LOCTITE

BEYOND THE BOND

HYDROGEN READY THREAD SEALING SOLUTIONS AND LEAK PREVENTION

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• WHITE PAPER

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EXECUTIVE SUMMARY

In an era marked by a growing emphasis on sustainability and the pursuit of clean energy alternatives, green hydrogen emerges as a particularly compelling solution. Yet, throughout its entire life cycle spanning from production to distribution, the imperative to minimise or eradicate leaks looms large, presenting economic burdens on top of the potential safety hazards.

Addressing the challenges posed by the minute size of hydrogen molecules, making connections while maintaining a seal becomes a formidable task. Threaded connections are often avoided in hydrogen-related equipment. Instead, engineers frequently resort to costly assembly processes such as seal welding or the adoption of more expensive connection methods. In this study, we showcase the efficacy of anaerobic thread sealants and thread sealing cord as outstanding solutions for effectively preventing leaks in threaded joints, offering a pivotal contribution to the seamless integration of green hydrogen in our pursuit of sustainable energy solutions.

INTRODUCTION
HYDROGEN: A PROMISING ENERGY SOLUTION

Hydrogen provides a useful means to store and transport energy. Hydrogen in its pure molecular form (H_2) is rare on our planet and therefore must be produced, either from water by electrolysis or from natural gas and coal. Under certain conditions which depend on the way it is produced, hydrogen can be a sustainable energy solution and can substitute or replace energy sources that have a greater impact on the environment.

According to the RSE report 'Hydrogen. An Energy Carrier for Decarbonization', green hydrogen is among the main options for the complete decarbonization of the energy system by 2050. The European Commission predicts that green hydrogen use will grow to 13–14 percent of the energy economy by 2050; the International Energy Agency forecasts there will be about 2.5 million hydrogen-powered cars globally by 2030.

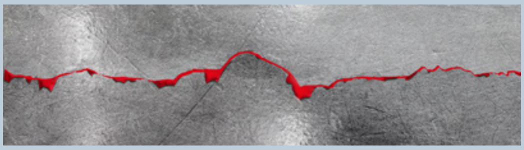
The development of this sector is certainly favored by certain intrinsic characteristics of hydrogen that can be summarized as follows:

- It is the most abundant element in nature (more than 90 percent of the matter in the universe is made of hydrogen) and the earth is very rich in this element; just think of the fact that every molecule of water contains two hydrogen atoms.
- It is a highly flammable gas that does not emit CO_2 and whose combustion products are water and heat.
- It has a high energy density (120 MJ/kg, compared with 55.6 MJ/kg for methane, 47.3 MJ/kg for gasoline and 44.8 MJ/kg for diesel).
- It is possible to store it in large quantities and for extended periods.

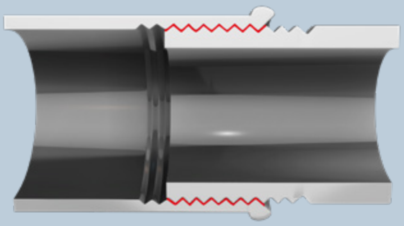
Hydrogen has enormous application potential: from its traditional use as a reagent in heavy industries (foundries, iron and steel, chemical, petrochemical, fertilizer, and gold companies), to its use in generating industrial heat in hard-to-abate sectors (e.g. textile or paper mills), generating and storing electricity, and powering heavy transport. The above-mentioned RSE report predicts that by 2050 hydrogen will be increasingly introduced for non-traditional uses.

According to data from the International Energy Agency, 70 million tonnes of hydrogen are produced each year: 76 percent from natural gas, 22 percent from coal and 2 percent from water electrolysis (IEA, 2019). Thus, not all hydrogen is equal; depending on how it is produced, it conventionally takes on a different color. Thus, one speaks of grey hydrogen if it is produced by the combustion of fossil sources and thus emits carbon dioxide, of blue hydrogen if it is produced from fossil sources but with carbon capture systems, which can thus reduce greenhouse gas emissions from polluting plants or remove them directly from the atmosphere, of green hydrogen if it is produced by renewable energy (e.g. solar and wind) and of purple hydrogen if it is produced by nuclear energy. Therefore, one cannot speak generically about hydrogen, but must study and trace its production chain.

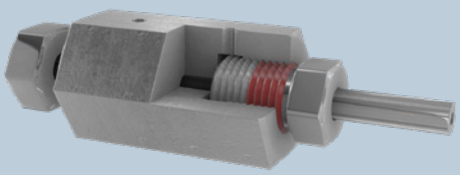
In the European Hydrogen Strategy, the priority for achieving carbon neutrality goals by 2050 is to develop green hydrogen in the long run, fostering an integrated energy system, and blue hydrogen in the short- and medium-term transition phase, which can rapidly reduce emissions from hydrogen production, and to pursue the development of a sustainable market on a significant scale. Clearly, the integration of renewable sources into hydrogen production plays an important role in this process.



All metal materials, however finely processed, have surface roughness. Therefore, even in precise fits such as interference fits, there will be contact points and voids between the parts. This can create escape paths, especially for small molecules such as hydrogen molecules. Once applied, anaerobic adhesives distribute evenly, filling all spaces and creating 100 % contact between parts, thus ensuring a complete and reliable seal.



In metal fittings, there is never complete contact between the parts; otherwise, it would be impossible to assemble the fittings. For this reason, it is essential to evenly apply products that can fill the spaces and create a complete seal, preventing leakage. Anaerobic solutions, as well as LOCTITE 55, offer a reliable and durable solution for sealing even the smallest molecules, such as hydrogen.



Once anaerobic adhesive is applied to a threaded fitting, it distributes evenly during assembly, creating a complete and uniform contact area, thus ensuring a safe and reliable seal.

Renewable energies, especially wind and solar, are not predictable and programmable: solar panels, for example, work effectively only in daylight and during the summer period; wind turbines run only in the presence of wind. Thus, in the absence of certain weather conditions, the systems stop and do not produce energy. There are also times when excess energy production occurs, and it is often necessary to limit energy production due to a lack of energy storage capacity. Hence, hydrogen could be the perfect complement to renewable energy generation, providing a means to store this excess energy for later use.

To solve the problem of seasonal storage, the cleanest and most efficient solution is to use the energy from renewable sources to produce electricity, which can then be used in an electrolyser to convert water to hydrogen and oxygen. The hydrogen generated can then be immediately distributed through natural gas networks or stored in tanks and then converted back to electricity, but also to thermal energy, when needed. This is a closed loop which is self-powering and can be applied at the industrial level and even at the smart city level.

Along with the challenges associated with hydrogen storage, transportation is also one of the critical issues in the transition to hydrogen, mainly because its sustainability must be ensured. These days, hydrogen is transported in the form of compressed gas in cylinders, in liquefied form in cryogenic tanks, and by hydrogen pipelines in what form is it transported in pipelines. Transportation in dedicated pipelines or in a mixture with natural gas seems to be, at least on paper, the most reasonable option.

Hydrogen leakage is a serious challenge for natural gas pipelines. Because hydrogen can leak even more easily than methane through the smallest holes, cracks and weld seams, the transportation and eventual storage of this gas is a major obstacle to its wider adoption as a fuel and feedstock. Hydrogen permeation and embrittlement only exacerbate the problem.

The rate of natural gas leakage is already higher than that estimated by the Environmental Protection Agency. Research published in the American Journal of Science found that losses in the US methane supply chain in 2015 were 2.3 percent of gross production, about 60 percent higher than the EPA inventory estimate (Alvarez et al., 2018). The white paper ‘Atmospheric implications of increased hydrogen use’ (April 2022) commissioned by the UK government and authored by scientists from the University of Cambridge and the University of Reading states that leakage rates for hydrogen are likely to be higher because H_2 molecules are smaller than CH_4 molecules.

COST-EFFECTIVE SEALING SOLUTIONS *FOR THREADED CONNECTIONS IN HYDROGEN PIPING*

For these reasons, threaded connections are often recommended to be seal-welded or avoided altogether. This introduces significant costs to a system due to more expensive components as alternatives to threaded connections or the required skilled labour to perform seal welding. These costs may be avoided or reduced if an appropriate sealant is used to make a reliable seal with standardized and readily available threaded connections. Guidelines provided by the American Society of Mechanical Engineers (ASME) code for hydrogen piping and pipelines (B31.12-2023) allow for threaded connections. Taper-threaded joints (NPT in accordance with ASME B1.20.1) may be used on systems with design pressures below 20,670 kPa (3,000 psig) and up to 48,280 kPa (7,000 psig) when specified by engineering design (ASME, 2023).

Anaerobic adhesives and sealants are well placed to offer a sealing solution for hydrogen gas. They are reactive adhesives that cure rapidly to a thermoset plastic when in contact with metal surfaces in the absence of air. Close-fitting metal threads create near-perfect curing conditions and therefore these materials make ideal thread sealing compounds, overcoming many of the limitations of traditional sealing methods. As they are applied to the threads in a liquid state, they can fill any void or imperfection between the mating threads. When confined between the metal threads, there is insufficient oxygen to keep the material stable in its liquid state – rapid polymerization then creates a thermoset plastic that provides a mechanical bond between the two components. Since the sealing performance is not dependent on compression between the threads, the assembly can be initially aligned to any orientation and any excess material that is squeezed out of the joint can be wiped away. This means the joint has a clean appearance and provides resistance to vibrational loosening, temperatures as high as 200°C and pressures up to the burst pressure rating of most systems. Further discussion of anaerobic thread sealants and their ability to provide a sealing solution for gases and liquids is provided in the white paper of McGurk et al. [7].

TEST METHOD
TESTING THREAD SEALANTS FOR HYDROGEN GAS LEAK PREVENTION

To demonstrate the compatibility and effectiveness of the sealing solutions, Henkel designed an experiment and contracted an outside laboratory to perform a low-pressure hydrogen gas leak test on three different thread sealant materials using the pressure drop method. Additionally, the sealants were used on assemblies utilizing both American National Standard Taper Pipe (NPT) thread and British Standard Pipe Taper (BSPT) thread which are the most common pipe thread types globally. All assemblies were made of 304 stainless steel components since 300-series alloys are the most used in gas transmission piping systems (European Industrial Gases Association, 2014).

Since there are no reference standards regarding hydrogen sealant testing, we created a test set-up based on the available standards, such as ASTM D6396 (Standard Test Method for Testing of Pipe Thread Sealants on Pipe Tees), ASTM D1599 (Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings), LOCTITE STM 772 (based on the two previous ASTM), and EN 751-1 (Sealing materials for metallic threaded joints in contact with 1st, 2nd and 3rd family gases and hot water – Part 1: Anaerobic jointing compounds).

Based on these standards, we created a tool and defined the parameters for testing.

Two types of thread sealants were selected for testing: anaerobic thread sealants (LOCTITE 577 and LOCTITE 567) and a non-hardening thread sealing cord (LOCTITE 55). LOCTITE 577 is the most common anaerobic sealant for BSPT or other straight-(parallel-)to-tapered connections, while LOCTITE 567 is the most common anaerobic sealant for NPT, tapered-to-tapered thread connections.

LOCTITE 55 is the most common non-hardening sealing yarn and is often utilized in applications requiring small adjustments before use. All three sealants are already certified in accordance with at least one regional approval for natural gas. As hydrogen is being explored for blending with natural gas into the existing natural gas infrastructure, this was an important consideration.

The test involved two pressure steps. Specifically, for LOCTITE 55, the pressure tested was 9 bar (131 psi) with an increase to 10.3 bar (150 psi), while for LOCTITE 567 and 577, the pressure tested was 20 bar (300 psi) with an increase to 31 bar (450 psi).

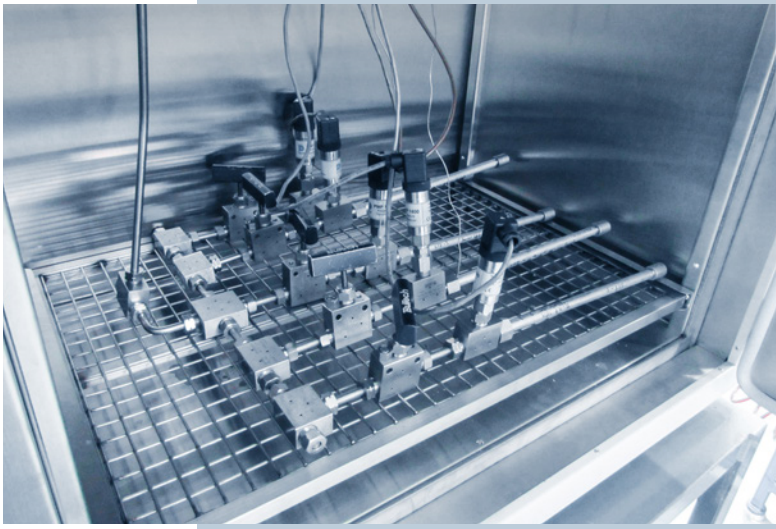


FIGURE 1: Test set-up

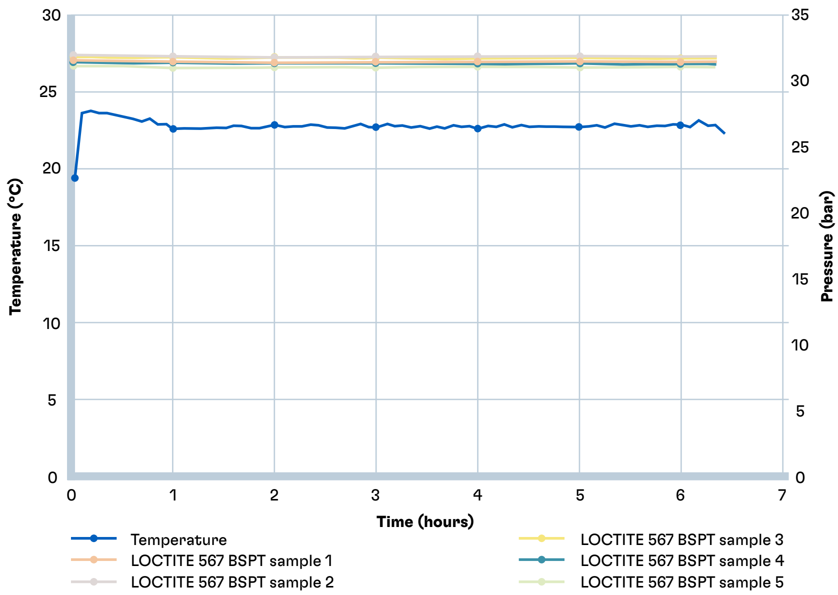
RESULTS

The temperature and pressure were logged throughout each of the tests. Points were plotted to identify any leakage for each of the thread sealant materials. The volume of gas in the system was very small so any drop in pressure would be noticeable.

LOCTITE 567

Figure 2 summarises the results obtained for LOCTITE 567 under one pressure test condition. Specifically, the graph shows the pressure and temperature compared to the 31-bar hydrogen pressure leak test for the BSPT fitting samples. No decrease in pressure was observed, thus there was no leakage.

FIGURE 2: Plot of temperature and pressure for LOCTITE 567 BSPT fitting at 31-bar pressure



LOCTITE 577

Figure 3 summarises the results obtained for LOCTITE 577 under one pressure test condition. Specifically, the graph shows the pressure and temperature compared to the 31-bar hydrogen pressure leak test for the BSPT fitting samples. No decrease in pressure was observed, thus there was no leakage.

FIGURE 3: Plot of temperature and pressure for LOCTITE 577 BSPT fitting at 31-bar pressure

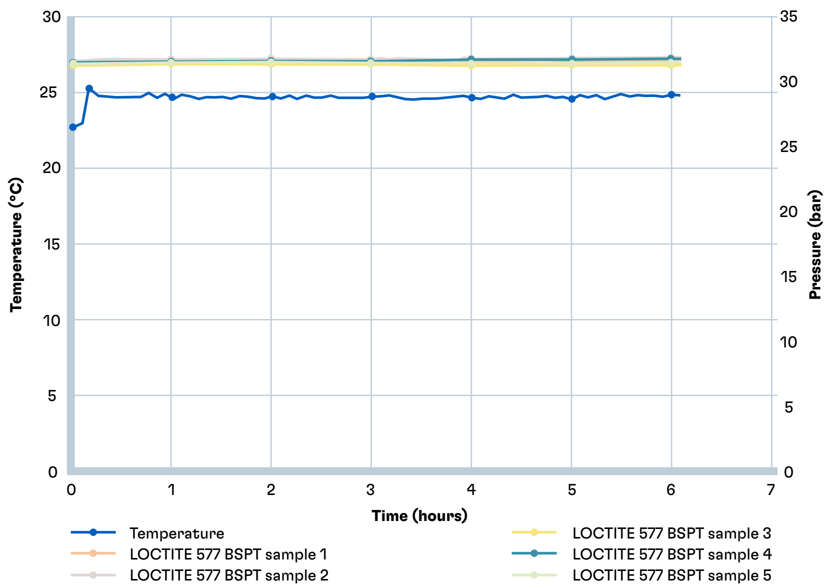
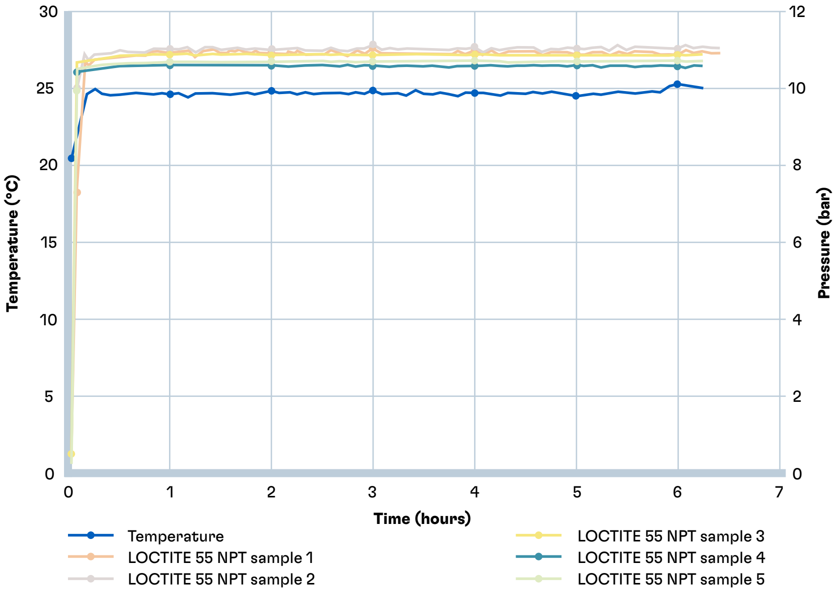


FIGURE 4: Plot of temperature and pressure for LOCTITE 55 NPT fitting at 10.3-bar pressure



LOCTITE 55

Figure 4 summarises the results obtained for LOCTITE 55 under one pressure test condition. Specifically, it shows the temperature and pressure graph at the second pressure test condition of 10.3 bar for the NPT fitting. There was no apparent decrease in pressure, so it can be concluded that there was no leakage.

SUMMARY TABLE

Figure 5 illustrates all the results obtained from the tests at different pressures and for different types of NPT and BSPT fittings:

Test Assembly	Sealant	Test pressure (step 1)	Test result	Test pressure (step 2)	Test result	Test gas
¼" NPT – 304 stainless steel ▪ Pipe nipple (10" long) ▪ Connector ▪ Plug	LOCTITE 55	131 psi (9 bar)	✓	150 psi (10.3 bar)	✓	**Hydrogen**
	LOCTITE 567	300 psi (20 bar)	✓	450 psi (31 bar)	✓	
	LOCTITE 577	300 psi (20 bar)	✓	450 psi (31 bar)	✓	
¼" BSPT – 304 stainless steel ▪ Pipe nipple (12" long) ▪ Connector ▪ Plug (316 stainless steel)	LOCTITE 55	131 psi (9 bar)	✓	150 psi (10.3 bar)	✓	
	LOCTITE 567	300 psi (20 bar)	✓	450 psi (31 bar)	✓	
	LOCTITE 577	300 psi (20 bar)	✓	450 psi (31 bar)	✓	

FIGURE 5: Summary table of test results

CONCLUSION

- The sealing tests described in this paper were conducted to show how anaerobic thread sealants and LOCTITE 55 thread sealing cord products provide an effective sealing solution for the prevention of hydrogen leakage in threaded fittings.

- Pressure transducers were used to measure pressure, providing an electrical output calibrated to give a pressure reading with an accuracy of between 0.05 and 0.1 bar.

- All samples were successfully tested. No significant pressure drops occurred for any of the tested samples at any of the pressures considered.

- It can be concluded that LOCTITE 55 non-curing thread sealing cord offers a solution for sealing hydrogen gas at lower pressures of up to 10 bar (150 psi) on NPT and BSPT fittings.

- The anaerobic curing thread sealants successfully sealed hydrogen gas to a pressure of 31 bar (450 psi) on NPT and BSPT fittings. As these products cure to form a thermoset polymer, it is expected that they could seal at even higher pressures, although this was not possible using the available test equipment.

- All products tested here, along with LOCTITE 570 and LOCTITE 638, have also been tested and certified by Kiwa for hydrogen sealing applications, according to AR 214. Kiwa NV is a Europe-based institution in the testing, inspection and certification market.

- The sealants evaluated in this report provide a convenient, reliable and cost-effective method of sealing threaded fittings for use with hydrogen gas. The anaerobic thread sealants also offer an extra layer of security for the sealing of threaded connections by preventing self-loosening, which is important given the flammability risks associated with hydrogen gas.

- Anaerobic thread sealant solutions have also been used in high-pressure hydrogen applications. We know of customers using our anaerobic sealants at up to 1,000 bar in their hydrogen thread sealing applications. At the time of authoring this paper, Henkel is conducting lab tests under similar conditions to validate the overall applicability of these products for use in high-pressure hydrogen environments. If you are interested in the results of these tests or in learning more about these products for your application, please feel free to contact the authors of this paper or your local Henkel representative.

REFERENCES

[1] RSE report 'Hydrogen. An Energy Carrier for Decarbonization', January 2021

[2] International Energy Agency (IEA) 'The Future of Hydrogen' June 2019

[3] Ramón A. Alvarez, Daniel Zavala-Araiza, David R. Lyon, David T. Allen, Zachary R. Barkley, Adam R. Brandt, Kenneth J. Davis, Scott C. Herndon, Daniel J. Jacob, Anna Karion, Eric A. Kort, Brian K. Lamb, Thomas Lauvaux, Joannes D. Maasakkers, Anthony J. Marchese, Mark Omara, Stephen W. Pacala, Jeff Peischl, Allen L. Robinson, Paul B. Shepson, Colm Sweeney, Amy Townsend-Small, Steven C. Wofsy and Steven P. Hamburg, 'Assessment of methane emissions from the U.S. oil and gas supply chain', American Journal of Science, June 2018

[4] Nicola Warwick, Paul Griffiths, James Keeble, Alexander Archibald, John Pyle, University of Cambridge and NCAS and Keith Shine, University of Reading, 'Atmospheric Implications of increased hydrogen use', UK government, April 2022

[5] European Industrial Gases Association (EIGA), 'Hydrogen Pipeline Systems', IGC Doc 121/14, 2014

[6] American Society of Mechanical Engineers, 'Hydrogen Piping and Pipelines', B31.12-2023

[7] Ged McGurk, Mike Feeney, Siva Ayadurai, Oliver Droste, white paper 'High pressure leak prevention – improved performance and reliability from anaerobic thread sealing compounds', March 2016

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