

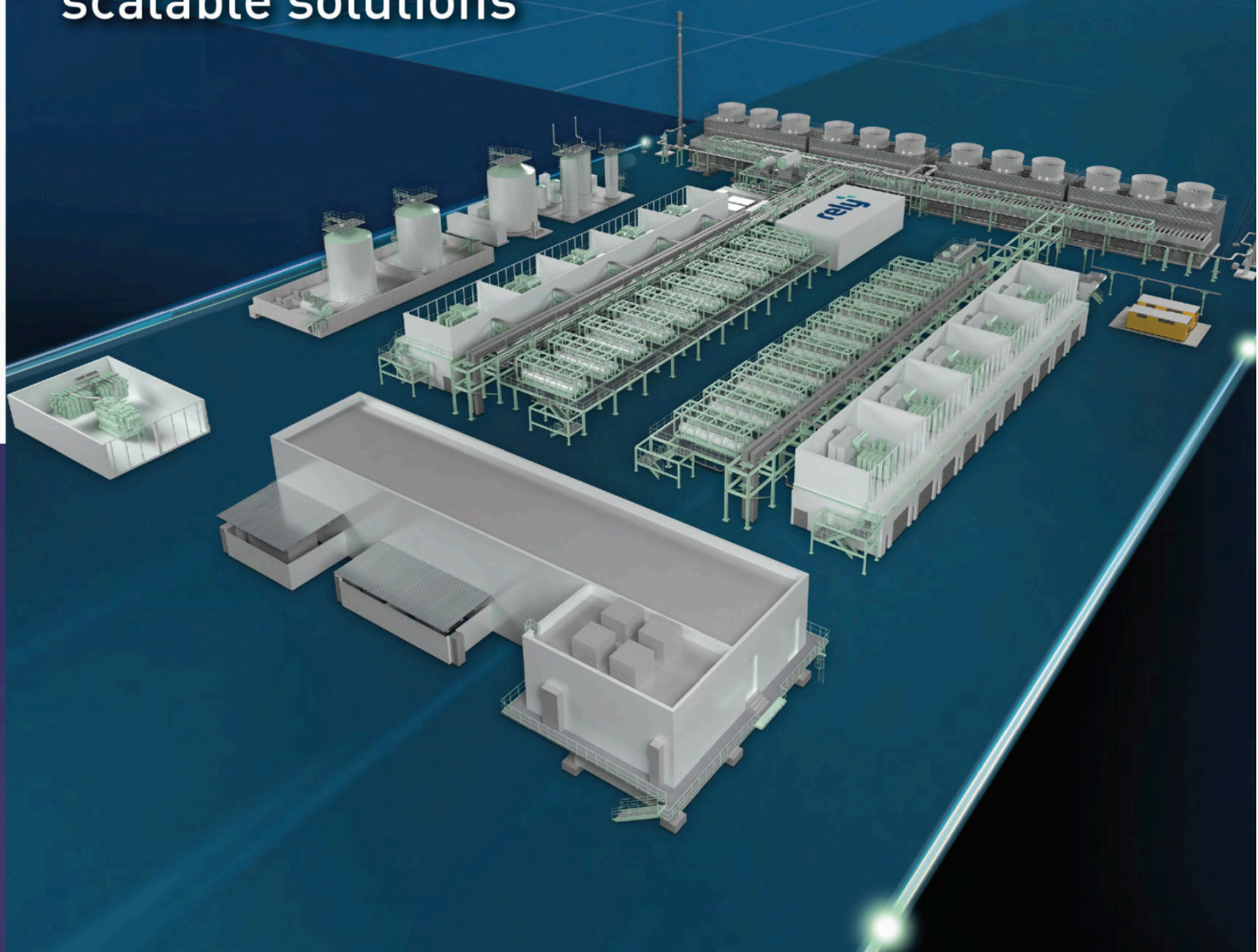
Knowledge platform – driving technology to the global hydrogen community



Hydrogen Tech World


cover story


Rely: from engineering complexity to scalable solutions




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Ensuring safe hydrogen transport: solving seal integrity challenges

For safe hydrogen transport, custom engineered sealing solutions are often relied upon for their high performance under extreme operation conditions. Both advanced polymer seals and metal sealing solutions withstand cryogenic temperatures, high temperatures, and high pressures. One major challenge is hydrogen containment, which is solved using specialized materials and precision designs to ensure minimal leakage rate.

By Clara Souève, Digital Content Strategist, Omniseal Solutions

The reliability of transport systems plays a fundamental role in the broader hydrogen value chain as the integrity of these sealing systems directly impacts sustainability goals and overall system efficiency. By minimizing energy losses during transportation and ensuring secure delivery, advanced transport infrastructure contributes significantly to hydrogen's viability as a clean energy solution. This article explores various hydrogen transport applications and their stringent requirements based on environmental and operational conditions.

Sealing conditions in various H₂ transportation methods

Hydrogen transportation consists of gaseous hydrogen via pipelines and compressed gas

trailers, as well as liquid hydrogen through cryogenic tankers, with maritime shipping emerging for international trade. Each transport method presents unique challenges, requiring containment systems that maintain integrity under varying operational and extreme conditions.

Pipeline transport

The use of existing natural gas pipelines for hydrogen transport – whether through blending hydrogen with natural gas or through dedicated hydrogen pipelines – presents various technical challenges, particularly concerning material compatibility and sealing performance. These pipelines, originally designed for natural gas, must be adapted to handle the unique properties

of hydrogen, which differ significantly from those of other gases. Hydrogen's small molecular size requires careful consideration in transport infrastructure.

Key challenges in sealing for pipeline transport include:

- **Permeation risks:** Due to its small molecular size, hydrogen poses a higher risk of permeating through seals. To mitigate leakage, it is vital to use sealing materials with low permeability. Therefore, soft sealing materials, elastomers or fluoropolymers should be selected carefully to minimize these risks.
- **Material degradation:** Hydrogen embrittlement can progressively weaken metal components. Sealing materials resistant to hydrogen penetration and degradation are essential to maintaining pipeline integrity.

Compressed gas transport

Compressed gas transport involves storing hydrogen at high pressures in tube trailers or cylinder bundles, typically between 200 and 700 bar. Commonly used for smaller-scale transport over short distances, this method relies on hydrogen compression to reduce volume and enable efficient storage and handling. However, transporting hydrogen at high pressures poses considerable sealing challenges.

- **Pressure fluctuations:** Hydrogen transport involves frequent pressure changes during loading, unloading, and transit, which can cause seal deformation or fatigue, potentially compromising long-term performance.
- **Temperature variations:** The compression and expansion of hydrogen result in substantial temperature fluctuations. Seals must be made from materials that maintain their elasticity and resilience to handle these temperature fluctuations without losing their sealing capabilities.

- **Leakage concerns:** At elevated pressures, even minor imperfections in seals can lead to leakage. Minimizing leakage is essential for ensuring safety, performance, and efficiency in hydrogen transport systems.

Liquid hydrogen (LH₂) transport

Transporting liquid hydrogen is employed when higher storage density is required. It is typically transported using road tankers and storage tanks, with potential future maritime applications. Because liquid hydrogen must be kept at cryogenic temperatures of -253°C (-423°F), maintaining a stable environment is critical for safety and efficiency, introducing several unique sealing challenges:

- **Extreme cold temperatures:** At cryogenic temperatures, materials contract and may become brittle, necessitating the use of seals with flexibility at low temperatures. To prevent failures, seals must maintain maximum leak tightness under these extreme conditions.
- **Vapor leakage risks:** Even minor leaks in cryogenic systems can cause boil-off losses, where liquid hydrogen vaporises and escapes. This is a major concern, as it not only leads to fuel wastage but also poses safety hazards. Seals must be designed to prevent even the smallest leaks.
- **Ice formation:** At such low temperatures, moisture can freeze and form ice, potentially degrading sealing surfaces and impairing seal performance. Addressing this challenge requires specialized materials and custom design solutions that accommodate ice formation without compromising seal integrity.

Reliable sealing for extreme H₂ conditions

Several key factors impact the safety and performance of hydrogen pipelines, storage tanks, and critical infrastructure. Whether the challenge involves high pressures, temperature fluctuations, or chemical exposure, effective sealing solutions are essential to ensuring long-term, leak-tight performance.



Polymer spring-energized seals & metal seals

Advancements in materials science help mitigate hydrogen embrittlement while enhancing durability and safety. Ongoing innovation addresses both current and future hydrogen transport challenges, including the development of hybrid sealing solutions that combine metal and polymer technologies for improved reliability.

Hydrogen has already emerged as a viable clean energy source for transport, fuel cells, electrolyzers, and power generation. It also plays a role in industries such as aviation, space propulsion, nuclear energy, semiconductor manufacturing, and industrial chemical processing. Collaboration across these sectors supports the development of sealing solutions that enhance performance, safety, and efficiency in hydrogen applications.

Material characteristics & performance requirements

Once the sealing conditions and challenges of each hydrogen transport method are understood, the next critical step is selecting the appropriate sealing technology. This choice is essential for ensuring safe and efficient hydrogen transport across all delivery methods. The selection process involves reviewing key material characteristics and performance requirements of both polymer and metal sealing solutions, particularly their ability to manage permeation, wear resistance, and long-term reliability under hydrogen exposure.

A well-informed approach to material selection is crucial for achieving leak-tight performance, preventing system failures, and enhancing the overall efficiency of hydrogen transportation.

Polymer-based sealing solutions

Fluoropolymers are commonly employed in hydrogen applications due to their flexibility and versatility in different sealing environments. Many engineering and manufacturing companies worldwide rely on fluoropolymers to support sustainability goals and energy circularity. These materials are particularly valued for:

1. **Low friction**, making them highly effective in dynamic applications such as valve stems, pumps, and compressors, where continuous motion and pressure variations are prevalent.
2. Fluoropolymers also provide excellent **mechanical and chemical stability**, as well as durability – significant because a major challenge for these materials is hydrogen permeation, which can result in gradual leaks and diminished sealing efficiency, especially under high-pressure scenarios.



Rulon® fluoropolymers

To address these issues, recent advancements in polymer technology have focused on improving permeation resistance through custom-engineered fluoropolymers and hybrid sealing designs. Innovations in material science continue to enhance the durability, leak prevention, and long-term performance of polymer seals in increasingly demanding hydrogen transport applications.

Metal sealing systems

In addition to polymer-based seals, metal seals are also a reliable option due to their resistance to cryogenic temperatures, high pressures, and prolonged hydrogen exposure. Materials such as stainless steel, Inconel, and nickel-based alloys offer robust mechanical strength and are naturally resistant to hydrogen embrittlement, ensuring leak-tight performance in static applications such as pipelines, hydrogen tanks, and high-pressure fittings.

While metal seals offer exceptional durability and efficiency, they require precise surface finishes and increased installation forces, which should be considered during the hardware design stage. The choice of alloys, such as Inconel for extreme temperature durability and stainless steel for corrosion resistance, depends on specific application requirements.

Balancing polymer and metal sealing solutions is essential, taking into account the transportation method and operational environment.

Other critical performance factors in H₂ transport

Hydrogen transport systems are subject to thermal cycling, pressure variations, and mechanical stress, which can lead to the degradation of sealing materials over time. For long-term reliability, it is imperative to select soft sealing materials that can withstand these extreme conditions. Metal seals, which are inherently more resistant to hydrogen permeation, can be further improved with protective coatings such as gold and silver. The careful selection of hydrogen-compatible alloys, along with advanced surface treatments, helps mitigate hydrogen embrittlement, ensuring that seals maintain their performance over extended periods.

Safety & regulatory framework

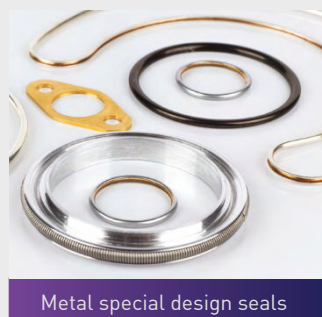
Ensuring safe hydrogen transport also depends on advanced detection technologies, i.e., hydrogen sensors, acoustic emission monitoring, and real-time pressure analysis, which are critical for early leak detection and failure prevention. Non-destructive testing (NDT) methods, such as helium leak detection and ultrasonic inspection, play a vital role in verifying seal integrity during both maintenance and assembly processes. Compliance with industry standards, including API 6D Annex M, ISO 23826, SAE J2601, and EC79, is also essential. These standards provide guidelines on seal performance, material selection, and leak prevention protocols. To meet regulatory requirements and ensure the safety and reliability of sealing solutions in hydrogen transport, rigorous testing – such as pressure cycling and permeation analysis – is necessary.



Metal axial seals



Metal C-seals



Metal special design seals



Metal E-seals

Sealing solutions for a safer H₂ future

Ensuring the safe transport of hydrogen in both dynamic and static applications, whether under cryogenic conditions or high pressures, requires specialized sealing solutions with tailored material properties. As hydrogen plays an increasingly significant role in the global transition to cleaner energy, ongoing advancements in sealing technology are essential to meeting the stringent demands of hydrogen applications across the value chain.

Omniseal Solutions continues to contribute to the development of precision-engineered

Download Omniseal Solutions' **Hydrogen Industry Handbook** to gain insights into advanced sealing and material solutions for key hydrogen applications and performance in extreme conditions.



sealing systems designed for high-performance applications. Advanced proprietary materials, including Rulon® fluoropolymers and Meldin® thermoplastics, are being utilized to create seals that address the evolving challenges of hydrogen transport, supporting cost-efficient manufacturing and innovation. A recent achievement includes the development of single-piece polymer gaskets exceeding two meters in size, surpassing the conventional sheet sizes available on the market.

About Omniseal Solutions

Omniseal Solutions is a global engineering company with over 65 years of expertise, dedicated to designing and manufacturing precision sealing and wear control solutions that protect critical applications in the most demanding environments. Committed to innovation, the company strives to push 'beyond the boundaries of possible'.

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LIQUID HYDROGEN VALVE

- Ferrite and other chemical element composition control, as applicable for -253°C working condition
- Fugitive Emission valve design to comply with ISO 15848, all classes
- Bellows seal design
- Available for online maintenance
- Optional vacuum jacket



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