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Perspective

Steel pipeline for the hydrogen storage and delivery: metallurgical viewpoint for Finnish ecosystem

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ABSTRACT

For more than a century, hydrogen has been used as an industrial chemical to produce ammonia for fertilizers and to process intermediate products in oil refineries. However, hydrogen has recently received renewed interest due to its ability to reduce carbon emissions to the atmosphere, particularly in the steel-making industries. Thus, hydrogen has the potential to play a critical role in combating climate change and achieving Finland's national goal of carbon neutrality by 2035. In this regard, national and global demand for hydrogen is rapidly increasing, and it is now three times more than what it was in 1975. The production and supply of hydrogen for industrial consumption would be a massive business that is expected to expand even faster than before. According to the IEA, the total demand for hydrogen in pure and mixed gas was approximately 115-120 million tones in 2018. (Gaseous) hydrogen can be efficiently transported by pipeline networks at a pressure of typically <100 bar. Pipelines provide an economical means of transporting hydrogen in large quantities over long/short distances, and hence they are often found serving end users who take hydrogen from a local central source of production. Nevertheless, the correct pipe material for hydrogen distribution must be designed and used, and the current natural gas pipeline infrastructure must be upgraded significantly if it is to be used for the delivery of pure hydrogen at high pressure. Hence, new research is needed to focus mainly on the possibility of use/modification of available natural gas pipeline network for hydrogen delivery as well as the study on the new economical pipeline material, exclusively for hydrogen transportation and storage.

1. Introduction

1.1 WHAT? (Challenge & Solution)

At the moment, available (natural) gas pipelines are the most viable solution for transporting large amounts of hydrogen over long distances, and pipeline transportation is expected to be the way by which hydrogen is delivered from potential large-scale, centralized production plants and will be distributed to end-user companies. However, current gas pipeline technology cannot meet the cost and performance targets required for the safe and successful implementation of this distribution network. As illustrated in Figure 1, atomic hydrogen can be absorbed in metallic materials and trigger material degradation and sudden failure in the form of hydrogen embrittlement [1]. As a result, it is critical to address this challenge in pipeline material during the hydrogen transporting, particularly for hydrogen gas in existing natural gas pipeline infrastructure as well as new pipeline infrastructure. Besides, hydrogen storage is also another challenge in keeping the system working continuously. It seems that there are no suitable geological formations in Finland for inexpensive hydrogen storage, such as salt caverns [2]. When hydrogen storage is used on a daily or weekly basis, pipeline storage is again a feasible option in Finland because the cost is comparable to salt caverns in the long-term approach. However, according to the literature, the cost for hydrogen pipeline storage is high, but according to only a few small projects. To summarize, the cost of a large-scale hydrogen pipeline and storage system in Finland is difficult to evaluate at the moment, and more investigation and demonstration projects are required.

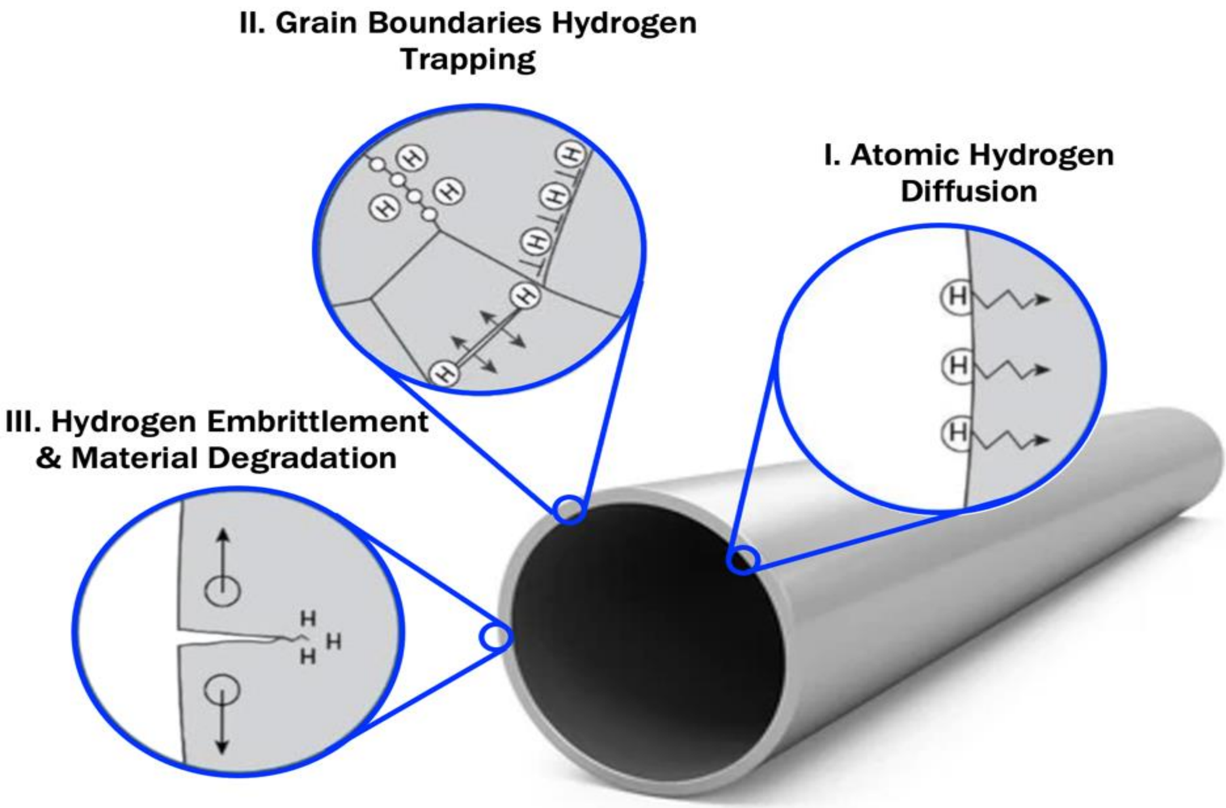

Figure 1. Schematic illustration of how atomic hydrogen may diffuse, being trapped, and accelerates the pipeline failure

1.2 WHY? (Main advantages of pipeline storage and delivery)

There is no doubt about the importance of hydrogen in the future of fossil-free life, especially in fossil-free steel manufacturing. Thus, the production of hydrogen will increase rapidly both globally and locally (here in Finland), which is why hydrogen is already determined as an essential constituent of the global transition to carbon neutrality. So, now is really a suitable time for Finland to start a serious debate on what hydrogen would mean for the Finnish climate target, energy system, and industries. The hydrogen ecosystem is no longer considered a pipeline dream in other countries. In France, for example, a pipeline network with a length of 550 km and an inner diameter of 100 mm transports 200×10^6 m^3 of hydrogen annually. Similarly, Belgium has already laid an 80-kilometer pipeline with an inner diameter of 150 mm and an operating pressure of 10 MPa. In England, a 16-kilometer pipeline with a pressure of 5 MPa is being built. Germany has one of the oldest and largest hydrogen pipelines in the world, reaching all the way to 220 kilometers. It has an inner diameter of 100-300 mm with an average operating pressure of 2 MPa, which has been connecting Dusseldorf and Recklinghausen for 60 years, and transports one million m^3 of hydrogen annually [1]. Overall, the following points can summarize the reasons why hydrogen is now important for Finland [2]:

- **Climate targets**

  Hydrogen can help Finland to decarbonize its industries. The research and actions can focus on the industrial processes that are currently using huge amounts of fossil fuels in their processes where the fossil fuels could be replaced by hydrogen, for instant, in steel production. Besides, fossil fuel-based should be replaced by green hydrogen, for example in fertilizer production or oil refineries processes.

- **Green energy transportation and storage**

  Hydrogen and hydrogen-derived fuels can help Finland store and transport fossil-free energy, and they can offer a viable alternative in mobility where electric batteries are not suitable because of the amount of energy range required and where biofuels need to be complemented. This means cars and light commercial vehicles, trucks, heavy equipment, ship, trains, or aviation.

- **Finnish economy**

  Finland has a great potential to become a global producer and exporter of hydrogen of hydrogen-derived synthetic fuels, creating a whole new industry and adding high-skilled jobs to its economy. However, because hydrogen is a light gas composed of small molecules with a low energy density, it must be handled with special equipment and procedures. Since hydrogen is so small, it can easily diffuse into some materials, including steel pipes, increasing the probability of unexpected failure. It also passes through seals and connectors more easily than larger molecules like natural gas. Hydrogen can be mixed with natural gas and injected into the current gas grid, but as it tends to embrittle current metal pipes, the percentage of hydrogen in the current pipes can't be very high. In reality, either conversion of the current pipes or completely new pipes will be needed. This is why infrastructure such as pipelines and distribution networks are critical and important. While hydrogen can be produced locally near to place where it is consumed, its storage and delivery advantage from scale economies and technological developments.

1.3 HOW? (First steps)

Literally, the feasibility study is the first stage of any new technology and infrastructure. Therefore, there is an essential need for the research at least in two main areas: i) study on already available pipeline network in order to utilization, adoption, and improvement of them for more efficient hydrogen delivery, ii) study on the potential new steel material, specifically for ecconomic and safe transportation and storage of hydrogen. Numerous indicators suggest that we are now on the verge of a tipping point, according to the European Commission's hydrogen strategy for a climate-neutral Europe. New investment plans, often on a gigawatt scale, are announced every week. From November 2019 through March 2020, market analysts boosted the list of planned worldwide investments from 3.2 Gigawatt to 8.2 Gigawatt of electrolyzers by 2030 (of which 57 percent in Europe). Figure 2 presents the expected growth of hydrogen use in Europe by 2030 and 2050.

According to Figure 2, considering both usual business and ambitious plans, it is not possible to provide the new network, particularly for hydrogen delivery, immediately, and the use of the available network for natural gas is unavoidable sometimes, and research is needed to be conducted for implementation. However, the new material should be developed for the extensive future demand. For example, in order to replace coal in the novel processes used to produce steel, about 140 TWh of hydrogen, or almost 40% of the total hydrogen produced in 2015, will be required for the direct reduced iron (DRI) process. Regards steel chemistry, it should be an economical composition and suitable for welding considering the hydrogen embrittlement of both pipe material and welded parts. From the technical and metallurgical point of view, the chemical composition should be clean low-alloy steel to keep the impurity level as less as possible in order to have a good fracture toughness. On downsides, the hydrogen pipeline network does not currently have any inherent disadvantages, but the difficulties and constraints posed by technology might be viewed as such. However, as technology advances, the drawbacks are probably going to get smaller, allowing hydrogen to enter the energy market. By the way, similar to how electrical grids experience power losses, there is a loss of hydrogen gas as it moves through the pipeline system. In order to increase the efficiency of hydrogen pipelines, continuous improvement is necessary. Due to the low pressure of 4 bars at which natural gas is delivered, less expensive polymer materials can be used in place of expensive steel pipes. However, since hydrogen has a density that is about 1/8th that of natural gas, it must be compressed to high pressure of between 10 and 20 bars in order to increase its delivery speed. Energy delivery is ineffective if the pressure is not raised. Hence, due to their high porosity, the polymer materials used to construct gas pipelines are not suitable for use in pipelines designed to transport pressurized hydrogen. Therefore, the majority of hydrogen pipelines are currently constructed using low-carbon steel [3].

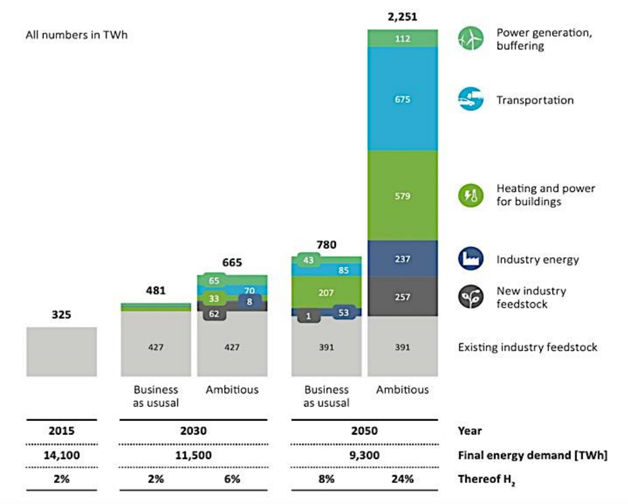

Figure 2. Estimated growth of hydrogen use in the EU by the years 2030 and 2050 [4]

In order to create a hydrogen economy, low-cost materials for building a massive network of hydrogen pipelines must be developed. Furthermore, the efficient and safe distribution and delivery of hydrogen can be severely impacted by hydrogen embrittlement, which leads to sudden cracks and failure in pipelines. Infrastructure for hydrogen is currently being built slowly, delaying its wide adoption. Planning, coordination, and investment that involve both international and local governments, businesses, and investors are probably necessary to address this. Moreover, research is needed to better understand how hydrogen interacts with pipeline materials. It is necessary to address the embrittlement of steel pipelines, for instance, by creating new coatings to prevent direct contact between steel and hydrogen. Additionally, a better understanding of the effects of pressure cycling (in terms of cycle depth and cycling frequency) on pipeline fatigue is necessary because it is preferable to transport hydrogen at different pressures depending on the demand.

1.4 WHO? (Main Player)

One of the main stages of making a concept or idea for a product or service is marketing research in order to make sure if there is potential demand and market for it. In the case of the steel pipeline, considering the possibility of production in the north of Europe, SSAB would be one of the main key players based on its capacity, capability as well as its plan to be the first fossil-free steel maker. According to the EU ambitious plan presented in Figure 2, Europe would need 80 GW of green hydrogen to build its planned new trade relation. However, the initiative envisions that only half of the proposed 80 gigawatts of new hydrogen capacity would be produced in Europe. The other 40 gigawatts would be produced in North Africa and Ukraine since those regions have access to cheap solar and wind power. The hydrogen produced in these regions would then be imported to Europe via pipelines which needs even higher number of pipelines than that produced in Europe. To quantify this and make it a bit more clear, according to the initiative, the construction of a long new hydrogen pipeline system from Egypt, via Greece to Italy, around 2,500 km with 66 GW capacity, having 2 pipelines of 48 inches each, would cost of about €16.5 billion [5]. This means that large-scale hydrogen project deployment undoubtedly requires legal protection and financial support from the public sectors and international/national/regional authorities.

2. Conclusion

Pipeline infrastructure must be rapidly developed and established if a hydrogen economy is to be realized for future carbon-neutrality societies, not only in terms of material development but also in terms of technological advancement to tackle any catastrophic failure, leakage, embrittlement as well as to build required equipment and components to permit high-pressure delivery of hydrogen. Before it can play a role in the clean energy supply chain, a hydrogen pipeline network must overcome several technical and technological obstacles. Hence, different research areas are needed to be investigated to achieve a mature technology for cost-efficient and safe transportation, remembering the fact that the contemporary natural gas network has evolved over decades to the point where it runs smoothly. Technology will undoubtedly adapt as the price of fossil fuels rises and governments feel obliged to plan for an alternate/hydrogen energy system.

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Ethical issue

The author is aware of and complies with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

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