
# The Anatomy of a Hydrogen Fitting

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**Abstract:**
One of the most formidable challenges in the development of safe, reliable, and leak-tight hydrogen fuel cell vehicles and infrastructure is the nature of hydrogen itself. Hydrogen is a small-molecule gas. Hydrogen molecules can easily migrate through the tiniest of crevices and diffuse into the materials designed to contain them. In the hydrogen mobility marketplace, hydrogen must also be stored at pressures in excess of 875 bar to achieve the necessary energy density on a vehicle. At refueling stations, rapid thermal and pressure changes can also impact system integrity as hydrogen leaves storage tanks and decompresses.

These challenges highlight the importance of uncompromising performance in fittings that join critical parts of high-pressure hydrogen fuel systems. Higher-performing fitting technology is available today to provide such performance. This paper will take a close look at specific fitting design that delivers the gas seal tightness, tube grip strength, vibration resistance, material integrity, and efficient installation critical for hydrogen technology.

# The Clean Transportation Energy Landscape

As the world fights to curb fossil fuel emissions, several alternative fuel technologies are gaining traction in both the passenger car and heavy-duty trucking markets.

Electric or electrified vehicles (EVs) have grabbed much of the attention. Many major automakers have embraced electrification in some capacity, while some well-known new entrants have gained significant market share.

However, even as EVs grow increasingly popular, the technology has some significant limitations that could inhibit broad-scale adoption to replace traditional gasoline- and diesel-powered vehicles, including:

**Driving range**. EVs generally have far shorter ranges than most conventional vehicles. Most EVs are limited to traveling about 100 miles on a charge, though some higher-performance models can travel in excess of 200 or 300 miles.[1] Meanwhile, heavy-duty long-haul applications requiring lengthy range are currently not compatible with today's available battery power.

**Lengthy recharge times.** Fully recharging an EV battery pack can take anywhere from 3 to 12 hours, and a "fast charge" to 80% capacity can take up to 30 minutes.[1] Even with an EV that can achieve longer ranges, these lengthy recharge times can inhibit long-distance travel and transport.

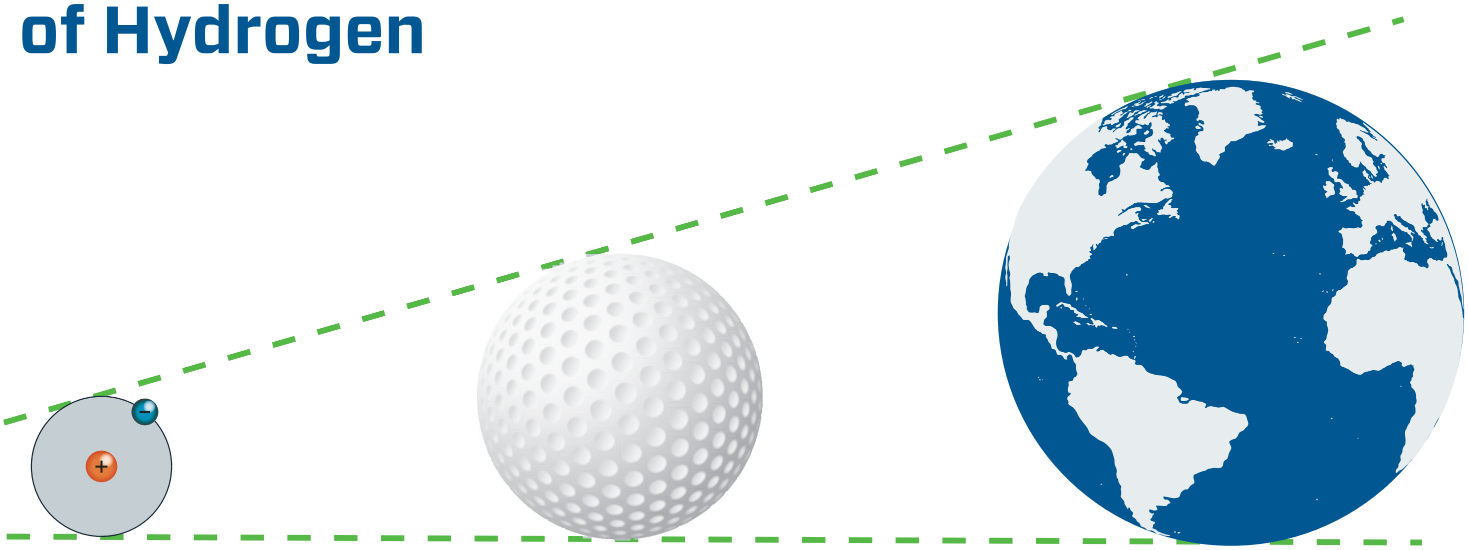
**Higher Costs.** Existing battery technology can come at a high price, and overall service life has room for improvement. Frequent replacement can be costly, while negatively impacting the environment.

Though EV technology is steadily improving in these areas, another clean transportation technology has already overcome these challenges: hydrogen fuel cell vehicles. Via high-pressure onboard storage, hydrogen fuel cell vehicles readily achieve a 300+ mile range on a single refill. In heavy-duty applications, a full hydrogen tank can deliver a range of 1000 miles. Additionally, they can refuel in fewer than four minutes on average.[2] Also, these vehicles utilize advanced technologies found in EVs that increase efficiency, including regenerative braking, high torque levels, and experience fewer failure modes.


Indeed, hydrogen vehicles represent one of the most promising and viable transportation technologies developed to date, capable of delivering the performance drivers expect while providing distinct environmental benefits. Hydrogen fuel cell vehicles and refueling infrastructure will require high-quality systems and components for long-term sustainability and reliability.

To that end, it is critical to consider the unique needs of hydrogen systems—and the tubing and fitting connections that are used to build them. This paper will examine why safe, reliable hydrogen containment can present challenges to traditional fitting technology and will detail specific design elements that make a fitting well-suited for hydrogen applications.

# The Unique Nature of Hydrogen



The size of a single hydrogen atom compared to a golf ball is the same ratio as a golf ball's size compared to that of Earth.

Hydrogen is one of the smallest molecules found in nature—making effective containment within hydrogen fuel systems a considerable challenge. Being so small, hydrogen molecules can migrate through even the smallest of openings that may exist in a tube fitting connection.

The need for leak-tightness throughout the system is especially important considering the high pressures at which hydrogen must be transported and stored to deliver the promised benefits.

- **Leak-tightness is essential for safety.** Escaping gas in any kind of fluid system poses an inherent safety risk, especially in hydrogen transportation applications where end users interact with dispensers on a regular basis (i.e., refueling).
- **Leak-tightness is essential for efficiency.** A leak-tight system is able to effectively utilize all hydrogen gas while producing no waste.

Additionally, hydrogen molecules can be absorbed on the surface of stainless steel and the individual atoms split apart. They have a very small diameter and can diffuse into the austenitic crystal lattice formed by the much larger iron, nickel, chromium, and molybdenum atoms. Diffusion into 316/316L stainless steel occurs very slowly, but at high pressures and over long periods of time, significant amounts of hydrogen atoms can accumulate in the lattice. This phenomenon is known as hydrogen embrittlement. Even when present at large concentrations, hydrogen atoms do not negatively affect the strength of 316/316L. However, should fatigue cracks be present in a component, hydrogen atoms would make it easier for these cracks to propagate through a component. Lower-performing alloys may be more susceptible to this issue over the long term.

# Why Fittings Matter


Combined with the unique challenges of hydrogen itself, fuel cell vehicle applications have some inherently challenging operating conditions with which system components must contend.

- To achieve the desired energy density, hydrogen is stored in on-vehicle tanks at between 350 and 700 bar. This is a considerable amount of pressure, and systems must be designed to handle it.
- On-vehicle systems experience significant amounts of stress and vibration while the vehicle is in transit. Systems must be able to withstand fast speeds, bumpy roads, and a range of weather conditions.
- Refueling stations must be easily, readily, and safely operable by the average consumer.

For all of these reasons, it is critically important that the hydrogen systems for both on-vehicle and the infrastructure needed are designed and built to meet the highest levels of quality. Tube fittings responsible for maintaining connections throughout these systems play an especially important role in hydrogen fuel systems and must deliver leak-tight performance for years—or even decades.

Read on to find out the performance characteristics of a fitting that can deliver the kind of reliable performance that hydrogen applications demand.

# Performance Characteristic
# **Gas Seal Tightness**

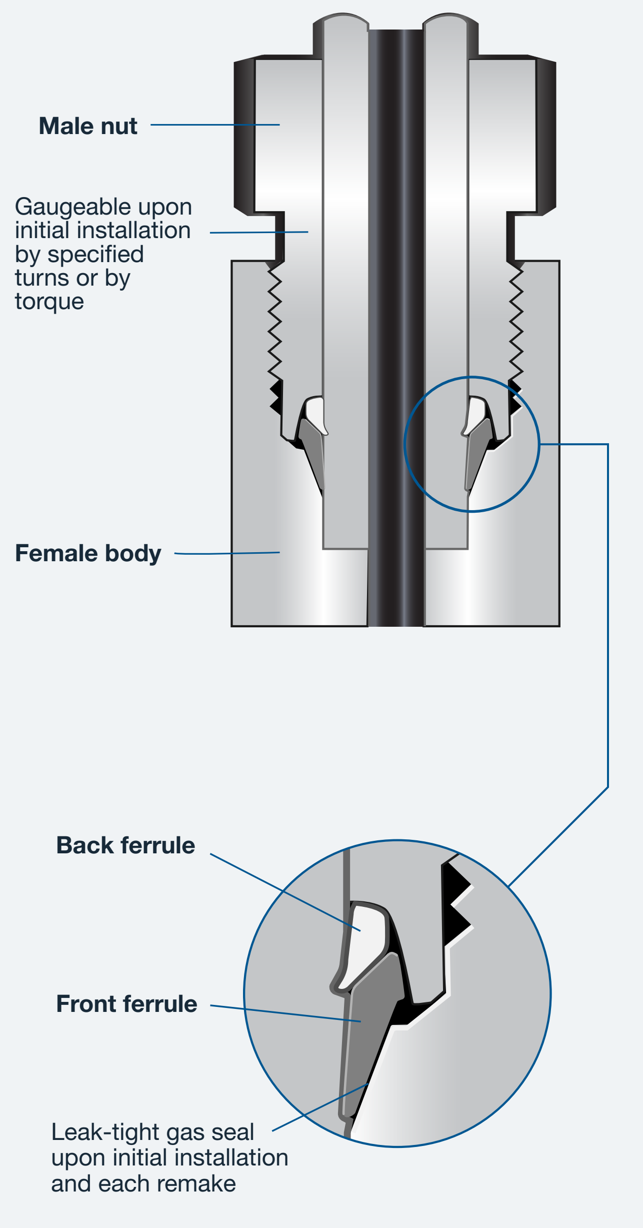
Maintaining a leak-tight seal at every connection point in a hydrogen system is essential to safety, reliability, and efficiency. And due to hydrogen molecules' miniscule size, creating such a seal with traditional fitting technology can be a challenge.

Traditional-style cone and thread fittings are sealed along a single line of contact on a narrow surface. This type of seal is sufficient for many general industrial applications and can provide acceptable performance with liquid and large-molecule media. However, hydrogen's challenging nature can compromise a narrow seal once in operation.

An ideal design for hydrogen system fittings incorporates two contact zones across longer sealing surfaces—one along the tube and another along the fitting. These contact surfaces should be angled slightly, providing the optimized stress level to maintain an uncompromising seal.

A fitting designed for hydrogen can achieve this robust seal through two ferrules—a front ferrule that creates a long plane of contact and a back ferrule that effectively grips into the tubing itself and creates its own surface seal. Long, precise machined surfaces on the front ferrule can further contribute to a highly reliable gas-tight seal.

This cutaway image shows how optimized seal contact can be achieved with two-ferrule fitting technology.




Swagelok® FK series tube fitting

# Performance Characteristics

## Tube Grip Strength

In hydrogen systems, a fitting's grip strength—the persistent force at which the fitting grips the tube—is another key performance attribute. Hydrogen system fittings must be able to withstand the high pressures required throughout the generation, transport, storage, and dispensing process, as well as the significant vibration that can occur on a moving vehicle.

Traditional cone and thread connections, National Pipe Thread (NPT) Fittings, and O-ring face seals can create grips suitable for a variety of applications but have limitations when it comes to transportation applications where regular agitation can compromise the threads' ability to remain tight. Cone and thread fittings also have a tendency to gall, a phenomenon where the two metals cold weld themselves together, which can compromise a reliable connection and make replacement or maintenance difficult.

A fitting with two low-temperature case-hardened ferrules, designed to utilize hinging and colleting action, can deliver outstanding grip strength for uncompromising applications. With this design, a hardened front ferrule enables the fitting to physically collet into the tubing, creating a pressure rating of up to 1050 bar (15 229 psi)—ideal for the heightened pressures of hydrogen storage both on vehicles and within refueling infrastructure.

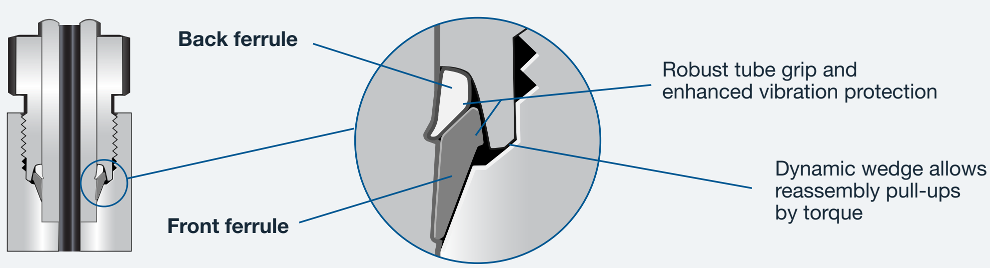
## Vibration Resistance

Tube connections on a moving vehicle or within hydrogen refueling infrastructure are subject to more regular shock and vibration than typical stationary fluid system applications, making it essential that the fitting can withstand ongoing, significant agitation.

A two-ferrule mechanical grip fitting can enable a slight amount of movement in the fitting while maintaining grip and force. This movement, called "spring back," creates robust vibration resistance. This is ideal for both on-vehicle operation and use within refueling infrastructure, where compression and dynamic conditions can create significant vibration.

Spring back also helps fitting connections withstand significant thermal changes that can cause metallic alloys to expand and contract, which can compromise performance. Hydrogen gas temperatures may vary from as low as -40ºC and up to 85ºC.

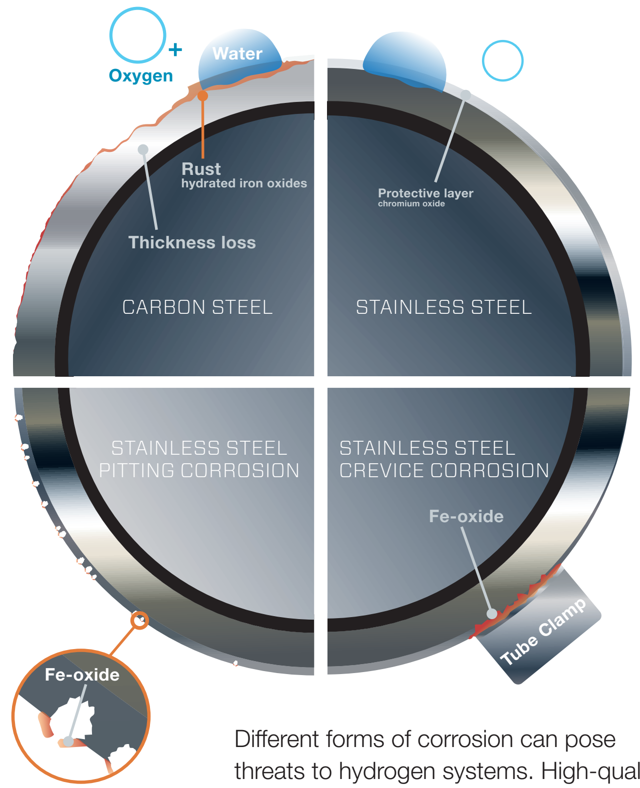
Two-ferrule fitting technology can deliver outstanding grip strength and vibration resistance.



# Performance Characteristic
# **Material Integrity**

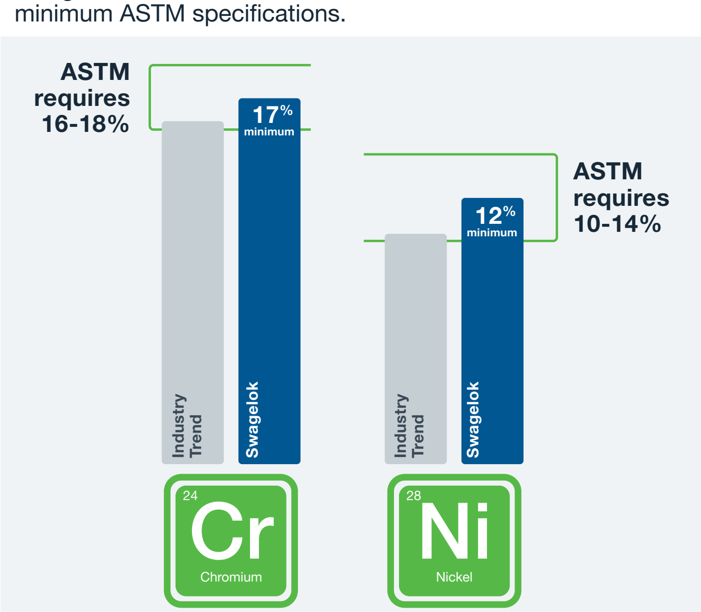
Corrosion control is important in any application where tube fittings are expected to provide reliable performance. Corrosion occurs when a metal atom is oxidized by a fluid, leading to a loss of material in the metal surface. This loss reduces the wall thickness of a component and makes it more prone to mechanical failure. In hydrogen transportation applications, both vehicles and refueling infrastructure are regularly exposed to adverse weather conditions, making it especially important that materials of construction can resist problematic corrosion throughout a system's lifetime.

And as noted, hydrogen embrittlement can compromise lower-performing stainless steels, a prevalent alloy type used for fittings, valves, and tubing in hydrogen vehicles and refueling infrastructure.




Different forms of corrosion can pose threats to hydrogen systems. High-quality alloys can help prevent corrosion-related issues on vehicles and infrastructure.

Swagelok® 316 stainless steel exceeds minimum ASTM specifications.




Higher concentrations of chromium and nickel in fluid system components can help defend against common corrosion and hydrogen embrittlement by retaining greater ductility in critical components. The American Society for Testing and Materials (ASTM) requires a minimum of 10% nickel in 316 stainless steel. However, it has been shown that higher-quality 316 stainless steel with 12% minimum nickel is better suited for the unique challenges of hydrogen.[3]

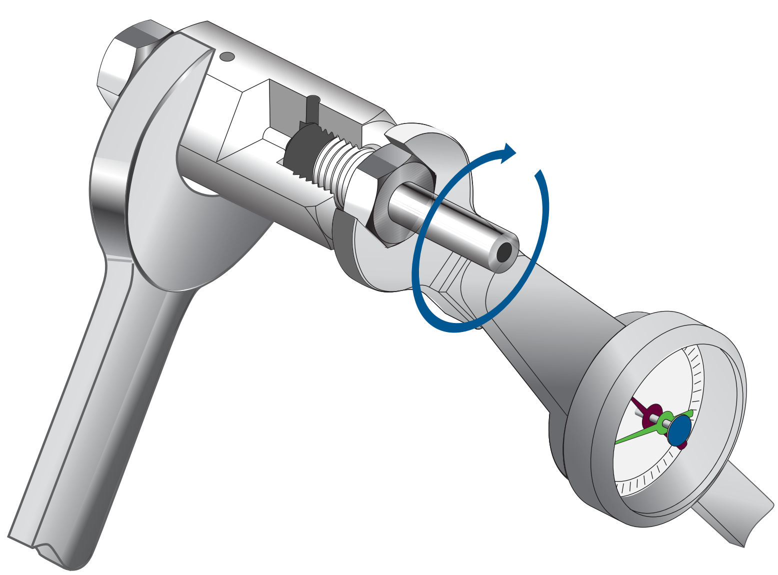
# Performance Characteristic
# **Ease of Installation**

As demand for hydrogen-based transportation grows and as OEMs ramp up the construction of refueling infrastructure to support widespread adoption, specifiers should consider fittings that deliver a simple, fast, easily repeatable, and first-time quality installation process.

As an example, cone and thread fittings require specialized tools and materials, as well as lubricant oils to reduce friction during the coning and threading process. Further, using the coning and threading tools, the tube must be properly coned and threaded before being joined with the fitting. Proper care must be taken to ensure no burrs, gouges, or scratches have occurred during the process. Once the tubing preparations are complete, a collar is threaded onto the tubing and a gland nut is inserted into the fitting body for final tightening. Even for skilled installers, this adds time and complexity to the process.

Two-ferrule mechanical grip fittings allow assemblers to complete installations approximately five times faster than comparable cone and thread fittings, providing a first-time, leak-tight seal. This functionality eliminates the need for rework after initial site installation while significantly reducing the overall cost of maintenance.

Mechanical grip fittings follow a simpler installation process with less opportunity for errors by technicians, leading to more consistent, reliable performance over the lifetime of the equipment. Finally, no special tools are needed; these kinds of fittings require just a simple wrench to install using either torque or turns assembly methods.



# A Solution Designed for Hydrogen
# The Swagelok® FK Series Fitting

For hydrogen applications, seal tightness, grip strength, vibration resistance, material integrity, and ease of installation are all essential. Each of these qualities comes together in the Swagelok FK series fitting, a solution designed specifically for hydrogen applications.

FK series fittings are compatible with a variety of tubing types and materials, with low-temperature case-hardened ferrules and hinging-colleting action that deliver leak-tight performance, reliable tube grip, and vibration resistance.

The FK series fitting is EC-79, HGV 3.1, and EIHP certified and also certified for the H70 pressure class.

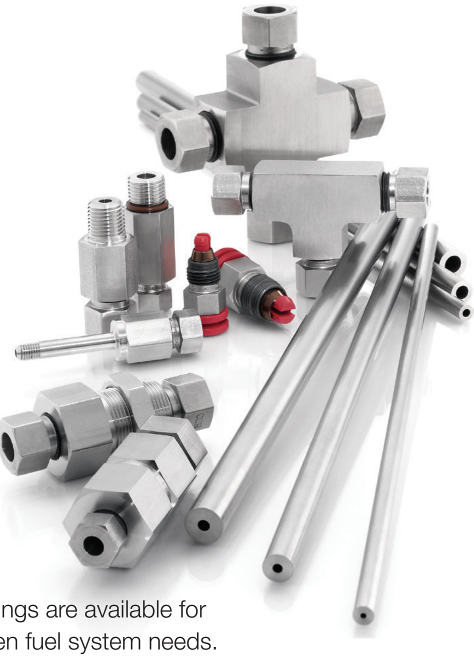
FK series fittings are manufactured using 316/316L stainless steel with 12% minimum nickel content to resist corrosion and hydrogen embrittlement.

A simple, patented, two-piece design consists of a female fitting body and preassembled cartridge containing the male nut, along with color-coded front and back ferrules on a disposable plastic arbor. The preassembled cartridge ensures that installers have correct ferrule orientation, visual confirmation of ferrule presence, and proper installation into the female body. Components are released only after the nut is threaded finger-tight on the fitting body. This simplified labor process means that FK series fittings install up to five times faster than traditional cone and thread fittings and do not require special tooling.

FK series fittings are backed by our full suite of service offerings, including specialized training, on-site evaluations, design and assembly services, and much more.

The long-term viability of hydrogen transportation will depend on safe, reliable, and durable hydrogen vehicles and infrastructure. Selecting and specifying the right components for critical systems can help achieve these goals. FK series fittings have been used in a wide variety of industries and applications since their introduction and are an optimal choice for today's—and tomorrow's—hydrogen vehicles and infrastructure.

Interested in learning more? **Get in touch with your local authorized sales and service center** today to start a conversation about FK series fittings and all of the service and support we're committed to providing the hydrogen mobility industry.



FK series fittings are available for your hydrogen fuel system needs.

swagelok.com

Contact your local authorized
Swagelok sales and service center.

Sources:
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