Technology**	**Energy source**	**Carbon footprint**
Electricity	Green hydrogen	Electrolysis	Wind, solar, hydro, geothermal, tidal energy	minimum
	Pink hydrogen		Nuclear	
	Yellow hydrogen		Mixed energy from the power grid	medium
Fossil sources	Blue hydrogen	Reforming natural gas and carbon storage	Natural gas, coal	low
	Turquoise hydrogen	Pyrolysis	Natural gas	solid coal as a by-product
	Gray hydrogen	Reforming natural gas		medium
	Brown hydrogen	Gasification	Lignite	high
	Black hydrogen		Pit coal	

Currently, about 600 t H_2 per day is produced, which requires an electrolysis power of about 0,5 GW.

If it is considered that in 2050, Romania will allocate about 10 TWh for the supply of electrolyzers for the production of hydrogen, which determines a production of about 0,2 Mt H_2/year, electrolysis of at least 1500 MW shall be required.

„Clean" hydrogen results in the supply of electrolyzers from renewable energy sources or from nuclear sources considered „clean". The level of emissions attached to the hydrogen generated in the electrolyzers powered by the power grid depends on the energy mix from which the electricity is produced.

The hydrogen produced by electrolysis of water determines the lowest emissions if the electrolyzers are supplied from renewable sources: solar (1,0 kg CO_2 equiv/kg H_2), wind (0,5 kg CO_2 equiv/kg H_2), nuclear (0,6 kg CO_2 equiv/kg H_2 and 0,115 g nuclear waste) or hydropower plants (0,3 kg CO_2 equiv/kg H_2) [4].

Given the 60% energy efficiency of an electrolyzer, it is always more efficient to use directly the electricity generated by power sources and only the excess energy to be used to power the electrolyzers. An electrolyzer can be sized to operate above 3 MPa.

Only water and electricity are needed for the production of hydrogen when using electrolysis (Table 3) [5]. Theoretically, for 1 kg H_2, 9 kg of water is required. In reality, given the electrolysis efficiency and water preparation processes, a quantity of 17···22 kg of water per 1kg of H_2 is required.

Table 3 - *Theoretical water required for hydrogen production*

No.	Technology	Water needed [kg water/ kg H_2]	Electricity required
1	Electrolysis	17···22	51,4 kWh/kg H_2
2	Reforming natural gas and CO_2 storage	13···18	
3	Coal gasification	40···86	

In order to achieve the 1.5°C target, a quantity of about 0,2 Mt H_2 will have to be generated in Romania in 2050, which will require about (3,4···4,4)) million m^3 of water – about 157···203 kg/s (for 550 Mt H_2 annually, a quantity of 9,4.··12,1 m^3 is required, less than 0,25% of clean water consumption [1]).

3. Use of hydrogen with low carbon footprint

Of course, the most important component of the Power-to-X concept is the production of green hydrogen by electrolysis, using electricity from renewable energy sources. Hydrogen can be used directly in combustion plants (internal combustion engines) or in fuel cells, but it can also provide the basis for the production of new gaseous or liquid fuels such as methane, methanol, synthetic natural gas, E-petrol, E-Diesel, E-kerosene, which can be used in thermal power plant combustion plants, in industry, in long-distance truck transport or can be injected into natural gas networks.

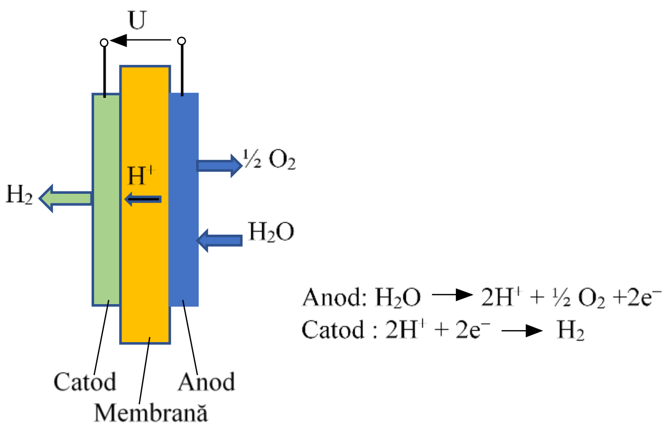

Fig.1. Operation of an electrolyser.

The hydrogen obtained by electrolysis of water can be attached pollutant emissions of 26 g CO_2/kWh.

Pure hydrogen by combustion provides above 1000°C without generating CO_2.

To limit transport costs, 85% of the hydrogen produced is expected to be used locally.

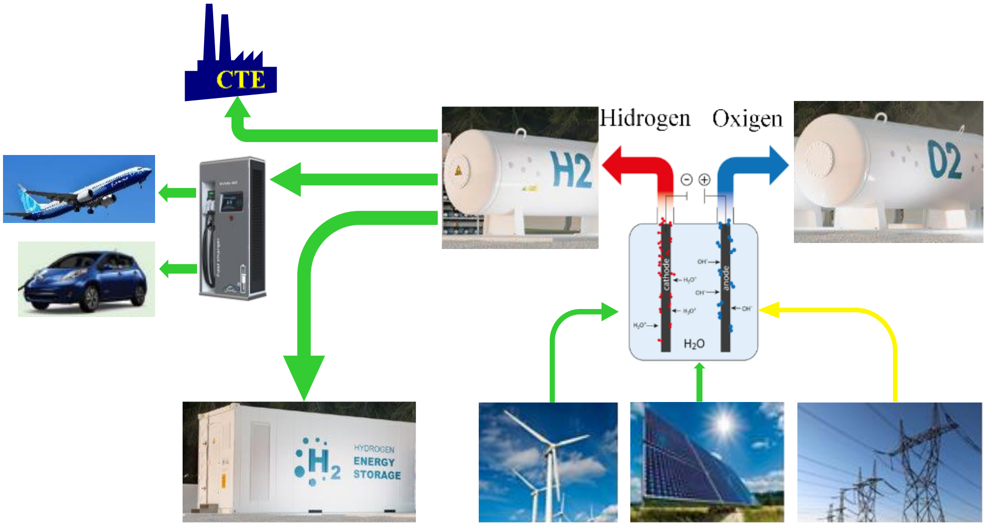

Fig. 2. Production and use of green hydrogen as a fuel source.

Figure 2 [5] shows the main hydrogen production solutions with a low carbon footprint and the main fields of use as a fuel source.

4. Transport of hydrogen

Considering the low volume density of hydrogen, in order to ensure its transport, it is necessary to transform it from gaseous form into an appropriate form (liquid hydrogen, ammonia, liquid organic hydrogen carriers) and reconversion into gaseous form (if it is required) to the end user.

Considering that the most important wind potential is located in Dobrogea, it is estimated that most water electrolysis installations will be located in this area, and the hydrogen will be transported to the place of use through pipelines.

The pipeline transport of hydrogen gas, with pressures of 7···10 MPa, is attractive for short distances, and it is possible to partially use the current methane gas transport infrastructure, with losses of several percent. This mode of transport is currently commercially available and becomes advantageous with the increase in transport volume. It is not possible to apply in areas without a pipe network of materials suitable for hydrogen.

Transportation by compressed H_2 pipes at relatively short distances can reach below \$1/kgH_2. The costs may be lower if the existing natural gas structure is used. Check the compatibility of the pipe material with H_2 (most pipes are compatible) [3] Gaseous H_2 transport is a mature technology. Volumetric energy density (MJ/m^3) is about one-third that of natural gas, but the mass density of H_2 is about 9 times lower.

There is currently a mixture solution of H_2 with natural gas in the existing network. Some existing equipment accepts a mixture of up to 20% H_2 by volume.

The transport in liquid form is specific to the import of hydrogen from long distances using special ships. The transport takes place on ships with a pressure of 0,1···0,4 MPa. Liquid hydrogen has a density about 80% higher than compressed hydrogen at 70 MPa.

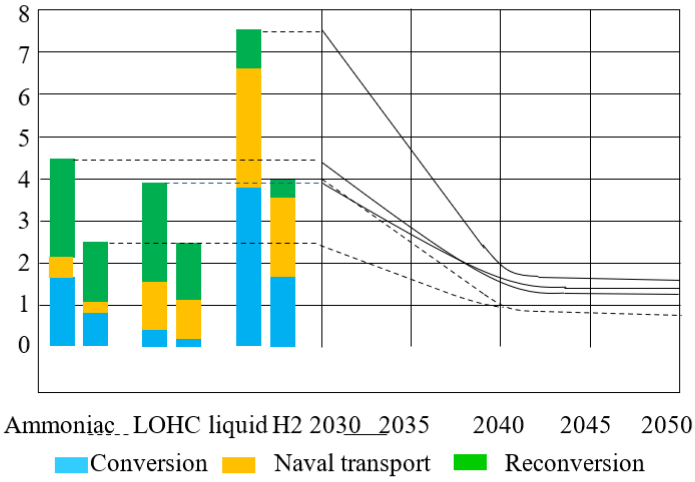

Fig. 3. Estimated transportation cost of hydrogen [\$/kg H_2]: optimistic estimates; pessimistic estimates.

The cost of transportation in liquid form is affected by the fact that liquefaction and maintaining the temperature of -253°C requires about 30···36% of the energy contained in hydrogen and 0,05···0,25% is used for fueling the vessel and storage per day [3]. The cost of shipping, with pressure of 25 MPa, with naval units up to 2000 t H_2 (fig. 3) [3], with a reduction in the volume density of 500···800 times compared to atmospheric hydrogen due to the energy requirement for transport, becomes uneconomical for long distances. At present, the transport of liquid hydrogen is of no commercial nature. There are in the project ships of 50,000 m^3. A sphere of 4700 m^3 contains 334 t of liquid H_2.

For transport by ships over 10000 tH2 the cost is around 40 $/t H_2.

Liquefaction theoretically requires about 2.67 kWh/kg H_2, if the inlet pressure is 2 MPa, but H_2 regasification is simple.

For short-distance transport, special trucks are used with up to 4···4.5 t H_2 liquid.

An advantageous way of transporting hydrogen is in the form of ammonia obtained by reacting with nitrogen in the air.

Ammonia has a density 1800 times higher than atmospheric hydrogen, but with a transport efficiency (round trip for ammonia) of about 50%. (12···26)% of the energy contained in hydrogen is used for the synthesis of ammonia and 13···36% of the energy contained in hydrogen for reconversion at the destination. It is possible to transport a much larger volume and therefore a much larger energy. Also, the transport of ammonia is commercially validated, being specific to the products needed for agricultural fertilizers.

Hydrogen can be converted to ammonia by reacting with nitrogen in the air, using electricity, water and air than hydrogen, which means that a larger volume of energy can be traded. There is a well-established international trade in ammonia that can be harnessed. It is currently used as a raw material, especially to make fertilizers. Ammonia is easily liquefied and contains 1.7 times more hydrogen per unit than liquid hydrogen. At 20°C, a pressure of 0.75 MPa is required for liquefaction and at –33°C liquefaction is done at atmospheric pressure.

Ammonia can also be used as a fuel (e.g. in ships carrying it) but combustion leads to nitrogen oxides. The disadvantage is that ammonia is toxic if leaks occur and is a potential source of nitrogen oxide emissions.

Transport in the form of liquid organic hydrogen carriers LOHC, although it has some advantages in transport (it comes in the form of oil) is still not sufficiently studied.

5. The cost of hydrogen

The cost of hydrogen with a low carbon footprint is the essential factor that determines its competitiveness on the energy market and therefore the increase in the share of hydrogen in the energy industry. From the point of view of the costs of hydrogen with a reduced carbon footprint, only solutions with electrolysis production using renewable energy sources and the SMR (*Steam methane reforming*) solution together with CCUS (*Carbon Capture Use and Storage*) are considered, which becomes competitive in the case the low price of natural gas, but with the increase in the price of methane gas, the SMR solution becomes uncompetitive.

Figure 4 [6] shows the cost forecast for hydrogen production based on renewable energy sources depending on the price of the energy generated by these sources in three scenarios. It is considered in the first scenario that the price of electricity generated by renewable sources of 34 $/MWh in 2020 will reach $11/MWh in 2050; in the second scenario, renewable energy costs 40···45 $/MWh, and in 2050 it will reach 11 $/MWh and in the third scenario, renewable energy costs 50···62 $/MWh, and in 2050 it will reach 23···45 $/MWh.

The data in figure 4 highlight the fact that the cost of hydrogen obtained on the basis of electricity from renewable sources will decrease from 3···8 $/kg to 1···3 $/kg.

To limit the costs of producing hydrogen by electrolysis of water, investors will place electrolysis plants in areas with the best solar or wind resources.

It is necessary to take into account both the costs, because due to the low demand for electrolyzers their cost is high, as well as the possibilities of procuring the materials necessary for a massive production of electrolyzers.

The data shown in Figure 4 show that with the commercial development of hydrogen applications, all costs, including transport costs, will be reduced so that in 2050, the cost of hydrogen to the user will reach 1,8···2,5 $/kg.

A major impediment to reducing costs for electrolyzers is the need for the use of rare materials that account for less than 10% of the total cost of an electrolyzer. Not so much their cost is a barrier, but their limited availability. Studies are currently underway to replace rare materials with ceramic materials, which would help reduce the costs of making electrolyzers.

The cathode is usually made of platinum. Since the anode is subject to an intense oxidation process, iridium is used due to its high durability. The life of an electrolyzer is 10 years [7]. Platinum is recyclable, so it does not cause difficulties in supply. Iridium is used around 1.25 g/kW (compared to the annual Iridium production of 7···7,6 t /year) which limits the production of electrolyzers to 10···12 GW/year.

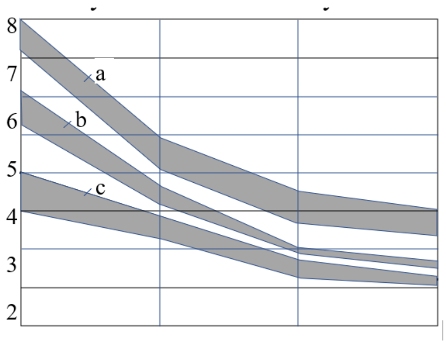

Fig.4. Estimated cost of green hydrogen [$/kg]:
a) high values of the price of electricity from renewable sources;
b) average values of the price of electricity from renewable sources;
c) reduced values of the price of electricity from renewable sources.

Studies are underway to increase the efficiency of the membrane (polymer, inorganic).

6. Conclusions

Based on the above, some conclusions can be highlighted as follows:

i. The use of hydrogen as an energy carrier is one of the effective solutions for decarbonising of the energy system. It is an attractive energy carrier (140 MJ/kg) at least 3 times more than a classic fuel and when burned does not cause polluting emissions.

ii. By using the surplus production of renewable sources, nuclear sources and hydro sources, the use of hydrogen-based solutions can ensure the necessary flexibility of the electricity system. In this way, hydrogen becomes an important factor for the promotion of renewable energy sources.

iii. The EU's energy strategy takes into consideration the installation of 40 GW in electrolysers up to the year 2030

iv. Of course, in order to achieve the EU's objectives, specialists are needed to ensure the design, construction and operation of electrolysis installations, transport and use of hydrogen [8]. The training of these specialists for the electricity system in Romania is also advantaged by the fact that there are currently qualified personnel in the field who ensure the operation of hydrogen cooling installations of large generators in power plants as well as personnel from companies producing chemical fertilizers based on ammonia.

v. There are a number of challenges and opportunities determined by the impact of hydrogen on how energy is produced and used in the European

Union [9]. These must be considered in the hydrogen strategies of European countries.

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