# Thermoplastic materials for hydrogen production: A longer service life and higher effectiveness

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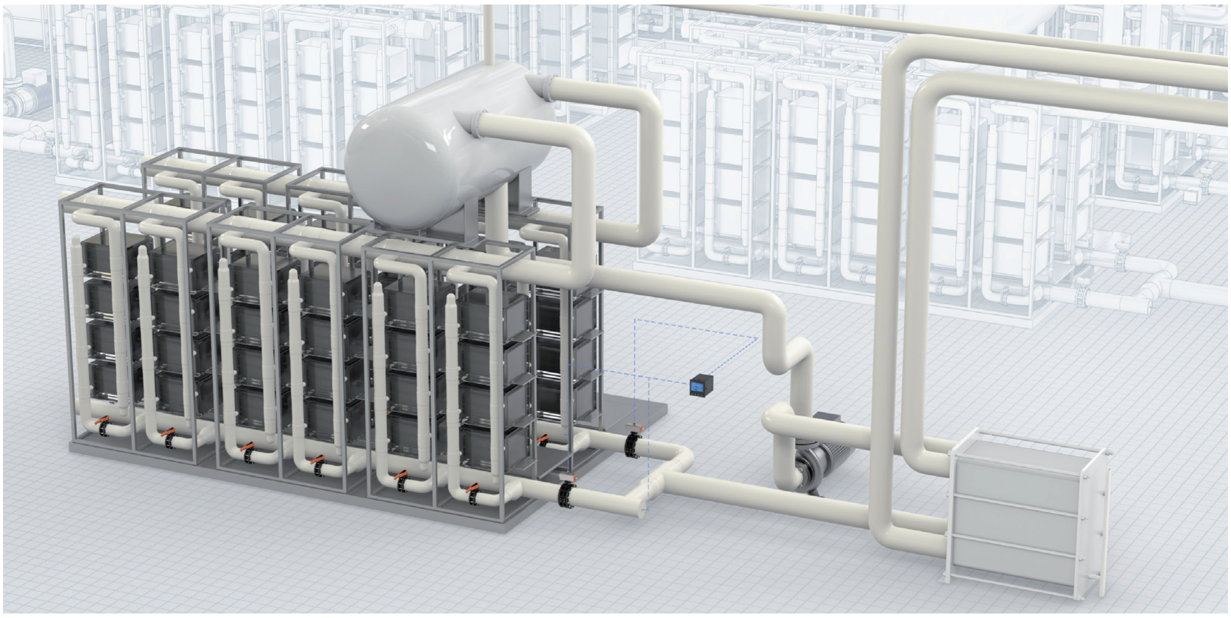

*Proton exchange membrane (PEM) electrolyzers utilize a proton exchange membrane and a solid polymer electrolyte. When voltage is applied, water is separated into hydrogen and oxygen, while hydrogen protons pass through the membrane and produce hydrogen gas on the cathode side. The effectiveness and the lifespan of PEM electrolyzers depends on the quality of the supplied water. Ultrapure water is essential for optimal performance.* *Image: GF Piping Systems*

**Hydrogen will play a pivotal role in the future of energy supply, as green hydrogen has the potential not only to decarbonize entire industries but also to serve as a storage solution for surplus energy from other renewable sources. This significance is reflected in the growth projections for the hydrogen economy: estimates suggest that by 2050, the market for green hydrogen will reach 600 million tons and generate $1.4 trillion in revenue, with the potential to reduce up to 85 gigatons of $CO_2$ emissions (Green Hydrogen Study by Deloitte, 2023).**

In this context, piping systems are an effective tool as they are used across the hydrogen value chain. This is particularly true for the production phase during which piping systems transport media including ultrapure water, gas and water mixtures, as well as chemical substances, and therefore have a significant effect on both quality and cost-effectiveness.

One crucial factor is the selection of the correct piping material as decades of experience in challenging sectors such as the chemical process industry have shown. While traditional metal pipes are a common choice for hydrogen production, these sectors are dominated by thermoplastics which serve as a high-performance alternative. The goal here is to demonstrate that thermoplastic piping systems show great potential for hydrogen production and that they are superior to metal pipes in applications involving ultrapure water.

## Ultrapure water at the core of $H_2$ production

To continuously produce hydrogen, electrolysis stacks require deionized water (purified water). The manufacturer of the electrolyzer specifies water purity requirements in line with the ISO 22734 standard for industrial electrolyzers. However, while the water treatment process is designed to achieve the required quality, it is essential to ensure that deionized water remains uncontaminated on its way to the electrolyzer stack. The presence of impurities in the feed water can lead to performance degradation, resulting in higher energy consumption, increased maintenance costs, and downtimes for maintenance. Among the possible contaminants that can affect the electrolysis stack are dissolved metal ions and organic materials (total organic carbon, TOC). These contaminants can potentially compromise electrode performance and damage membranes by interacting with by-products generated from hydrogen production.

The media that need to be transported are another potential source of contamination. In addition to purified water, some electrolyzers require highly corrosive substances which can reduce the lifespan of materials and put considerable stress on piping systems. These types of electrolyzers, which use liquid electrolytes, feature complex water circuits that require the regular addition and removal of water to prevent contamination.

Overall, this leads to four major criteria for the selection of piping materials:

- Low leach-out values in order to prevent contamination
- A low surface roughness of the pipe walls to prevent deposits
- The design of the plant (as temperatures, pressures, and media differ depending on the production method)
- The position within the plant due to varying temperatures and pressures

### Thermoplastics in electrolyzers

For thermoplastic piping systems, the greatest potential lies in the transport of purified water from the water treatment stage to the inlet of the electrolyzer. To better understand the benefits, it is worth taking a look at the specific demands of different production methods.

- AEL: During alkaline electrolysis, highly concentrated potassium hydroxide (KOH) is used as an electrolyte which is very challenging both for metal and plastics. In this case, it is possible to implement certain fluoroplastics in atmospheric design.
- PEM: Proton exchange membrane electrolysis effectively transforms ultrapure water into a condensate that includes hydrogen and water supersaturated with oxygen. As a result, thermoplastics with low leach-out values are generally regarded as appropriate for this application. However, it is essential to take into account the high temperatures and pressures present in the stack intake to ensure optimal performance.
- AEM: Anion exchange membrane electrolysis uses a combination of ultrapure water and KOH with a low concentration of 1-3 % that is ideally suited for thermoplastics, leading to similar system requirements compared to PEM electrolysis.
- SOEC: Solid oxide electrolyzer cells operate at much higher pressures and temperatures than what plastics can withstand, making them less suitable for this application. However, ultrapure water is an important component in this process as well. It is introduced during electrolysis and is intended to vaporize within the system later, reducing the risk of contamination.

### Thermoplastics stand out with their high chemical resistance

Plastic piping systems are suitable for applications in PEM, AEM, and low-pressure AEL electrolysis. They combine a high corrosion and chemical resistance which can contribute to an extended service life and reduced maintenance requirements. Additionally, thermoplastics offer flexible welding technologies, such as infrared fusion, which allows for precise welds that enhance performance. Their lightweight characteristics facilitate an easier and quicker installation, often positioning them as a cost-effective alternative to metal. Moreover, plastic piping


*Fig 1: Enapter is the first manufacturer of AEM electrolyzers in Germany. The electrolyzers separate water into hydrogen and oxygen while hydroxide ions pass through the membrane and produce hydrogen gas on the cathode side. Based on custom design drawings by GF, the company installed PROGEF PP-H piping components combined with Ball Valves Type 542 and electrically actuated Pro Ball Valves Type 546.*
*Image: Enapter*

systems have demonstrated their effectiveness across various industries, for example in semiconductor manufacturing, where high chemical resistance is essential for an optimal operation.

In the field of hydrogen production, chemical resistance is equally important, especially in the context of alkaline electrolysis. During this process, potassium hydroxide (KOH) is circulated over the electrodes at concentrations of 25-30 % and at temperatures around 80°C, facilitating the production of gaseous oxygen and hydrogen. The combination of high temperatures and the aggressiveness of KOH can impact metals and thermoplastics. Consequently, the specifications for materials used in these applications are stringent. Nevertheless, certain fluoroplastics have proven themselves in these conditions. Ongoing research aims to explore the potential suitability of additional plastic materials.

For applications in PEM and AEM electrolysis, fluoroplastics or polyolefins are a versatile option thanks to their material properties. Certain types of electrolyzers incorporate various circuit designs that have distinct operational requirements. For instance, during the process of proton exchange membrane (PEM) electrolysis, supersaturated oxygen is effectively separated from the gas-water mixture within the condensation loop. The remaining hot condensate is subsequently directed back to the stack in conjunction with make-up water. While the condensate is still supersaturated with oxygen, it forms a highly corrosive fluid that can adversely affect both metals and specific thermoplastics. Appropriate plastic solutions are available for these applications and may be utilized depending on the pressure conditions.

Regarding chemical resistance, it can be concluded that plastics have proven themselves as a viable alternative to metal pipes across various industries, and now show comparable potential for hydrogen production. Given the diverse operating principles and designs of electrolyzers, it is crucial to carefully select materials based on the specific types of fluids, temperatures, and pressures involved. This meticulous approach will help ensure the maximum service life and operational safety of the systems

*Fig 2: From simple shut-off valves to fully automated control valves, the Ball Valve 546 Pro offers modular construction, simple operation, flexibility, and a high level of process safety.*

*Image: GF Piping Systems*

## Minimal leach-out values for a more efficient production

A key consideration for the use of thermoplastics in hydrogen applications involving purified water is their excellent leach-out characteristics. While the limits defined by electrolyzer manufacturers are not standardized, they are in the low ppb range for TOC and metal ions. In this context, a material such as Polypropylen-Homopolymer (PP-H) has a lot of potential as it combines corrosion resistance and cost-effectiveness with leach-out values that are significantly lower compared to stainless steel. The consequences of higher leach-out values have been demonstrated in scientific research. In a 2023 paper by the Royal Society of Chemistry, the authors concluded that “metallic contamination such as iron, nickel, and copper particles can be released into ultrapure water through corrosion and subsequently lead to significantly lower performance” (see Becker et al, Impact of Impurities, Sustainable & Energy Fuels, 2023,7,1565.).

The condensate loop is a typical example of this effect. Usually made of stainless steel, they are vulnerable to corrosion due to the high oxygen concentration. At temperatures exceeding 60°C, the combination of ultrapure water and stainless steel can result in a deposit of tiny iron oxide particles on the pipe walls. This phenomenon, also called “rouging”, is well-known in the pharmaceutical industry and often leads to short and costly maintenance intervals. In the case of electrolyzers, rouging can also drastically affect the service life of the resins required during the polishing of ultrapure water.

Thermoplastic piping systems, on the other hand, are capable of significantly reducing metallic and organic contaminants in purified water as well as electrolysis stacks compared to metal pipes. As a result, this may lead to a longer service life and increased efficiency, as less electricity is required to produce the same amount of hydrogen. The implementation of thermoplastics in electrolyzers therefore presents an opportunity to achieve both cost-effectiveness and energy efficiency – two critical factors for the growth of green hydrogen production.

## Optimizing plants through engineering

While planners and operators in the chemical process industry or semiconductor manufacturing have decades of experience with thermoplastics, they are not yet as prevalent in the hydrogen sector. Compared to metal, plastics have different material properties that need to be considered during the construction of electrolyzers. Additionally, the temperatures in certain applications can exceed the limits of these materials. During the engineering phase it is therefore advisable to qualify individual materials based on the specific design of the plant and piping system to ensure they meet the necessary service life requirements. Collaboration with experts in thermoplastic plant design, along with pipe manufacturers, can provide significant support in this process. Their expertise may facilitate the approval of specifications that exceed conventional temperature and pressure limits following a comprehensive professional examination. Possible services include the static proof of the piping system which is particularly important when switching from metal to plastic as factors like tension, bending, compression, and expansion are calculated. This is relevant because temperature changes between commissioning and operation or even during operation (e. g. start-up and shut-down) have different effects depending on the material. The hydraulic dimensioning process, on the other hand, evaluates the dimensions, pressure losses across the system or loop, heat losses, and pump performance. Furthermore, a thorough assessment of the system's peak load is a crucial element of the planning phase, contributing to the project's overall success and reliability.

Commissioning plants can also be optimized with the help of prefabrication. Extensive planning tools such as CAD libraries enable custom solutions that are tailored to the needs of a specific application. The headers that distribute ultrapure water across the stacks are ideal components for prefabrication, particularly in larger production plants. As the welding process is completed before the installation, the prefabricated components merely need to be connected mechanically, e. g. with flanges or screw threads. The result is a fast and efficient installation.

## Outlook

Electrolyzers are a challenging environment for many materials due to the necessary temperatures, pressures, and fluids. Depending on the type of electrolysis and the position within the plant, thermoplastics can also reach their limits. To maximize the potential of plastic piping systems, the cooperation between suppliers and manufacturers plays an important role as this leads to improved material properties and additional application scenarios. One key aspect of scientific research is the long-term stability of materials – because electrolysis technologies are constantly evolving as well. Currently, there is a trend toward higher temperatures and pressures which in turn will also affect material selection and require materials with new properties. For example, the operational parameters of alkaline electrolysis necessitate the selection of different materials for different applications to find the best economical and technical solution. The task of research is therefore to determine materials that can be implemented without restrictions. Apart from production, thermoplastics are also finding their way into other applications along the hydrogen value chain. They have potential for hydrogen utilization, e. g. in fuel cells on board ships or in Type-IV pressure tanks for vehicles. At the same time, thermoplastic piping systems have also been certified for hydrogen distribution.

## Conclusion

In applications involving ultrapure water, particularly in the realm of electrolyzers, thermoplastic piping systems have clear advantages over metals thanks to their chemical resistance, extremely low leach-out values, and high flexibility. As a result, thermoplastic piping serves as an effective and cost-efficient solution for addressing the complexities associated with electrolysis. However, it is imperative to undertake rigorous studies and material testing to ascertain their long-term stability and suitability for extreme operational conditions. Collaboration with research institutions and a commitment to continuous innovation will be instrumental in maximizing the benefits of thermoplastic piping systems. Currently, these systems are already enhancing the cost-effectiveness and energy efficiency of green hydrogen production.

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