



# HYDROGEN



## SOLUTIONS PAPER

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Vincent studied engineering and joined Vallourec in 2017. Before joining Vallourec, he spent 9 years with the French Ministry of Economy and the Ministry of Environment. He held several positions within the two ministries, notably in charge of industrial safety, consumer safety, pollution control and market regulation policies. As Vallourec's Strategy Director from 2017 to 2020, he was in charge of the group's business plan, focusing on marketing and industrial strategies and financial recovery trajectory. He also supported top management as Secretary of the Management Board and Executive Committee. In 2019, Vincent took part in the Energy Transition Opportunities (ETO) initiative and eventually joined the ETO in early 2020 when it became the newly created Energy Transition Office. As its Hydrogen Cluster Director, he looks after Vallourec's business development in the emerging hydrogen markets.



# HYDROGEN: A POTENTIAL CLEAN ENERGY GAME CHANGER

As the search for cleaner alternatives to fossil fuels continues, hydrogen is perched to play a major role in the energy transition of the 21<sup>st</sup> century.

While hydrogen is already produced for a variety of industrial uses, demand is set to grow as its role in the energy transition expands. The European Commission recently announced that by 2050, hydrogen should represent 12-14% of the EU's overall energy mix. The Hydrogen Council goes even further, suggesting an 18% share of total final energy consumption can be achieved.

## A VERSATILE MOLECULE TO FOSTER DECARBONIZATION

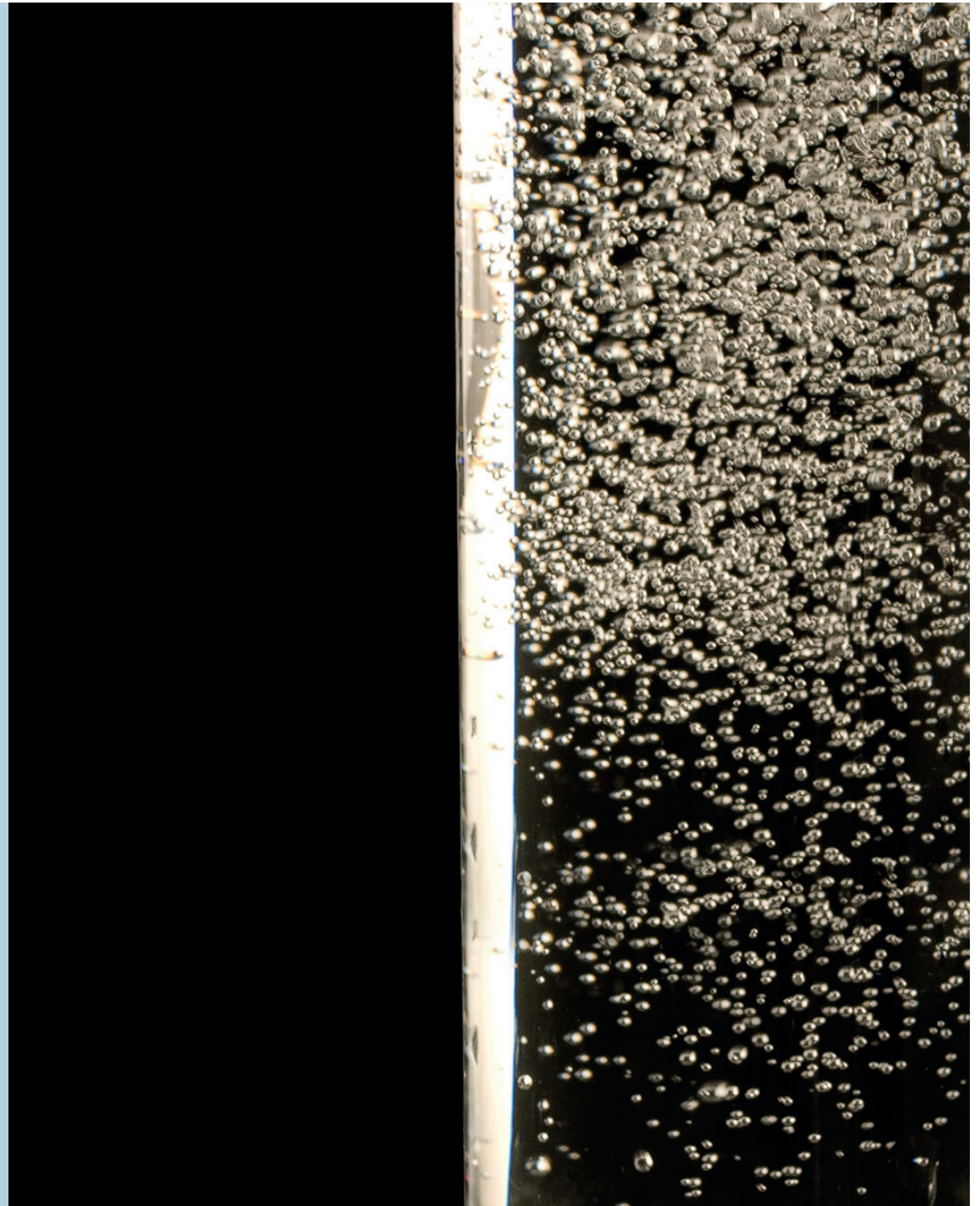
Hydrogen has many advantages as a sustainable energy option. As a chemical energy carrier, it can be stored and transported in a more stable manner than electricity. When combined with other elements into hydrogen-based fuels, it can provide a lower-emission feedstock for industry. Its use can also avoid the disruptions to supply that electricity-reliant energy systems have been known to suffer.

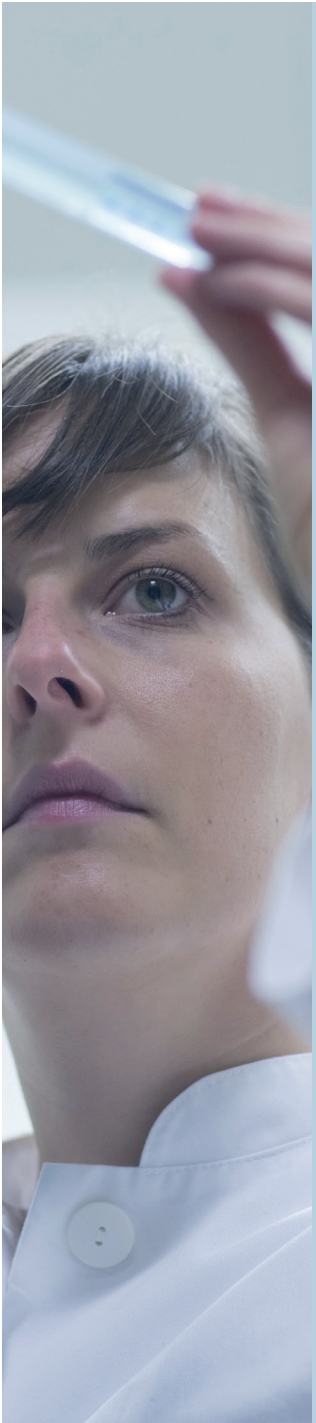
The growth in these hydrogen applications and its current contribution to decarbonization will benefit from the development of low-carbon hydrogen production, especially 'green' hydrogen, produced from renewables. 'Blue' hydrogen, which uses carbon capture and storage (CCUS), can be a useful complement in

some regions which are seeing a surge in market demand and help ensure a truly decarbonized future. Vallourec's expertise and support for CCUS value chains is therefore also playing a role in the development of the hydrogen market.

## THE ROAD TO SUCCESS

Irrespective of hydrogen sources, a lot of work must be done over the coming decades to create the hydrogen value chain and the robust infrastructure needed to ensure global success. Vallourec is perfectly positioned to help the industry overcome hydrogen's challenges: we draw on our experience providing tube technology for high-pressure storage and connections with excellent sealability and our know-how of metallurgies and corrosive environments to solve the problem of hydrogen embrittlement.





# OVERCOMING HYDROGEN'S CHALLENGES

Hydrogen's physical properties make the development of robust infrastructure complex. Vallourec's materials expertise is proving invaluable in developing the necessary solutions.

Over the next decade, extensive work must be done to create the hydrogen value chain: from storage, transportation and pipelines to means of distribution, and further end uses. These include uses in large industries and a strong mobility application in the form of fuel cell electric vehicles (FCEVs).

Fortunately, project developers can lean on the knowledge and experience of the very energy industry that hydrogen will eventually replace. As energy demand continues to rise alongside global temperatures, it is necessary to build on the technologies that have long kept the world supplied with fossil fuel energy, drawing on the industry's expertise and systems to aid in the transition and overcome hydrogen's specific challenges.

## MEETING THE HIGH-PRESSURE CHALLENGE

Hydrogen has very low energy density per unit of volume, meaning it takes up a lot of space and must be stored at very high pressure, typically up to 1,000 bar for mobility applications. Vallourec has years of technical experience designing tubes with the right steel grade and thickness for their intended purpose; both of these considerations are key to safe and successful high-pressure storage and transportation.

Our comprehensive pipe product and services offer is already being adapted to hydrogen storage, transmission and distribution, and includes solutions for fatigue-sensitive applications, high-pressure operations, and corrosive environments.

## COMBATING HYDROGEN EMBRITTLEMENT

When hydrogen atoms interact with metals, the hydrogen can cause embrittlement, or a reduction in the metals' ductility and strength. Vallourec sour service experts have extensive experience supporting the oil and gas industry working with hydrogen sulfide, which is a strong promoter of hydrogen embrittlement. This knowledge can be harnessed to overcome the equivalent problem from the dihydrogen molecule. Vallourec is able to leverage its comprehensive portfolio of solutions for sour environments, supported by hydrogen specific studies to reflect new applications.

## TACKLING SEALABILITY CONCERNS

Due to the relatively small size and low viscosity of dihydrogen molecules, leakage is a potential concern. Special equipment and procedures are needed to ensure its safe and efficient handling. Sealability of connections is crucial to prevent hydrogen escaping and diffusing into storage wells or the environment, as it is highly flammable and presents a risk of explosion.

Sealability and safe use are at the heart of Vallourec's expertise and tight connections offer. Our VAM® connections are recognized for their reliability in a wide variety of uses. Our engineers and researchers are currently leveraging their world-leading expertise in the subject to validate the tightness of connections for hydrogen storage wells.

## IMPORTANT PHYSICAL PROPERTIES OF HYDROGEN



### HIGH ENERGY

Hydrogen offers 3x the energy of gasoline per unit of mass, making it an attractive fuel source.



### LOW DENSITY

Hydrogen is the lightest element (1/10 of natural gas), so larger volumes must be moved to meet identical energy demand. Gaseous hydrogen needs to be stored and transported at high pressures, up to 1,000 bar; Vallourec has a strong track record with such high pressures.



### HIGHER VELOCITY FOR PIPELINE TRANSPORTATION

Hydrogen is flowing about 3 times faster than natural gas when transported in pipelines; when combined with lower density, this means that the energy flow in a pipeline is about 80% compared to a natural gas pipeline in similar conditions.



### HIGHLY FLAMMABLE

Hydrogen has high flame velocity (8x methane) and ignition range (6x wider than methane). Gas tightness and reliability of solutions, a key expertise and commitment of Vallourec, will be essential.

All these technical challenges will certainly find appropriate responses. Vallourec will contribute to these, so that the required infrastructure can be safely developed. In this way, the full potential of hydrogen as a low-carbon technology can be unleashed.



# PARTNERING ON THE HYDROGEN INFRASTRUCTURE BUILD

Vallourec is at the vanguard of hydrogen research and development, working on solutions concerning storage and transport.

Hydrogen today is usually stored in compressed gas or liquid form in small-scale tanks for distribution for nearby applications. For hydrogen to become a viable worldwide energy option, other large-scale storage and transportation solutions must be developed.



## PIPELINE TRANSPORTATION

Already a rapidly developing sector, hydrogen transport via pipeline can benefit from Vallourec's expertise in pipe and tube metallurgy in relation to hydrogen.

Our comprehensive line pipe product and services offer is being adapted to hydrogen transmission. It includes seamless line pipe for on and offshore use with fatigue-sensitive applications, high-pressure operations and corrosive environments. We are also repurposing our solutions for ultra-deep and sour service environments, developed with a focus on combatting hydrogen embrittlement, and Serimax welding and field joint coating services.

## COLLABORATION DRIVES SERVICES AND SOLUTIONS

Vallourec collaborates with a panel of carefully selected subcontractors and subsidiaries on associated services such as external anti-corrosion and thermal insulation coating, CRA lined pipe, bends, welding and multi-jointing. We provide integrated, reliable and competitive solutions for projects, either to develop new assets or repurpose pipelines for hydrogen transportation - in its pure state or blended with natural gas.

Vallourec is also a valued member of the European Pipeline Research Group (EPRG) and its joint industry project studying the behavior of hydrogen on metals.

## SUPPORTING REUSE OF EXISTING ASSETS

The possibility to reuse existing assets, already in service with another fluid, such as natural gas, will be a key enabler for the cost-effective development of a hydrogen infrastructure.

Leveraging our keen expertise around the metallurgy of pipes and tubes in relation to hydrogen, Vallourec aims to accompany customers repurposing their pipes for a new fluid and is assessing the best solutions to support them in this ambition. For example, we are exploring the potential of adapting our innovative solutions for non-destructive testing and inspections, as well as coating solutions, which would ensure proper material behavior and guarantee operational safety.

In addition, Vallourec is ready and able to act as a potential supplier for newbuilds, which could see the launch of pilot projects as soon as 2021. Leveraging decades of know-how and experience in industrial tubular development, Vallourec is positioned to help customers thrive in a market that should witness a boom throughout the 2020s.





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## UNDERGROUND STORAGE SOLUTIONS

According to the International Energy Agency, geological storage holds the most promise for large-scale hydrogen storage over the long-term.

Salt caverns are one such geological formation that might provide ample storage possibilities for hydrogen. Currently used for natural gas, salt caverns offer excellent sealability of the salt structure, together with efficiency, low operating costs, and significant economies of scale.

### THE CHALLENGES OF SALT CAVERNS

Track record is currently limited, with only four salt caverns for hydrogen storage in operation in the world today (three in the US, and one in the UK). Key challenges will be to ensure the integrity and safe operation of hydrogen caverns. This raises questions on the design of the wells relating to material selection and connections and on operating conditions in terms of cyclicity and monitoring schemes, for example.

Providing benchmark tubular solutions for the energy sectors, Vallourec is utilizing its sour service expertise and Oil Country Tubular Goods (OCTG) applications to help customers optimize tubing sealability to explore further salt cavern development for hydrogen.

In much the same way as for oil and gas, OCTG tubing can conduct hydrogen to and from the storage areas within salt caverns. Vallourec works with a wide range of steel grades, leveraging developments for severe sour service environments, which offer good resistance to hydrogen embrittlement. We follow a very careful manufacturing process to ensure a well-controlled surface state.

With the increasing interest and development of hydrogen economy, many storage operators are studying the transition to hydrogen and are launching more and more pilot projects. Vallourec is already supplying tubings for several pilot wells, supporting operators throughout their projects and helping them meet their challenges.

### SEALING THE DEAL

Connection sealability is of course critical for safe and successful salt cavern use. Vallourec's most suitable connections are currently being tested to confirm that they perform as well with hydrogen as they do with natural gas and helium, the standard tracer gas used in our testing facilities, but analysis carried out so far comes with strong confidence to reach excellent performance in hydrogen service.

As an alternative to our VAM® connections, we also offer our customers weldable grades. Indeed, as some of them prefer orbital welded connections to threaded seals, Vallourec has developed grades with optimized weldability performance that are also qualified for sour service. This enables customers to choose their preferred well design.

### INTELLIGENT PIPES

Vallourec's full-service offer also includes a new generation of smart pipes that offer continuous, real-time data. Our innovative Intelligent Pipe solution features pipe integrity management sensors that monitor pipe temperature and pressure of the entire wellbore in real time and thus ensure safety by detecting leakage.

We are keen on customizing this solution for underground storage activities, to help operators anticipate any abnormal annulus behavior, alert them of any issue and provides key data regarding the environment surrounding the well. This would mean gaining vital knowledge about the formation beyond the casing, including any geological shifts.

By combining Intelligent Pipe with both our internal pipe database and Smartengo Running Expert digital solution, Vallourec offers a truly complete digital pipe traceability solution that enhances operations and safety.



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## POWERING AHEAD ON HYDROGEN VEHICLES

Vallourec's technology for high-pressure hydrogen forms part of the drive toward mass commercialization of hydrogen-powered fuel cell electric vehicles (FCEVs) through the development of an increasingly robust refueling station infrastructure

Today, 15% of global greenhouse gas emissions are directly tied to vehicles with internal combustion engines. Over the last few years, the automotive industry has begun to move toward battery electric vehicles (BEVs), but internal combustion engines still account for 90% of today's new car sales.

FCEVs offer an opportunity to bring both these figures down, and they hold some significant advantages over their BEV cousins. When deployed at scale, refueling takes about as long as it does to fill up a traditional gas tank,

compared to the hour or so to charge a BEV at a fast-charging site. And even though a hydrogen refueling station might have a larger footprint than a charging site, over the long term, fewer stations would be needed to service an FCEV fleet than a BEV fleet. At present, however, no real global hydrogen refueling station infrastructure exists.

We are committed to the development of the distribution infrastructure needed to support the growth of FCEVs fleets.

Hydrogen refueling stations generally combine Hydrogen compression, cooling storage and dispensing. Stationary storages of gaseous hydrogen generally combine several cascades with various levels of pressure, up to very high levels of 500 bar (which is common for heavy duty vehicles) or even 1,000 bar (for light duty vehicles), and an increasing number of applications with tank pressure of 700 bar.

Leveraging its expertise, Vallourec is providing solutions for high-pressure components in hydrogen refueling stations. A particular focus is high-pressure storage: Vallourec supplies pipes intended for high-pressure storage in pressure vessels or piston accumulators. Together with partner customers, we can

supply these key components and take high-pressure storage to the next level, especially in terms of larger volumes – enabling larger capacity storage and higher dispensing capacities.

Our unique manufacturing range allows for the largest dimensions: up to 660mm outside diameters, wall thicknesses up to 65mm, and inner volumes up to 3,000 liters (fit for pressure up to 1,000 bar) are feasible. Our experts are available to support our customers to optimize their designs to adjust to the needs of their projects, and to innovate together for safe and efficient refueling stations.

Our technical teams are engaged in optimization analysis with several partners. For instance, we are researching and testing different designs for hydrogen compression and high-pressure storage in refueling stations as well as assessing with customers the potential innovations we could add to products, materials and testing services.

## CONCLUSION

### AND MORE TO COME

The potential of hydrogen is immense, and not only as a clean power for tomorrow's vehicles. When created with renewable energy sources, it can be at the forefront of a decarbonized future that will serve as a crucial element in the fight against climate change. That is a battle for which Vallourec is proud to offer support.

Drawing on the innovation and expertise of solutions providers like Vallourec, governments, international bodies and key industrial players must work together to finance and build the infrastructure necessary to make hydrogen power a reality. As a tubular solutions leader in the energy industry, we have always partnered with our stakeholders to overcome technical challenges and develop methods and materials that respond to problems in all sorts of environments. Now, Vallourec is primed to play a central role in the energy transition.

With our cutting-edge products and expertise in materials, connections and the energy lifecycle, Vallourec is ready to bring value not only to our industry customers but to the entire world in the pivot toward a cleaner tomorrow.





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