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FROM NATURAL GAS TO GREEN HYDROGEN

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Since hydrogen usually exists on Earth as part of a compound, it has to be synthesized in specific processes in order to be used as a product or energy source. This can be achieved by different technical methods, and various primary energy sources, – both fossil and renewable fuels, in solid, liquid or gaseous form, – can be used in these technical production processes. Hydrogen has only a very low volumetric energy density, which means that it has to be compressed for storage and transportation purposes. The most important commercial storage method, – especially for end users, – is the storage of hydrogen as a compressed gas. A higher storage density can be achieved by hydrogen liquefaction. Novel materials-based storage media (metal hydrides, liquids or sorbents) are still at the research and development stage.

The storage of hydrogen (for example, to compression or liquefaction) requires energy; work is, in present, on more efficient storage methods.

Unlike electricity, hydrogen can be successfully stored in large amounts for extended periods of time. For example, in long-term underground storage facilities hydrogen can play an important role as a buffer store for electricity from surplus provided by renewable energies.

At present, pure hydrogen is generally transported by lorry in pressurize gas containers, and in some cases also in cryogenic liquid tanks. Moreover, local/regional hydrogen pipeline networks are available in some locations. Another solution for storage and transportation are Liquid Organic Hydrogen Carriers (LOHC) that can use long pipe networks and ships. In the near future, the natural gas supply infrastructure or oil (transportation pipelines and underground storage facilities) could also be used, in specific conditions, for the storage and transportation of pure or blended hydrogen with methane. This could be essential for transition because most important primary energy source for hydrogen production currently is natural gas, at 71%, followed by oil, coal and electricity (as a secondary energy resource). Steam reforming (from natural gas) is the most commonly used method for hydrogen production.

In this new light, the article explores the trend and prospects for hydrogen, presented in the literature, as a source of energy competing with gas and oil resources in the global energy system of the future.

KEY WORDS: *hydrogen, natural gas, water, green, future.*

ОТ ПРИРОДНОГО ГАЗА К ЗЕЛЕНОМУ ВОДОРОДУ

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Поскольку водород обычно существует на Земле в составе соединения, его необходимо синтезировать в определенных процессах, чтобы использовать в качестве продукта или источника энергии. Это может быть достигнуто различными техническими методами, и в *этих технических производственных процессах могут использоваться различные первичные источники энергии – как ископаемое, так и возобновляемое топливо в твердой, жидкой или газообразной форме. Водород имеет только очень низкую объемную плотность энергии, что означает, что он должен быть сжат для целей хранения и транспортировки. Наиболее важным коммерческим методом хранения, особенно для конечных пользователей, является хранение водорода в виде сжатого газа. Более высокая плотность хранения может быть достигнута за счет сжижения водорода. Новые носители для хранения на основе материалов (гидриды металлов, жидкости или сорбенты) все еще находятся на стадии исследований и разработок.*

Для хранения водорода (например, для сжатия или сжижения) требуется энергия; в настоящее время ведется работа над более эффективными методами хранения.

В отличие от электричества, водород может успешно храниться в больших количествах в течение длительного периода времени. Например, в долгосрочных подземных хранилищах водород может играть важную роль в качестве буферного хранилища для электроэнергии из избытка, обеспечиваемого возобновляемыми источниками энергии.

В настоящее время чистый водород, как правило, транспортируется грузовым транспортом в баллонах с газом под давлением, а в некоторых случаях также в резервуарах для криогенной жидкости. Кроме того, в некоторых местах имеются местные/региональные сети водородных трубопроводов. Другим решением для хранения и транспортировки являются носители жидкого органического водорода (LOHC), которые могут использовать длинные трубопроводы и суда. В ближайшем будущем инфраструктура снабжения природным газом или нефтью (транспортные трубопроводы и подземные хранилища) также может быть использована в определенных условиях для хранения и транспортировки чистого или смешанного водорода с метаном. Это может иметь важное значение для переходного периода, поскольку в настоящее время наиболее важным первичным источником энергии для производства водорода является природный газ (71%), за которым следуют нефть, уголь и электроэнергия (в качестве вторичного энергетического ресурса). Паровой риформинг (из природного газа) является наиболее часто используемым методом получения водорода.

В статье исследуются тенденции и перспективы использования водорода, представленные в литературе, как источника энергии, конкурирующего с ресурсами газа и нефти в глобальной энергетической системе будущего.

КЛЮЧЕВЫЕ СЛОВА: *водород, природный газ, вода, экологичность, будущее.*

ТАБИҒИ ГАЗДАН ЖАСЫЛ СУТЕККЕ ДЕЙІН

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Сутегі әдетте қосылыстың құрамында жер бетінде болғандықтан, оны өнім немесе энергия көзі ретінде пайдалану үшін белгілі бір процестерде синтездеу керек. Бұған әртүрлі техникалық әдістермен қол жеткізуге болады және осы техникалық өндірістік процестерде энергияның әртүрлі бастапқы көздерін – қатты, сұйық немесе газ түрінде қазба және жаңартылатын отынды пайдалануға болады. Сутегі тек өте төмен көлемдік энергия тығыздығына ие, яғни оны сақтау және тасымалдау үшін қысу керек. Сақтаудың ең маңызды коммерциялық әдісі, әсіресе соңғы пайдаланушылар үшін, сутекті сығылғын *газ ретінде сақтау болып табылады. Жоғары сақтау тығыздығына сутекті сұйылту арқылы қол жеткізуге болады. Материалдарға негізделген жаңа сақтау құралдары (металл гидридтері, сұйықтықтар немесе сорбенттер) әлі де зерттеу және әзірлеу сатысында.*

Сутекті сақтау үшін (мысалы, қысу немесе сұйылту) энергия қажет; қазіргі уақытта сақтаудың тиімді әдістерімен жұмыс жүргізілуде.

Электр қуатынан айырмашылығы, сутегі ұзақ уақыт бойы көп мөлшерде сәтті сақталуы мүмкін. Мысалы, ұзақ мерзімді жер асты қоймаларында сутегі жаңартылатын энергия көздерімен қамтамасыз етілген артық электр энергиясының буферлік қоймасы ретінде маңызды рөл атқара алады.

Қазіргі уақытта таза сутегі жүк көлігімен қысым газ баллондарында, ал кейбір жағдайларда криогендік сұйықтық резервуарларында тасымалданады. Сонымен қатар, кейбір жерлерде сутегі құбырларының жергілікті/аймақтық желілері бар. Сақтау мен тасымалдаудың тағы бір шешім – ұзын құбырлар мен кемелерді қолдана алатын сұйық органикалық сутегі тасымалдаушылары (LOHC). Жақын болашақта табиғи газбен немесе мұнаймен жабдықтау инфрақұрылымы (көлік құбырлары мен жер асты қоймалары) метанмен таза немесе аралас сутекті сақтау және тасымалдау үшін белгілі бір жағдайларда пайдаланылуы мүмкін. Бұл өтпелі кезең үшін өте маңызды болуы мүмкін, өйткені қазіргі уақытта сутегі өндірісі үшін ең маңызды бастапқы энергия көзі табиғи газ (71%), одан кейін мұнай, көмір және электр энергиясы (екінші энергия ресурсы ретінде) болып табылады. Бу риформингі (табиғи газдан) – сутегі алудың ең көп қолданылатын әдісі.

Осы жаңа көзқараста мақалада болашақта жаһандық энергетикалық жүйеде газ және мұнай ресурстарымен бәсекелесетін энергия көзі ретінде әдебиетте ұсынылған сутекті пайдалану тенденциялары мен перспективалары зерттеледі.

ТҮЙІН СӨЗДЕР: *сутегі, табиғи газ, су, экологиялылық, болашақ.*

1. INTRODUCTION

The name *"hydro-gène"* (water producer) was first coined in 1787 by the french chemist Antoine-Laurent Lavoisier[2], from the greek words *"hydor"* (water) and *"genes"* (producing).

Hydrogen is the simplest chemical element. It's the most abundant chemical element, estimated to contribute 75% of the mass of the universe. Evident, despite its simplicity and abundance, hydrogen doesn’t occur naturally as a gas on the Earth – it’s always combined with other elements (for example: Water is a chemical compound of Hydrogen and Oxygen, with the crude chemical formula H_2O).

Moreover, hydrogen occurs in almost all organic compounds. It is not only living creatures that are composed of organic compounds. Fossil energy sources also consist primarily of carbon-hydrogen compounds. The hydrocarbon methane, the main constituent of natural gas, is made up of one carbon atom and four hydrogen atoms (CH_4). In the same time, in higher alkanes such as petrol and diesel fuel the *carbon-hydrogen* ratio decrease. So, the higher the hydrogen content of a hydrocarbon, the lower the carbon dioxide content and hence the lower the greenhouse gas emissions on combustion (oxidation).

Due to economic importance at a certain historical moment, each part of the energy system enjoyed a form of political support. This was and still is true for fossil fuels and now for renewable energy sources, in all sectors: energy, heating and cooling and transport.

[2]***Antoine-Laurent Lavoisier****, (born, 26 August, 1743 – died, 8 May 1794, Paris, France), prominent french chemist and leading figure in the 18th-century chemical revolution who developed an experimentally based theory of the chemical reactivity of oxygen and coauthored the modern system for naming chemical substances.*

The hydrogen sector is no exception to the rule, also receiving some attention from policy makers through dedicated policies. But until maturity, more dedicated political support is needed, at every stage of technological training, in order to penetrate the energy market and grow the hydrogen market as a product [1,2].

2. PAST, PRESENT, AND FUTURE OF HYDROGEN

2.1. The Past of Hydrogen [3,4,6]

Almost since its discovery, hydrogen has played an important part in contemporary visions of the future, especially in relation to the energy industry and locomotion.

As early as 1874, the French science fiction writer Jules Verne *(b.1828 – d.1905)* in his novel *"L'Île mystérieuse"* (The Mysterious Island) saw hydrogen and oxygen as the energy sources of the future. In his vision, hydrogen would be obtained by the breaking down of water (via electrolysis). Water, respectively hydrogen, would replace coal, which at the time was the dominant energy source in the energy supply industry. So, *"Water will be the coal of the future"*.

The 1960s, provided further impetus to the fantasies surrounding hydrogen, the successful use of hydrogen as a rocket propellant and of fuel cells to operate auxiliary power units in space (in terms of space technology, that of the Russia or former USSR was substantially more advanced than that of the United States).

Also in the 1960s, first passenger cars were fitted with fuel cells as basic prototypes resp. technology demonstrators.

NASA has used liquid hydrogen since the 1970s, – especially in the context of the US Apollo space travel program – to propel the space shuttle and other rockets into orbit. Hydrogen fuel cells power the shuttle's electrical systems, producing a clean byproduct – pure water, which the crew drinks.

Also in the 1970s, under the impression of dwindling and ever more expensive fossil fuels, the concept of a (solar) hydrogen economy was developed, with H_2 as the central energy carrier.

Since the 1990s, hydrogen and fuel cells have made huge technical progress in the mobility sector.

After the turn of the century, not least against the background of renewed global raw material shortages and increasingly urgent questions of sustainability, the prospects for a hydrogen economy were considered once again (*Rifkin, 2002*).

More recently, the focus has increasingly been on hydrogen's role in a national and global energy transition. Within this context, the value added of hydrogen (from renewable energies via electrolysis) in an increasingly electrified energy world has also been subject to discussion. Nevertheless, an important role is envisaged for hydrogen, – especially as a clean, storable and transportable energy store, – in an electricity-based energy future (*Nitsch, 2003; Ball/Wietschel, 2009*).

Demand for hydrogen, which has grown more than threefold since 1975, continues to rise – almost entirely supplied from fossil fuels, with 6% of global natural gas and 2% of global coal going to hydrogen production (*see Figure 1*).

Grey hydrogen is currently used as a feedstock to produce methanol and ammonia. Green hydrogen could replace much of it, without significant changes in equipment or

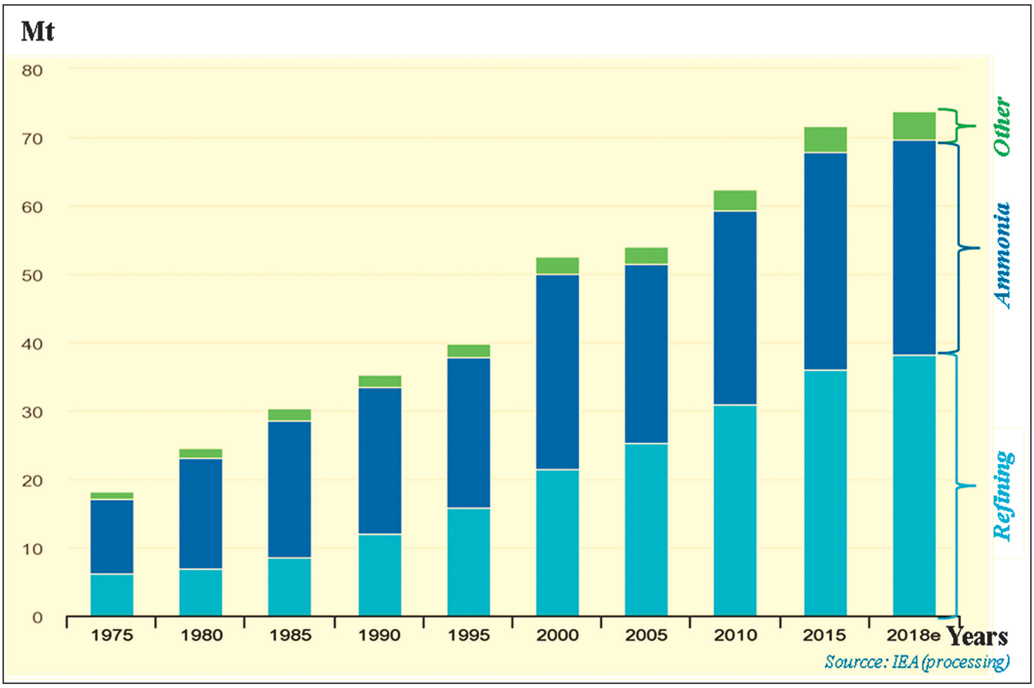

Figure 1 – **Global demand for pure hydrogen, 1975-2018 [3]**

technology, but with major environmental effects, eliminating emissions associated with gray hydrogen production.

Therefore, it can be concluded that, hydrogen production is mostly based on natural gas and coal, which together account for 95% of production. In which, more than two-thirds of the 70 million tons of hydrogen produced a year comes from natural gas. And that process is responsible for about 830 million tons of carbon pollution a year, more than the combined emissions of Britain and Indonesia.

Consequently, hydrogen and energy have a long shared history – powering the first internal combustion engines over 200 years ago to becoming an integral part of the modern refining industry. Evident, it is light, storable, energy-dense, and produces no direct emissions of pollutants or greenhouse gases. But, for hydrogen to make a significant contribution to clean energy transitions, it needs to be adopted in sectors where it is almost completely absent, such as transport, buildings and power generation. Even today, coal remains a significant source of energy for the production of heat and electricity. The phasing out of coal energy production is a substantial opportunity for hydrogen to remove a large amount of CO_2 from the energy system; this, together with an ambitious development of renewable energy sources, are the best way to leave the past behind.

2.2. The Present of Hydrogen [3,4,6]

The Present, useable hydrogen can be separated from water, biomass, coal seams or natural gas. Today, hydrogen is insufficiently available. Approximately 70 million tonnes is produced globally, including approximately 9 million tonnes in the US which used in refining and treating metals, in food processing and also by NASA in the space program. According to Agora Energiewende, Germany's electricity system will require 102TWh of gas in 2025 and 133TWh in 2035 to ensure the dispatchable capacity of the electricity system. Thus, to replace the 133 TWh of gas with renewable hydrogen, Germany should install 75GW of offshore wind. A complete replacement of renewable gas by 2030 appears to be a difficult and sensitive target. Hydrogen, evident, the most abundant element in the universe, has often been argued as a way to power vehicles and power plants, but it is too expensive. Therefore, it is essential to rapidly increase clean hydrogen production and reduce costs by pursuing a liquidity market for this product by 2030, accessible to all economic sectors in transition.

On the one hand, most of the hydrogen used today is produced by reforming natural gas, which also releases a lot of carbon dioxide – CO_2. On the other hand, green hydrogen is extracted from water by electrolysis, – *electrolysis produces around 5% of global hydrogen, as a by-product from chlorine production*, – but it is still a very energy consuming process.

Advances in technology, commercialization driving down cost and strengthened political will to address climate change have brought, in present, renewed focus to the potential of hydrogen to contribute to de-carbonizing the energy system, particularly in complex sectors like heat and transport.

However, the huge advantage of clean hydrogen production is that energy can be stored more easily than other forms of renewables and for longer periods of time, which is why it is an essential part of the energy transition strategy at local, regional and global level, how the "world economy" aims to become carbon neutral by 2050. The production of clean hydrogen should play a key role in increasing the energy market in cogeneration – Combined Heat and Power (CHP), being able to provide heat as a by-product; in CHP hydrogen consumption is reduced by 30% compared to simple electricity production. The high efficiency of fuel use in CHP plants, of over 90%, has a great value, because the relatively large losses from the transformation of gas into energy (gas to power) are the main cost factor of the solution.

In addition to high efficiency, CHP using hydrogen is a highly flexible technology. Small-size CHP plants can be built fast and could be located near the point of use. In this sense will provide power where demand grows (heat pumps, e-charging stations) and heat to public heating networks

But currently, there is a lack in hydrogen production from renewable sources which do not provide electricity at all times. So, green hydrogen has been limited to demonstration projects. Considering this lack, policy makers need to ensure that" investments in security of supply today will not lock-in carbon by 2050." Otherwise, the European Union will face the risk that new investments in gas-fired power generation will take place over the next decade. To avoid this, Commission and the industry (e.g., EU Turbines association) are working on a proposal on how to determine hydrogen-readiness based on thresholds for additional investments needed to reach different H_2-readiness levels. Therefore, it can be said with certainty that interest in hydrogen as a fuel is growing from year to year and this may be the cause of the next industrial revolution.

2.3. The Future of Hydrogen [2–6]

The Future of Hydrogen provides an extensive and independent survey of hydrogen that lays out where things stand now; the ways in which hydrogen can help to achieve a clean, secure and affordable energy future; and how we can go about realizing its potential.

In terms of sufficient competition to keep prices low, future hydrogen leaders, such as Japan, Germany and South Korea, will register emerging markets in bilateral production agreements that exceed the number of countries in the Organization of the Petroleum Exporting Countries (OPEC). This will make hydrogen increasingly popular and move away the dependence on the oil economy and its charter agreements; it also meet the goals set out in the Paris Climate Change Agreement.

Regarding the development of a Plan on the future of green energy, it must, first of all, consider ways to increase the supply of hydrogen and, last but not least, determine which industries will become major consumers. *Figure 2* shows the numerous uses of hydrogen.

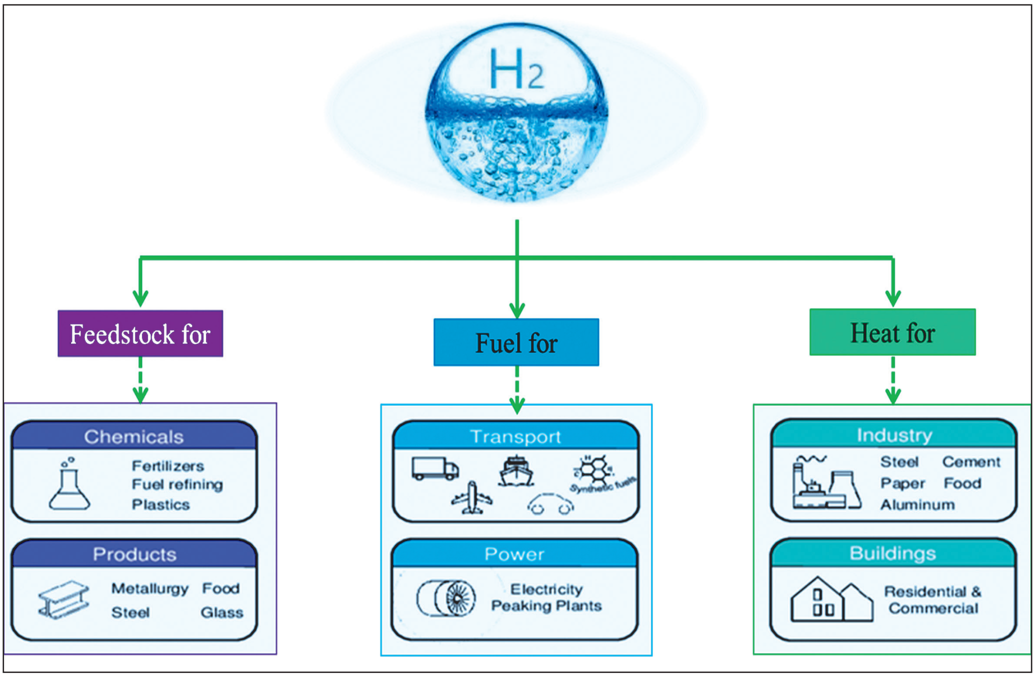

Figure 2 – **The numerous uses of hydrogen**

Hydrogen and fuel cells can be used in a broad range of applications. These range from powering buildings, cars, trucks, to portable electronic devices and backup power systems. Because fuel cells can be grid-independent, they're also an attractive option for critical load functions such as data centers, telecommunications towers, hospitals, emergency response systems, and even military applications for national defense.

Therefore, in the future, hydrogen could also join electricity as an important energy carrier. An energy carrier moves and delivers energy in a usable form to consumers. Renewable energy sources, like the sun and wind, can't produce energy all the time. But they could, for example, produce electric energy and hydrogen, which can be stored until it's needed. Hydrogen can also be transported (like electricity) to locations where it is needed.

3. Cost for green hydrogen [2–7]

Green hydrogen, in present, competes both with fossil fuels and with other shades of hydrogen. It is important, therefore, to understand the factors that determine the cost of green hydrogen.

The production cost of green hydrogen depends on the investment cost of the electrolysis, their capacity factor[3], which is a measure of how much the electrolysis is actually used, and the cost of electricity produced from renewable energy.

By year 2020, the investment cost for an alkaline electrolysis is about 800 dollars per kilowatt (USD/kW). If the capacity factor of the green hydrogen facility is low, such as below 10% (fewer than 876 full load hours per year), those investment costs are distributed among few units of hydrogen, translating into hydrogen costs is about of 6 USD/kg or higher, even when the electrolysis is operating with zero-priced electricity.

In comparison, the cost of grey hydrogen is about 1.9 USD/kg of hydrogen, considering a price range of natural gas of around 5.7 dollars per gigajoule (USD/GJ). If load factors are higher, however, investment costs make a smaller contribution to the per kg green hydrogen production cost (*see Figure 3*).

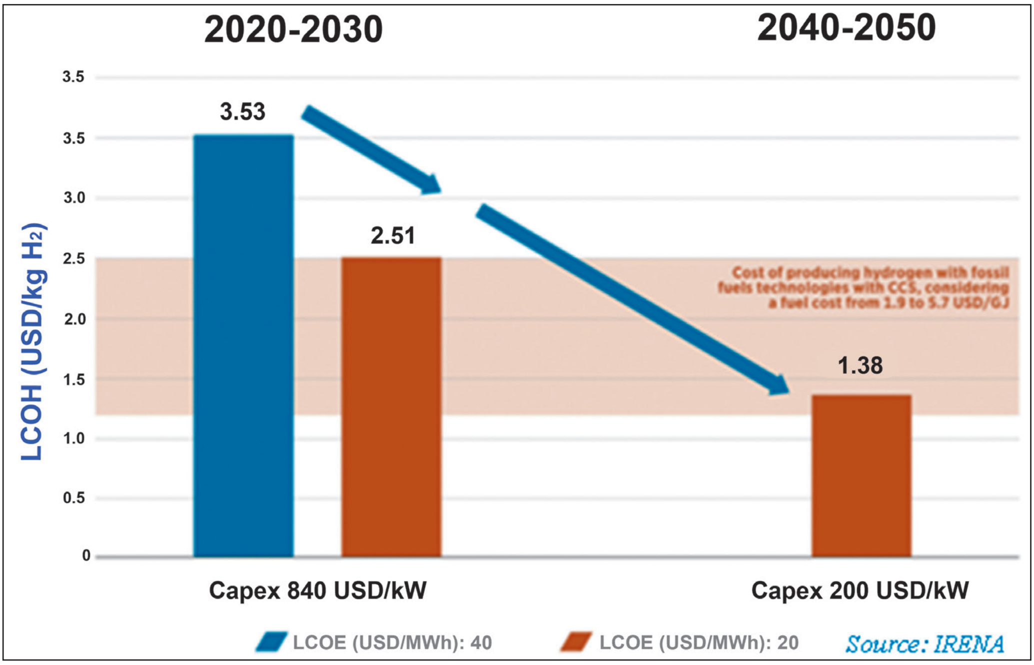

Figure 3 – **Green hydrogen production cost [6]**
(Electrolysis load factor: 4,200 hours (48%), conversion efficiency 75%).

Green hydrogen is today more expensive than the conventional production from fossil fuels.

[3]*The capacity factor can span between 0 - 100% and represents the average full load hours of use of the electrolyser as a percentage of the total number of 8.760 hours in a year of (for example, a capacity factor of 50% indicates an average use of 4.380 hours).*

Preparing for repowering with clean hydrogen also requires operators to gain operational experience with the new technology to reduce risks and to ensure they will be able to deliver on security of supply. Today, gaining this operational experience means operating at a loss, because clean hydrogen is still 5 to 10 times more expensive than natural gas. Today's funding schemes are inadequate for such real-life testing because the funding gap is insufficiently covered. Funding calls need to include hydrogen testing and repowering in real-life operations. These calls need to be centered around the main OPEX components (fuel) and cover 100% of the fuel price gap between natural gas and clean hydrogen. However, the cost of green hydrogen is falling rapidly to the point where it can compete with blue hydrogen.

Power generated with fossil gas (including the CO_2 price) is by far less expensive than with green hydrogen. The levelized cost of electricity (LCOE) with green hydrogen at 4 Euro/kg translates into approx. 214 Euro/MWh for a combined cycle power plant[4]. The levelized cost of electricity with natural gas with a CO_2 price of 50 Euro is 55 Euro/MWh[5]. Bridging this gap and creating price parity will require a CO_2 price of 525 Euro/tCO_2. If the costs fall to 2 Euro/kg of green hydrogen, 235 Euro t/CO_2 are sufficient to create price parity (assuming the same price for gas). Utilities will face difficulties to pass on these costs to the consumer as they are in competition with various retailers[6].

In the same time, as the facility load factor increases, the electrolysis investment cost contribution to the final hydrogen production cost per kg drops and the electricity price becomes a more relevant cost component. So, at a given price of electricity, the electricity component in hydrogen's final cost depends on the efficiency of the process [for example, with an electrolysis efficiency of 65% and electricity price of 20 dollars per megawatt hour (USD/MWh), the electricity component of the total cost would go up to 30 USD/MWh of hydrogen, equivalent to 1 USD/kg[7]].

Therefore, given today's relatively high electrolysis costs, low-cost electricity is needed (in the order of 20 USD/MWh) to produce green hydrogen at prices comparable with grey hydrogen.

The cost of renewable power (used to make the green hydrogen) and the cost and efficiency of electrolysis determine the green hydrogen production cost. Efficiency is a key aspect for the economics.

Lower Heating Value based electrolysis systems operate at 65-67% efficiency for hydrogen production. The theoretical, maximum electrical efficiency is about 75%.

The fact that hydrogen is a highly volatile gas that needs to be compressed for liquefied transportation and storage adds substantially to the lifecycle efficiency losses.

The objective of green hydrogen producers is now to reduce these costs, using different strategies. Once electrolysis costs have fallen, it will be possible to use higher-cost renewable electricity to produce cost-competitive green hydrogen.

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[4]Considering: power plant utilization of 4,500 full load hours with a 61% efficiency (LHV), 25 years lifetime, a capex of 650€/kW, WACC of 7%, variable O&M costs of 0.20c€/kWh and fix annual costs of 20€/ kW. The cost of hydrogen includes transport, storage and distribution

[5]Considering a fuel price of 1.25c€/kWh and a CO_2 fuel intensity of 0.20gCO_2/kWh. Other assumption on CAPEX, OPEX and operation parameter are those indicated in the previous footnote

[6]European Clean Hydrogen Alliance, Hydrogen in the energy system, 2021

[7]1 kg of hydrogen contains around 33.33 kilowatt hours (kWh)

Transport costs are a function of the volume transported, the distance and the energy carrier, so:

- At low volumes, the cost of transporting compressed hydrogen 1,000 km in a truck is around 3-4 USD/kg.

- For large volumes, shipping green ammonia is the lowest-cost option and adds only 0.15 USD/kg of hydrogen (without considering conversion costs, so cracking).

- Low costs can be achieved using large pipelines (around 2,000 tonnes per day) over short distances (Hydrogen transport by pipeline can be one-tenth of the cost of transporting the same energy as electricity) [4,6,7].

3.1. Hydrogen Storage [6,8]

Hydrogen storage is a key enabling technology for the advancement of hydrogen and fuel cell technologies in applications including stationary power, portable power, and transportation.

Today electrolysis (power-to-gas) is considered as energy storage in European legislation[8]. Storage systems are still largely double-charged with electricity grid tariffs, when extracting and re-injecting electricity in the grid. Even though this situation is improving, electrolysis requires more regulatory certainty at national level on the conditions under which it can be considered a storage technology. As for physical storage, hydrogen can be stored in steel tanks or in underground geological formations. While not all countries have suitable underground formations, the overall available capacity is vast. For example, the potential hydrogen storage capacity in Europe is about 2,500 Mt, or 82.8 petawatt hours (PWh). Moreover, when hydrogen is converted to LOHCs[9], green methanol or synthetic hydrocarbons, the fuels can be stored and transported using existing tanks, pipelines and other infrastructure [6].

Hydrogen has the highest energy per mass of any fuel; however, its low ambient temperature density results in a low energy per unit volume, therefore requiring the development of advanced storage methods that have potential for higher energy density.

In consequently, Hydrogen can be stored physically as either a gas or a liquid, thus:

1) Storage of hydrogen as a gas typically requires high-pressure tanks [350-700 bar (5,000-10,000 psi) tank pressure];

2) Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is − 252.8°C.

In *Figure 4* shows the hydrogen storage scheme.

Also, Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption).

It concludes that now is the time to scale up technologies and bring down costs to allow hydrogen to become widely used.

At this stage, as presented in this article, hydrogen is the fuel of the future.

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[8]*Electricity directive, Article 2 (59) - 'energy storage' means, in the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier;*

[9]*LOHC (Liquid organic hydrogen carriers), are organic compounds that can absorb and release hydrogen through chemical reactions. LOHCs can therefore be used as storage media for hydrogen.*

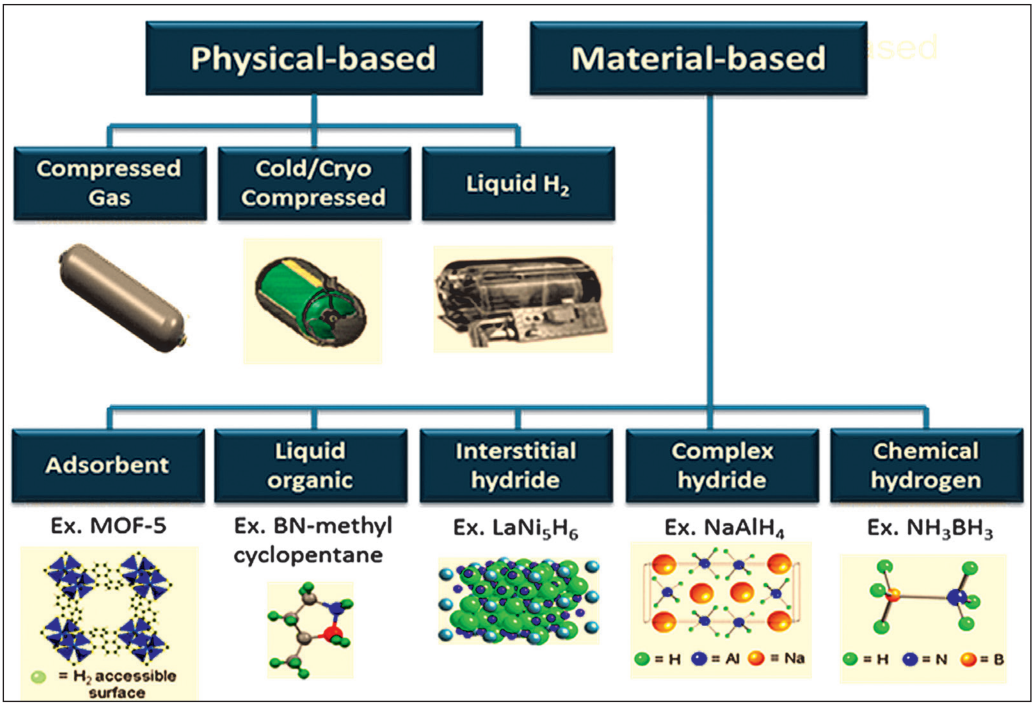

Figure 4 – **Scheme of the Hydrogen storage [8]**

CONCLUSIONS

Hydrogen is an alternative fuel that has very high energy content by weight. It's locked up in enormous quantities in water, hydrocarbons, and other organic matter. Hydrogen can be produced from diverse, domestic resources including fossil fuels, biomass, and water electrolysis with wind, solar, or grid electricity. The environmental impact and energy efficiency of hydrogen depends on how it is produced.

The attraction of hydrogen is that it can be used both as a feedstock and an energy carrier. Developments are coming thick and fast: from advances in hydrogen production to new catalytic materials that could replace platinum in polymer electrolyte membrane fuel cells that will cut their cost.

Across the world, researchers are trying to improve the efficiency and costs of producing, storing, transporting and using hydrogen in applications as diverse as heat and transport.

In the next 30 years, somehow or other, we need to cut energy-related carbon dioxide (CO_2) emissions by 60% to limit global warming to 2°C.

Demonstrator projects are underway that may provide the numbers and the technology to show where and how hydrogen can replace fossil fuels. But at some point governments or politicians will have to make a decision to encourage the infrastructure to be built.

Alternatively, hydrogen can be produced from water using electrolysis employing renewable energy sources such as electricity from wind and solar. Hydrogen produced through this method is referred to as "green hydrogen". This method generates zero carbon emissions and accordingly, avoids the embedded emissions of black hydrogen. Less than 0.1% of global dedicated hydrogen production comes from water electrolysis.

Production costs for hydrogen from water electrolysis are influenced by technical factors like conversion efficiency, annual operating hours and the cost of electricity. Costs of around 3 USD/kg for green hydrogen seem feasible in the coming decade in the best locations. The cost could halve again by 2040-2050. Even at that price hydrogen will be more expensive than natural gas. To carbon price of 25 EUR/t CO_2 makes only a 5% difference and cannot close the gap. A higher carbon price would be needed to make it competitive.

The World Energy Council (WEC) envisages hydrogen conversion could take place on retired oil and natural gas platforms in the Sea, and the existing pipeline infrastructure used to bring the gas ashore. Its analysis for using wind-power suggests offshore and onshore electrolysis could provide a capacity of 10GW by 2030, and over 50GW by 2050, for an investment of anywhere between 27 – 37 EUR billion – most of which would go on electrolysis.

Hydrogen has significant potential as a low-carbon source of energy, but is clearly in the early stages of development. A prosperous carbon neutral Europe will see additional demand for energy transport and energy storage. A system dominated by renewable sources will not be always able to generate carbon-neutral energy in the same moment and at the same site where it will be used. Additional options to transport and store energy will broaden Europe's options for a successful, cost-efficient transition to carbon neutrality. Therefore, an important part of the solution will be a well thought-through infrastructure for clean hydrogen; that is planned in coordination with other energy infrastructures considering the evolution of different generation and demand options. The conversion of existing natural gas network to hydrogen one is an interest option, that will need to be carefully evaluated in each case, and should be timely clarified. Repurposing existing underground gas storage sites, such as depleted gas fields or salt caverns offer opportunities for tomorrow hydrogen storage system. This will allow to store energy for longer time period and offer the power system a great amount of flexibility. In addition, in the early stages of the hydrogen ramp-up, mixing hydrogen into the existing gas grid will be relevant for distribution networks.

It concludes that now is the time to scale up technologies and bring down costs to allow hydrogen to become widely used. At this stage, hydrogen try hard to became the fuel of the future!

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