Compression, storage and distribution of gaseous hydrogen

If we are to develop a hydrogen economy, we must consider not only production and end-use but also the infrastructure required in between. The compression, storage and distribution of hydrogen are all vital to the system and there are some key factors that must be considered due to the difference in physical properties of gaseous hydrogen compared to other common gases handled in industry such as natural gas, nitrogen, or air.

Hydrogen is the smallest molecule in the universe, and leaks from components that would be considered leak-tight with other gases. Hydrogen also has a very low density compared to other gases, and very different thermal and acoustic properties. Additionally, molecules of hydrogen can split into ions and diffuse into the structure of materials such as steel. This can cause hydrogen embrittlement which reduces the lifespan of the affected components and can create hazards due to component failure.

Hydrogen's unique physical properties pose some unique challenges when considering compression. Although popular for most other gases incl. natural gas, turbine type compressors perform poorly with hydrogen's low molecular weight, yielding low compression ratios whilst requiring extreme rotational speeds. Sealing can also a be challenge due to the small size of the hydrogen molecule.

These are all challenges, but they are by no means insurmountable. And the world-class gas-handling expertise that exists within Scotland's existing supply chains means that many companies will have highly relevant skills, products and services that can be applied in the manufacturing, deployment and operation of hydrogen infrastructure.

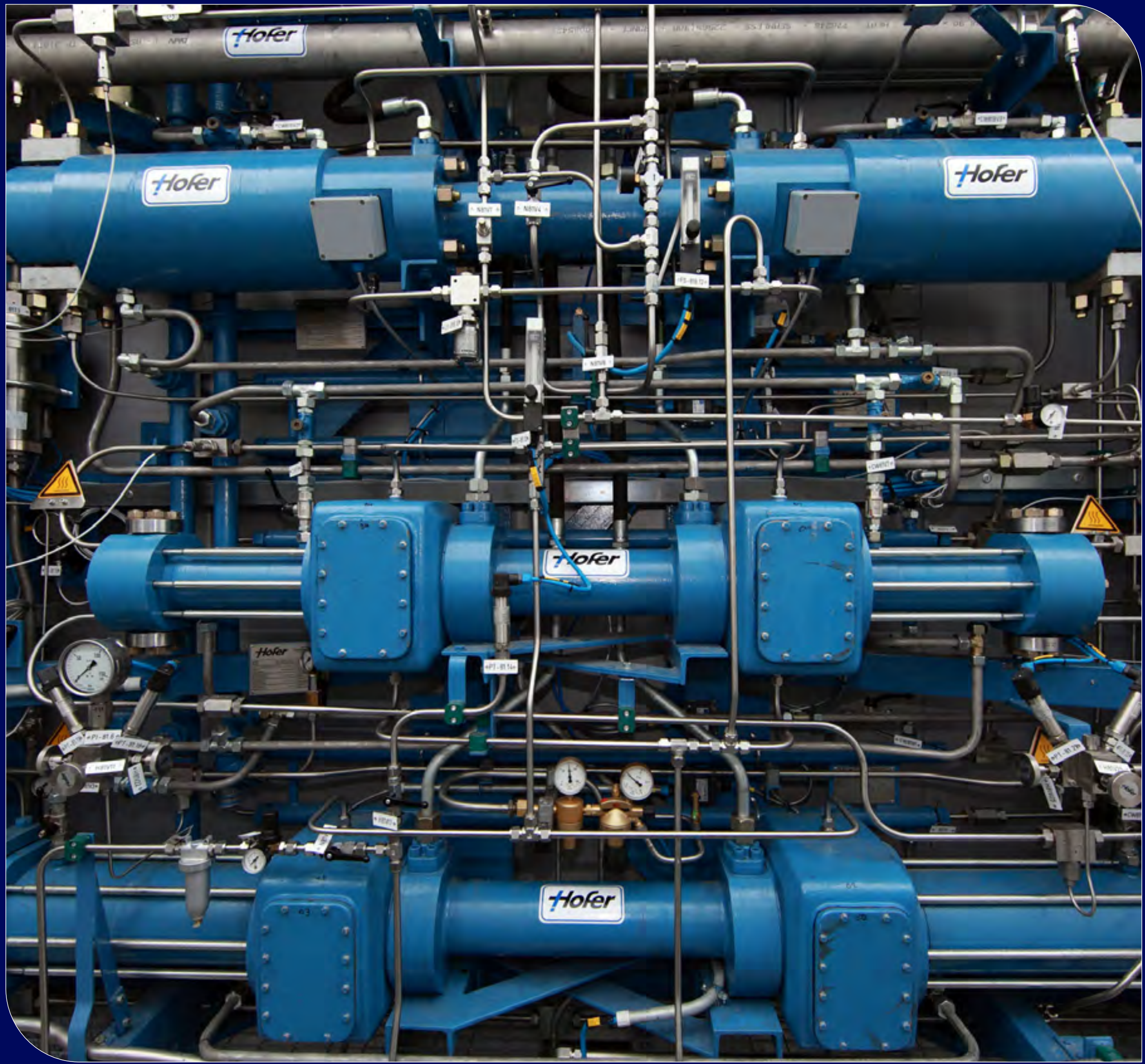
Hydrogen compression overview

Although hydrogen gas contains a lot of energy per unit of mass, it is a very low-density gas. Compression is an effective and proven method of increasing the gravimetric, and thus, energy density of hydrogen (as well as other gases) and is commonly used in order for hydrogen to be stored and moved around efficiently. Compressors take the hydrogen from a production process (e.g. an electrolyser or SMR plant) as input and compress it to several hundreds and as high as 1,000 bar pressure for storage.

For hydrogen and its various applications, compression technology is dominated by positive displacement compressors, which impart mechanical energy onto the gas, which is then converted into an increased density. Different compression technologies exist within the positive displacement category, and the application typically dictates which technology is most suitable. These technologies include reciprocal, diaphragm, hydraulic and ionic compressors.

Due to its low inherent density, high output pressures are commonly required to efficiently store hydrogen. However, there are limitations to the extent of compression during a single compression cycle and thus to achieve the high final pressures that are needed, multiple compression stages are usually required.

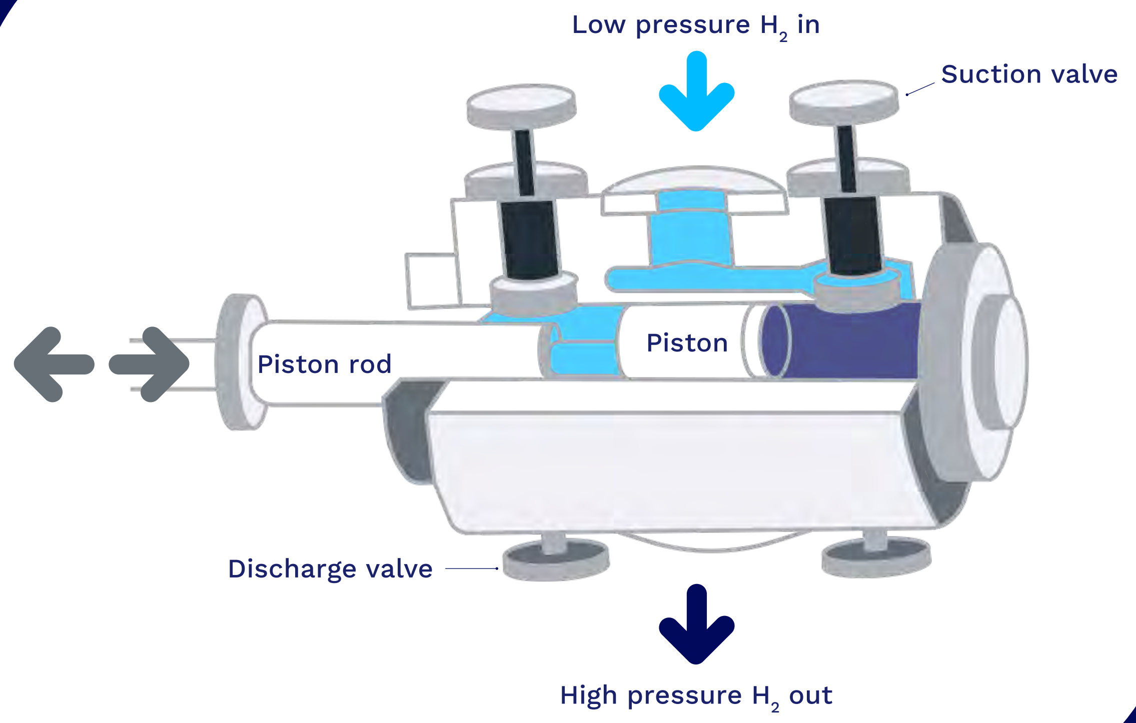
Despite hydrogen's favourable thermal properties, cooling is typically utilised in-between compression stages to reduce temperature build up in the hydrogen gas and equipment. This improves overall compression efficiency and reduces damage to compressor parts due to thermal stresses



Reciprocating Compressors

Reciprocating compressors are the most common technology used in hydrogen compression, due to their high volumetric compression rate and reliable operation both continuously and intermittently. They usually operate with lubricating oils, although non-lubricated designs exist for high purity applications. Output pressures of 400 bar can be achieved for lubricated compressors; 225 bar is typical for non-lubricated versions. Volumetric flow rates of 200,000 Nm^3/h are achievable

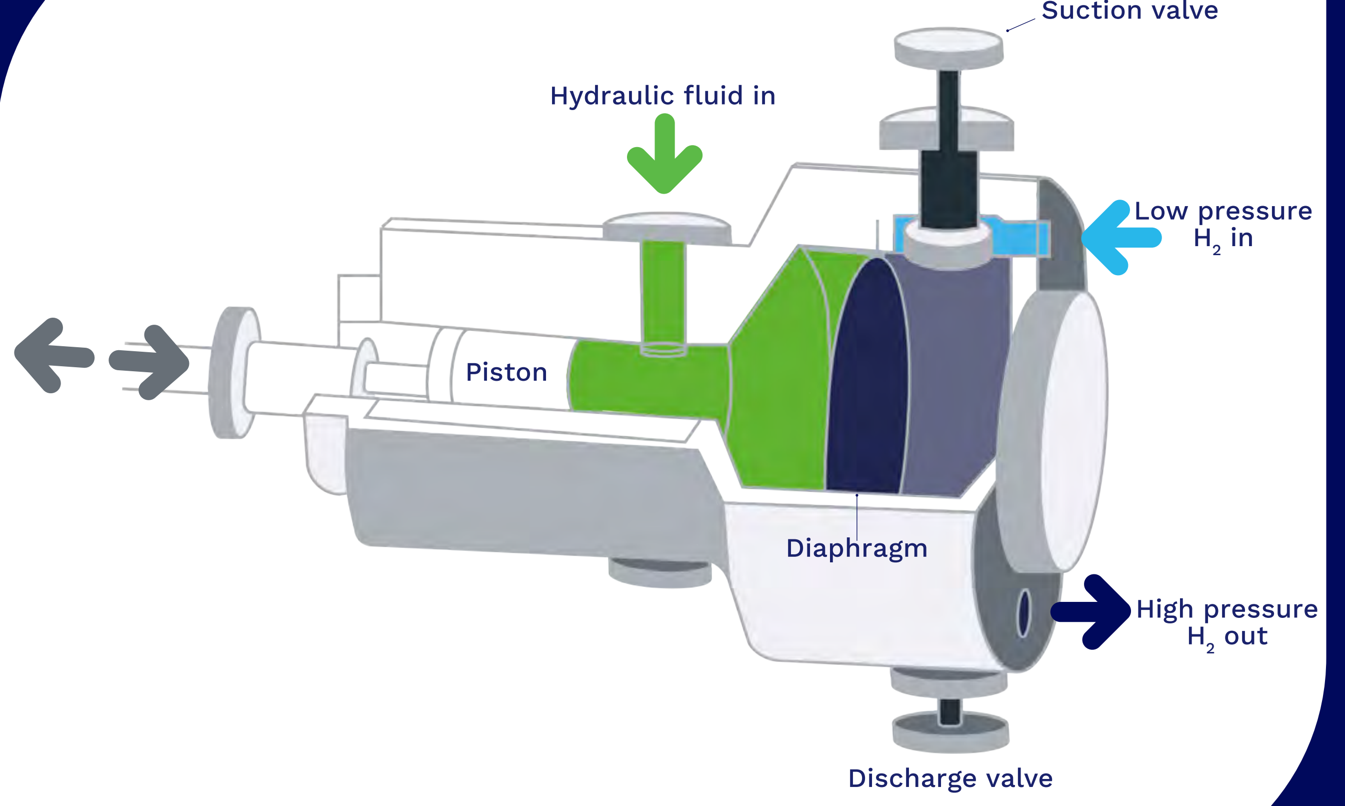
Reciprocating compressors are suitable and indeed used for many hydrogen applications, such as pipeline compression, industrial processes and geological storage



Diaphragm and hydraulic compressors

Diaphragm and hydraulic compressors are similar in operation to reciprocal compressors, but use a hydraulic fluid as the compression medium. Whilst in hydraulic compressors the hydraulic fluid and hydrogen are separated by a piston, in a diaphragm compressor separation is achieved by a multilayered membrane or diaphragm.

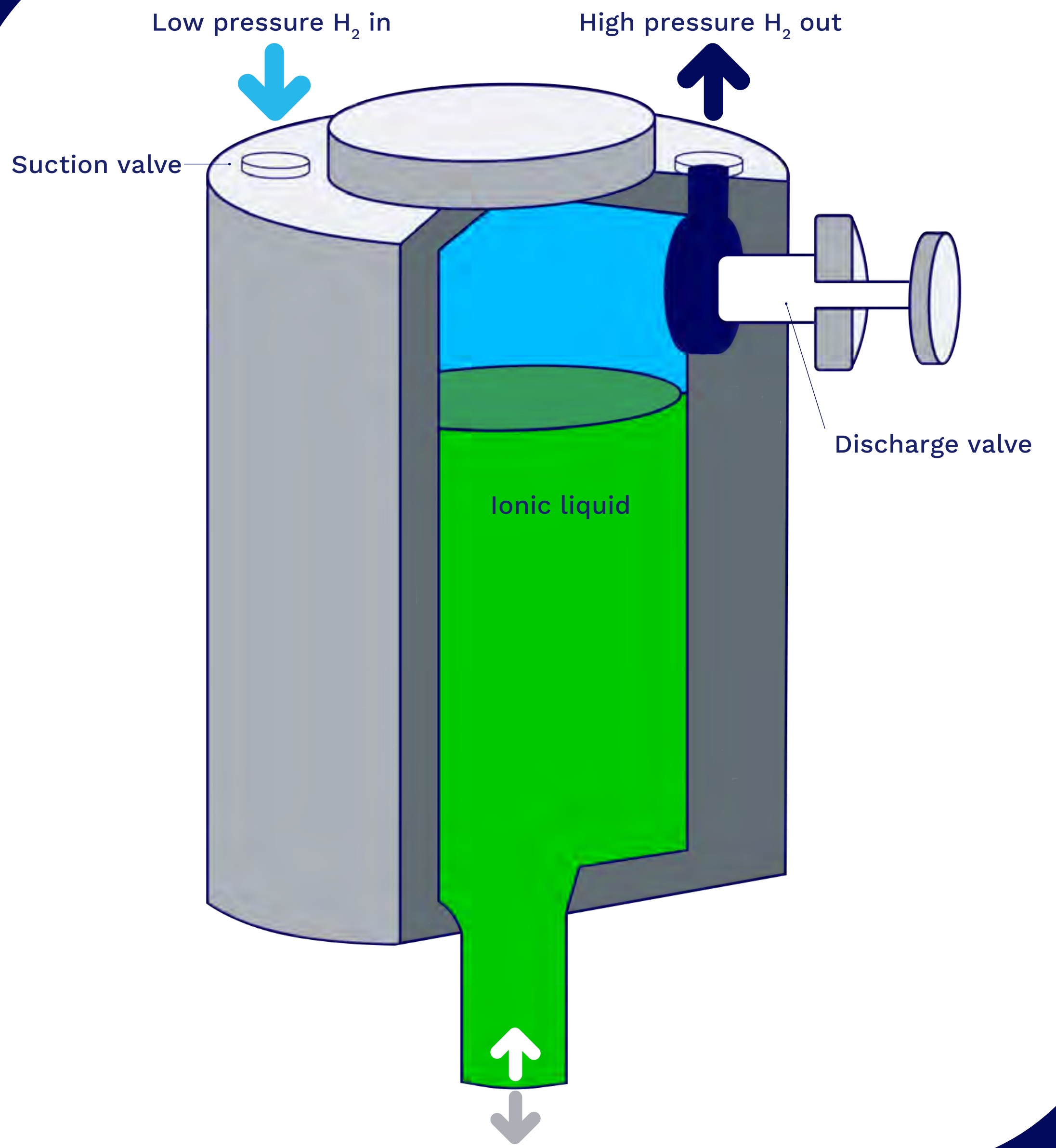
They are typically used in applications that are characterised by a requirement for both high pressure and high purity hydrogen, such as hydrogen refuelling stations. The process gas is hermetically sealed from the lubricated pars of the compressor, thus ensuring high hydrogen purity on discharge. Their volumetric flow rates are reduced as compared to reciprocating compressors, due to small swept volumes and reduced running speed, but they usually have good cooling capacity and temperature tolerance, allowing for higher compression ratios and therefore fewer compression stages. Better cooling also means higher compression efficiency, due to the process being closer to isothermal conditions. Although they are more suited for continuous operation, they can handle intermittent operation, which is typical for refuelling applications. Pressures up to 1,000 bar can typically be achieved at volumetric flows of 1,000 Nm^3/h.



Ionic compressors

Ionic compressors are similar in operation to hydraulic compressors, but use a non-volatile ionic liquid as the top section of the piston, reducing dead volume during compression and thus improving overall efficiency. This concept allows for fewer moving and wearing parts as well as good cooling characteristics, reducing overall maintenance. Like diaphragm and hydraulic compressors, they can handle high pressures up to 1,000 bar, albeit at reduced volumetric flow rates, up to c. 500 Nm^3/h. Ionic compressor are particularly suited for refuelling applications. Some ionic liquid may spill over into the hydrogen stream, but due to the non-volatile nature, separation post-compression is straightforward, ensuring high purity hydrogen.

Although not strictly required, some ionic compressor designs comprise metallic piston heads in addition to the ionic liquid, reducing the need for final separation of ionic liquid and hydrogen.



HYDROGEN COMPRESSION (1/2)

Sub-Component	Material(s)	Specifications
All Compressors		
Suction and discharge valves	Metals and a variety of polymers - for example Polyetheretherketone (PEEK) and Nylon	
Pistons	Steel	e.g AISI 316 or AISI 316L
Piston rings	Various including polymers or synthetic rubbers - for example Ethylene Propylene Diene Monomer (EPDM)	
Sealing rings	Various including polymers or synthetic rubbers - for example Ethylene Propylene Diene Monomer (EPDM)	
Piston housing	Steel	e.g AISI 316 or AISI 316L
Electric motor		
Manifolding pipework inter-stage	Steel	e.g AISI 316 or AISI 316L
Additional Components for Reciprocating Compressors		
Pressure packings		
Piston rods	Steel	e.g AISI 316 or AISI 316L
Rider	Metal or polymer for low friction contact - for example Polytetrafluoroethylene (PTFE - also known as Teflon)	
Flanges	Steel	e.g AISI 316 or AISI 316L
Lubricating oils		
Crank shaft and connecting rods		
Intercoolers inter-stage		

HYDROGEN COMPRESSION (2/2)

Sub-Component	Material(s)	Specifications
Additional Components for Diaphragm and Hydraulic Compressors		
Pressure packings		
Piston rods	Steel	e.g AISI 316 or AISI 316L
Rider	Metal or polymer for low friction contact - for example Polytetrafluoroethylene (PTFE - also known as Teflon)	
Flanges	Steel	e.g AISI 316 or AISI 316L
Crank shaft and connecting rods		
Intercoolers inter-stage		
Membranes and diaphragm materials	Multiple and different materials - metal, synthetic rubbers (for example EPDM or nitrile) and polymers	
Hydraulic/transmission fluid	Synthetic oils etc.	
Sump and pump		
Hydraulic fluid pressure limiter (pressure relief valve)		
Additional Components for Ionic Compressors		
Suitable ionic liquid	Specialist material	Typically Imidazolium based. Specialist and proprietary composition.
Hydraulic fluid and pump	Synthetic oils etc.	

Other compression technologies

Other mechanical compression technologies, such as screw and centrifugal compression are commonly used in industrial settings when handling heavier gases. They benefit from large volumetric capacities and reduced number of wearing parts, but their operation in pure hydrogen applications poses some unique challenges.

Screw compression

Screw compression is characterised by large capacity, small footprint and low discharge pressures. Compression is achieved through continuously rotating interlocking screws, thereby reducing compression chamber volume as the gas moves from suction to discharge line. Oil injection into the screws may be used for enhanced gas sealing. Although they have generally larger volumetric capacities than reciprocating compressors, they are limited to discharge pressures of c. 30 bar, making them somewhat less suitable for hydrogen storage applications. They do benefit from having a reduced number of moving and wearing parts, compared to reciprocating, diaphragm or hydraulic compressors, thus requiring less maintenance. This makes them attractive in applications that do not require high output pressures, such as gas boosting and refrigeration. They could also be considered for 1st stage compression in multi-stage compression for hydrogen storage.

Centrifugal compression

Centrifugal compression is another mature technology and has been used in hydrogen-rich applications, although its use in pure hydrogen applications has been limited. Compression is achieved dynamically by imparting kinetic energy to the inlet gas through a fast-rotating impeller. The gas then slows down on impacting and passing through a diffuser, converting kinetic into potential energy or pressure.

Centrifugal compression offers high volumetric flow rates, but output pressures are highly dependent on both impeller speed and gas molecular weight. Hydrogen's low molecular weight requires extreme rotational speeds, generating large g-forces, unsuited to most commonly used impeller blade materials. Pressure ratios therefore rarely exceed 1.1 for pure hydrogen applications, limiting their use to low pressure applications. Research and development in this field is ongoing to improve on this.

Hydrogen storage tanks overview

A hydrogen tank is a specialized container designed to store hydrogen in either gaseous or liquid form. The construction of a hydrogen tank must meet stringent physical requirements based on the pressure and temperature of storage. Key considerations for hydrogen tank design are:

- High pressure resistance, typically 200 - 700 bar, but sometimes higher
- Minimal hydrogen permeation and embrittlement
- Lightweight construction in case of mobile applications
- Safety features to prevent leaks and manage potential failures

Due to continuous improvements in materials science and manufacturing processes, hydrogen tank design has evolved over the years to address the above considerations, in particular with respect to weight reduction for mobile applications. The evolution of hydrogen tank designs is described by a Type classification, ranging from Type I to Type V, with different types having unique characteristics making them suitable for different applications.

Type I & II tanks

Type I tanks are the most basic and common hydrogen cylinder, constructed entirely from metal. The metal is usually steel or an aluminium alloy. They usually can withstand pressures up 300 bar and due to their high weight are primarily used in stationary applications, including industrial storage. Their simple design means they are relatively low cost. Overall gravimetric hydrogen density is as low as 1 wt.%

Type II cylinders are similar to Type I, that is, their basic construction consists of a metal liner, usually made of steel or aluminium, containing the hydrogen gas, but the liner is covered with a hoop wrap, usually made of carbon or glass fibre. They can withstand pressures up to c. 500 bar. The wrap provides structural strength, thereby reducing the overall amount of metal required and thus overall weight. The hoop wrap only covers part of the tank, i.e. the cylindrical face. The structural loading is split roughly 50:50 between metal tank and hoop wrap. Although the cylinder weight is somewhat reduced as compared with Type I, these cylinders are mostly used for stationary applications.

Stationary storage tanks or cylinders are usually placed on a hard, concrete surface. Cages, fencing or other means to restrict access are also required. Other support structures, such as cylinder banks, to help securely fixing cylinders in place, are common.

Type III tanks

Type III tanks comprise a metal liner, usually an aluminium alloy, completely wrapped in carbon fibre composite. The composite fibre wrap carries the full structural load, whilst the liner provides an impermeable barrier containing the hydrogen gas. This construction entails a significant weight reduction as compared to Type I and II (up to 7 wt.% H_2) and is therefore suitable for high pressure mobile applications. Type III cylinders are typically designed to operate at 350 bar, which is the current standard storage pressure in heavy duty vehicles, but occasionally can be used up to 700 bar, depending on design. Due to the more complex materials and manufacturing process, these tanks are usually too costly for stationary applications, although their tolerance for higher pressures makes them particularly suitable for stationary storage at refuelling sites.

Type IV and V tanks

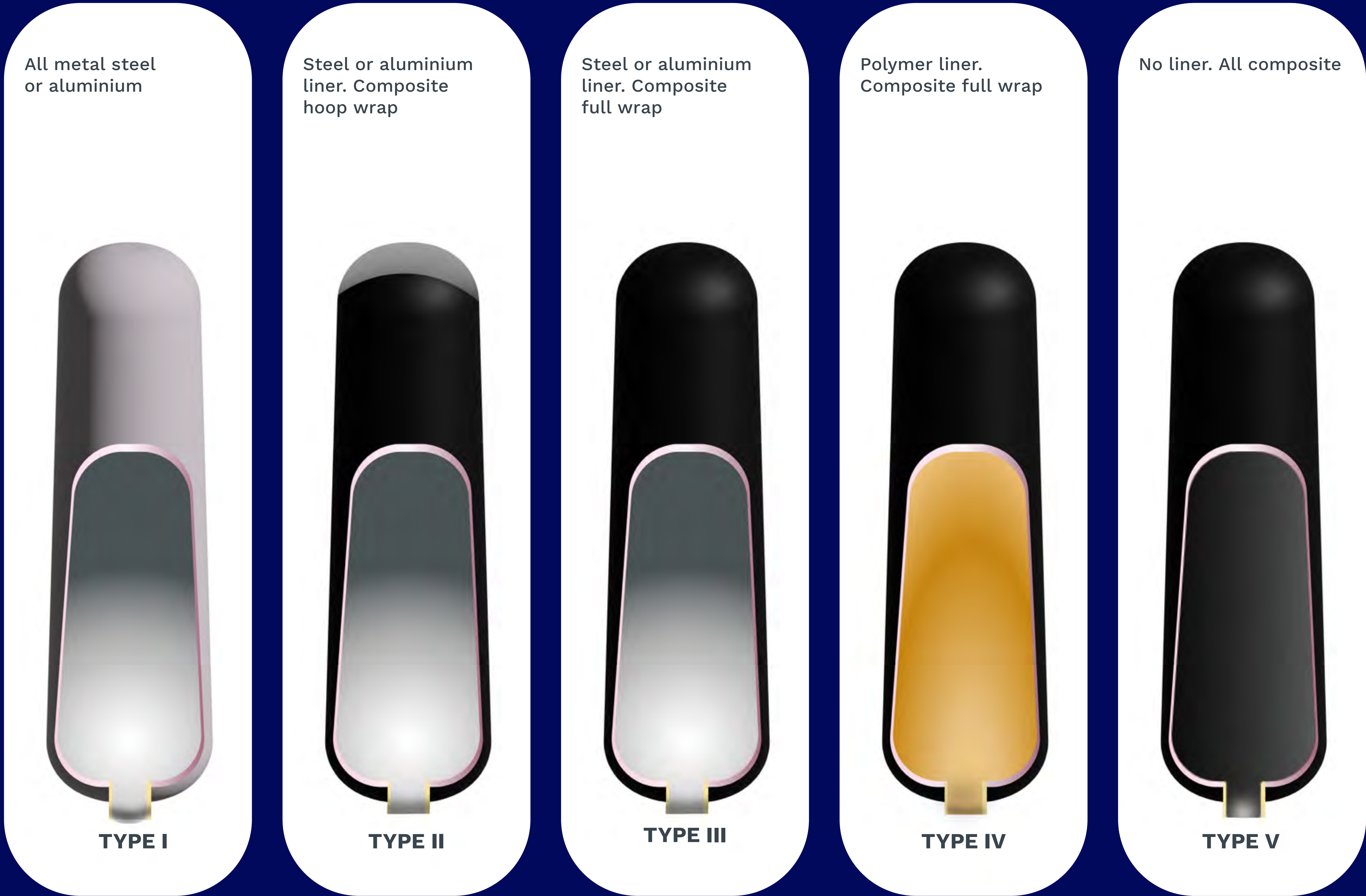
Type IV tanks enable further weight reductions as compared to Type III by using a polymer to construct the inner tank liner, thus presenting an all polymer tank. Liners are typically made of polyamide or HDPE, whilst the wrap is made of carbon fibre or a hybrid carbon/glass fibre. The construction is typically capable of withstanding pressures up 700 bar, e.g. suitable for light duty vehicles where space comes at a premium. All the structural load is carried by the composite wrap, as in Type III.

Type V tanks are an all composite cylinder without liner, currently considered for specialist applications only due to high cost and lower TRL. Thanks to advanced manufacturing techniques, including additive manufacturing, there is potential to change tank shape, moving away from cylindrical geometries, thereby improving overall packing density. Hydrogen permeation is still an ongoing challenge.

Hydrogen tanks in mobile applications

Using hydrogen tanks in mobile applications requires additional safety features (see regulations), such as leak detection, thermal sensors and thermally activate pressure relief devices to ensure safe operation. Securing the cylinders via straps or alternative means is also essential, whilst allowing for cylinder expansion/contraction during filling / dispensing is a critical design consideration.

The ISO 17519 standard which specifies the minimum requirements for the material, design construction and workmanship, manufacturing processes, examination and testing at time of manufacture of an assembly of permanently mounted composite tube(s) in a frame with associated components applies to Type III and Type IV tanks.


All metal steel or aluminium
TYPE I
Steel or aluminium liner. Composite hoop wrap
TYPE II
Steel or aluminium liner. Composite full wrap
TYPE III
Polymer liner. Composite full wrap
TYPE IV
No liner. All composite
TYPE V

Tube trailers

Hydrogen tube trailers are used to transport relatively small quantities of hydrogen by road. Currently, typical payloads are c. 300 kg, stored at 200 – 250 bar, but higher capacity trailers are under development, with potential to store up to 900 kg.

They are typically characterised by multiple cylinders stacked on a trailer. Tanks can be of different types, but due to the scale and associated costs are currently dominated by type I and II. Transition to lower weight tank construction is ongoing, with the potential of transporting larger quantities of hydrogen

Hydrogen tube trailers generally fall in either of two categories: Battery Vehicle or Multi Element Gas Containers (MEGC)and there are several standards and pieces of legislation that cover this topic:

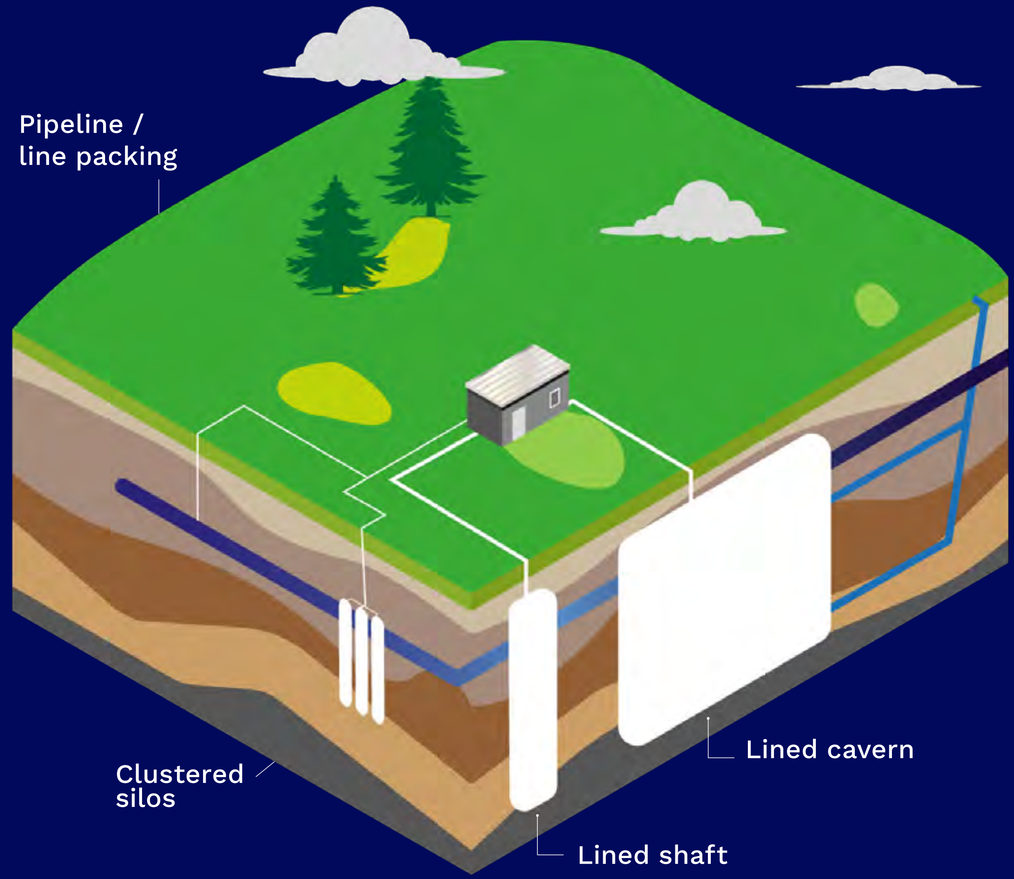
- Battery Vehicles have permanently mounted cylinders within a frame as part of the vehicle or trailer. Cylinders are manifolded but cannot be separated from the vehicle
- MEGC have cylinders that are manifolded and mounted within a frame on a trailer, but the entire assembly is autonomous and can be detached in its entirety from the vehicle or trailer
- Choice of trailer to load an MEGC is important. Carrying a 20' ISO frame on a 'swan neck' trailer provides better stability than on a short trailer

GWh scale storage

The tanks discussed so far can only store relatively small quantities of hydrogen, at the MWh scale. In a future scenario where hydrogen is distributed across the country via pipelines (see below), large scale storage (that is up c. 100 GWh or c. 3,000 tonnes of H_2) will also be required as is currently the case for natural gas. The stored gas functions as an energy reserve and is vital in accommodating any mismatches in supply and demand, addressing peak-shaving and inter-seasonal fluctuations. Underground storage is a prime candidate technology for this.

- Lined Rock Caverns – capable of storing up to 100 GWh. Geological surveys critical to assess suitability. Maximum structural homogeneity and minimum fracture density preferred. Caverns can be in excess of 100 metres in depth and several 10s of metres in diameter. Storage pressures are envisaged to be between 150 and 300 bar. Limited real-world deployment to date
- Clustered Silos – Steel, double wall tanks encased in concrete, with incompressible fluid between tank walls. Typical depth of 15 metres with a maximum storage capacity of c. 1 GWh.
- Lined Rock Shafts – similar to Lined Rock Caverns, but shafts are engineered/drilled and comprise multicomponent lining for structural integrity and to allow dissipation from the high-pressure gas, up to 200 bar. Due to drilled nature, capacity is somewhat reduced as compared to caverns, typically not exceeding 5 GWh.
- Line packing - Transmission systems are commonly used to temporarily store gas in pipelines, by pressurising them in a process called line packing.

All types of underground storage will be subject to relatively harsh pressure cycling, which must be accounted for in the design and structural supports.



COMPRESSED HYDROGEN STORAGE TANKS

Type I		Material(s)
Anciliary Components	Gauges	
	Ball valves	
	Pipework/manifolding	
Optional Components	Transducers	
	Actuated pressure relief valves	
	Actuated shut off valves	
	Temperature sensors	
Materials	Austenitic steels that cope with hydrogen embrittlement	Low carbon AISI 304L, 304 LN, 316L, 316Ti, 321, 317L
	Specialist alloys	
	Low strength steels	Preferred for better resistence against embrittlement
	Aluminium (as a tanks material)	

Type II		Material(s)
Anciliary Components	Gauges	
	Ball valves	
	Pipework/manifolding	
Optional Components	Transducers	
	Actuated pressure relief valves	
	Actuated shut off valves	
	Temperature sensors	
Materials	Austenitic steels that cope with hydrogen embrittlement	Low carbon AISI 304L, 304 LN, 316L, 316Ti, 321, 317L
	Specialist alloys	
	Low strength steels	Preferred for better resistence against embrittlement
	Aluminium (as a tanks material)	
	Carbon or glass fibre hoop wrap	

COMPRESSED HYDROGEN STORAGE TANKS

Type III		Material(s)
Anciliary Components	Gauges	
	Ball valves	
	Pipework/manifolding	
	Transducers	
	Actuated pressure relief valves	
	Temperature sensors	
	Leak detection	
	Fixings - for example straps, rubber or plastic-coated metal	
Materials	Aluminium alloy liner	AA6061 - Al plus small quantities of Mn, Fe, Mg, Si, Cu, Zn, Cr, Ti) AA7000 - Al plus small quantities of Mn, Fe, Mg, Si, Cu, Zn, O, Zr)
	Full composite (carbon fibre) wrap	

Type IV		Material(s)
Anciliary Components	Gauges	
	Ball valves	
	Pipework / manifolding	
	Transducers	
	Actuated pressure relief valves (TRPD)	
	Temperature sensors	
	Leak detection	
	Fixing (e.g. straps, rubber or plastic-coated metal)	
Materials	Polymer Lining	HDPE or Polyamide
	Full composite wrap	Carbon fibre or hybrid glass/carbon fibre

Type V		Material(s)
Anciliary Components	Gauges	
	Ball valves	
	Pipework / manifolding	
	Transducers	
	Actuated pressure relief valves (TRPD)	
	Temperature sensors	
	Leak detection	
Materials	All composite tank	Carbon fibre or hybrid glass/carbon fibre

HYDROGEN STORAGE CODES, REGULATIONS AND STANDARDS (1/2)

Organisation/Trade Association	Regulation	Details	Date of Publication
Codes of Practice			
British Compressed Gases Association	Code of Practice 4	Gas supply and distribution systems (excluding acetylene)	Revision 5: 2020
	Code of Practice 29	Battery-vehicles and multiple-element gas containers	Revision 3: 2022
	Code of Practice 33	The bulk sotrage of gaseous hydrogen at users' premises	Revision 1: 2012
	Code of Practice 34	The application of Pressure Equipment (Safety) Regulations to customer sites	Revision 2: 2024
	Guidance Note 13	DSEAR risk assesment guidance for compressed gases	Revision 1: 2021
American Society of Mechanical Engineers	Boiler and Pressure Vessel Code (BPVC)	Provides technical data used in the manufacturing, construction, and operation of boilers and pressure vessels.	Current version: 2023
Standards			
International Organisation of Standardisation	ISO 11119-1:2020, 11119-2, 11119-3, and 11119-4	Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes	Edition 3 - Published 2020
	ISO 17519:2019	Gas cylinders — Refillable permanently mounted composite tubes for transportation	Edition 1 - Published 2019
	ISO 3834-2	Quality requirements for fusion welding of metallic materials	Edition 3 - Published 2021
	ISO 11114	Gas cylinders — Compatibility of cylinder and valve materials with gas contents	Edition 3 - Published 2020
	ISO 1496-3:2019	"Series 1 freight containers — Specification and testing Part 3: Tank containers for liquids, gases and pressurised dry bulk"	Edition 5 - Published 2019
	ISO 17089-1:2019	Measurement of fluid flow in closed conduits — Ultrasonic meters for gas	Edition 2 - Published 2019
	ISO 5167 Series	Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full	Edition 3 - Published 2022
	ISO 9951:1993	Measurement of gas flow in closed conduits — Turbine meters	Edition 1 - Published 1993
	ISO 10790:2015	Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of Coriolis flowmeters (mass flow, density and volume flow measurements)	Edition 3 - Published 2015
British Standards Institution	BS EN 13445	A multi-part European standard (EN 13445) that specifies requirements for the design, construction, inspection and testing of unfired pressure vessels made from steels and steel castings as well as additional materials such as cast iron, aluminium, nickel, titan and copper.	Introduced in 2002 and updated 2009-2012
	BS EN 13807	Specifies the requirements for the design, manufacture, identification and testing of battery vehicles and multiple-element gas containers (MEGCs) containing cylinders, tubes or bundles of cylinders.	Published 2017

HYDROGEN STORAGE CODES, REGULATIONS AND STANDARDS (2/2)

Organisation/Trade Association	Regulation	Details	Date of Publication
Directives			
Health and Safety Executive	ATEX - 2014/34/EU	Two EU directives which describe the minium safety requiements for workplaces and exquipment used in explosive atmoshperes - ATEX Workplace Directive and the ATEX Equipment Directive	Published in 2014 and applicable from 2016
Health and Safety Executive	Dangerous Substances and Explosive Atmospheres Regulations 2002	Require employers to control the risks to safety from fire, explosions and substances corrosive to metal	Published 2002
Health and Safety Executive	Control of Major Accident Hazards (COMAH)	Regulations to ensure that businesses take all necessary measures to prevent major accidents involving dangerous substances and limit the consequences to people and the environment of any major accidents which do occur	Published 2015
UK Government	SI 1192 656 - The Planning (Hazardous Substances) Regulations 1992	These Regulations are made under the Planning (Hazardous Substances) Act 1990. That Act provides that the presence of or above the controlled quantity of a hazardous substance on, over or under land, requires hazardous substances consent.	Published 1992
European Commission	Pressure Equipment Directive (PED) - 2014/68/EU	Applies to the design, manufacture and conformity assessment of stationary pressure equipment with a maximum allowable pressure greater than 0.5 bar.	Current consolidated version: 2014
European Parliament	Transportable Pressure Equipment Directive (TPED) - 2010/35/EU	Addresses the safety requirements and the conformity assessment procedure for transportable pressure equipment used exclusively for the transport of dangerous goods (Class 2) within the EU.	Published 2010
Economic Commission for Europe of the United Nations	UN/ECE Regulation 134	Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV)	Published 2019
Economic Commission for Europe of the United Nations	ADR 2023 - Agreement concerning the International Carriage of Dangerous Goods by Road	Aims to regulate the international transport of dangerous goods by road between the UNECE Member States and other states that apply ADR (ADR contracting parties)	Applicable from January 2023

Hydrogen pipeline overview

Distribution of hydrogen by pipeline is expected to become mainstream, in particular when large quantities of gas are involved. This fact sheet focuses on distribution by a national network of pipelines, analogous to the network that is currently utilised for moving natural gas. This network comprises gas terminals, a backbone called the National Transmission System and the Local Transmission System for distribution to individual consumers, as well as bulk storage facilities.

Although it is envisaged that a hydrogen pipeline network will operate in a similar manner, there will be differences, due to a more decentralised domestic production of hydrogen as compared to natural gas, which is predominantly produced offshore or imported, with both entering the gas grid through a small number of terminals. Hydrogen is expected to be produced co-located with renewables, which are likely to be in areas of limited population density, requiring new pipelines to enable entry into a hydrogen gas grid. Repurposing the existing grid is also envisaged and early tests to check the suitability of the grid to accommodate pure hydrogen appear to be in support of this approach.

AI generated image of H_2 pipeline

Hydrogen Pipelines

Pipeline sections

Pipeline sections of up to 1050mm diameter are traditionally fabricated using high grade steel, suitable for operation in pure hydrogen. Oil and gas pipelines are commonly fabricated using carbon steels, such as API 5L X42, X50, X60 etc.. Only the lower strength steels in this range are suitable for hydrogen, i.e. X50 and lower, due to risk of embrittlement in higher strength steels, in accordance with EIGA guideline IGC Doc121/14. Pipeline sections are joined by a suitable welding technique (e.g. orbital) once moved in place.

Normalised, quenched/tempered and thermo-mechanically rolled used as appropriate for the material. Lower strength stainless steels should be considered for new pipelines, for instance 316 L or 304 L.

Pipeline operating conditions

The National Transmission System currently operates at pressures up to 85 bar, but this can vary depending on supply and demand and temperature variations. Due to this variability, pipelines (and any componentry in line) need to be able to operate in a large range of pressures and, in particular, they need to be able to withstand rapid cyclic pressurisation and depressurisation in hydrogen atmosphere. The equivalent NG standard for cyclic testing is covered in IGEM/TD/2

IGEM/TD standards currently cover operation in hydrogen between –20 to 120°C and pressures between 7 and 100 bar.

Small commercial and domestic supply lines operate at lower pressure, typically less than 7 bar, for which there is scope to use non-metallic materials, such as Polyethylene (PE80 or PE100, as appropriate for operating conditions). PE80 suitable for temperatures down to –20°C.

Compression stations

Compression stations are required on the pipeline network to compensate for pressure drops due to friction and gas offtake. Compressors on the natural gas grid operate with a relatively small pressure ratio of around 1.4, which avoids thermal effects and thus the requirement for cooling post compression. A variety of compression technologies could be considered when transitioning to hydrogen, but the large volumetric flow rates and small pressure ratios required would probably favour reciprocating or centrifugal compressors.

Hydrogen metering

Hydrogen metering in industrial-scale gas pipelines is essential for accurate flow measurement, safety, and efficiency in hydrogen infrastructure. Flow metering technology helps optimise pipeline distribution, manage system integrity, and ensure compliance with industry standards.

Multiple technologies are used for the measurement of industrial gases. Some technologies have been around for a long time such as differential pressure, turbine, and rotary meters. In recent years, there has been a tendency towards replacing these meters with newer technologies such as ultrasonic and Coriolis meters. Many of the same technologies are expected to be used with hydrogen, however, adaptations will be needed due to the fluid properties of hydrogen which can make flow measurement of hydrogen particularly challenging.

Relevant standards relating to flow measurement include ISO 5167 Series, ISO 17089-1:2019, ISO 9951:1993 and ISO 10790:2015

HYDROGEN METERING

Common Meter Types	Behaviour in Hydrogen vs Other Gases
Differential Pressure	Performance minimally impacted; dependes primarily on Reynolds number.
Turbine Meters	Turbine meter primarily sensitive to Reynolds number, but also gas density and viscosity. Perfomance for hydrogen will differ from other gases but it should be possible to apply a correction.
Rotary Meters	Rotary meters are relatively insensitive to changes in gas fluid properties. Some additional errors are expected with hydrogen however, due to the extremelt low density and propensity to leak through small gaps (slippage).
Coriolis	Potentially less accurate at low operating pressures due to very low density of hydrogen. At higher pressure, accuracy is expected to be similar to other fluids (natural gas, air, water etc).
Ultrasonic	Acoustic properties of hydrogen impact transducer response; specialised calibration needed for accuracy

Pipeline standards

The IGEM/TD series are relevant industrial standards covering construction, operation, maintenance of high-pressure onshore pipelines (incl. pure hydrogen and hydrogen blended with natural gas, with minimal hydrogen content 10%). The various standards within the series cover operation in hydrogen between –20 to 120°C and mean operating pressures between 7 and 100 bar.

Additional supplements and standards are available for systems operating at pressures below 7 bar, which is particularly relevant for (repurposing) domestic supply lines. This includes using non-metallic materials. Hydrogen pipeline operation is based on latest information and is regularly updated.

The IGEM/TD series also suggests relevant standards to be used for pipeline componentry, such as valves, but also regarding protective coatings applied to componentry.

Relevant standards are API 5L/EN ISO 3183 for the material grade and fabrication of steel pipes. Steel grades selected based on their mechanical properties. Non-metallic options available for low pressure systems, e.g. PE80 and PE100.

Bends and tees should follow BS1640-1 standard or equivalent.

Other relevant standards include The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2016 (UKEX), The Pressure Equipment (Safety) Regulations 2016, ATEX Directive 2014/34/EU, ATEX Workplace Directive 1999/92/EC & Pressure Equipment Directive (PED 2014/68/EU).

Additional Pipeline Componentry

Safely and efficiently operating a gas distribution network involves a host of components and equipment, listed here:

- Flanges
- Ball valves
- Regulators - pressure reduction skids
- Metering (ultrasonic, coriolis, etc.)
- Non return valves
- Flow control valves
- Flow arrestors
- Filters
- Pipeline sections - various diameters
- Heat exchangers
- Hydrogen compression, e.g. reciprocating or centrifugal
- Monitoring equipment - pressure gauges (absolute and differential)
- Temperature sensors (with HX)
- Control systems - SCADA etc.(supervisory control and Data Acquisition)
- Handheld leak detectors for maintenance
- Ultrasound monitoring for mechanical integrity, etc.

Further Supply Chain Opportunities

Compression

- Metal machining
- Precision machining
- Robot assisted manufacturing
- Additive manufacturing (polymer parts)

Tanks

- Forging
- Deep drawing
- Welding for MEGC metallic parts – EN ISO 3834-2
- Filament winding of carbon/fibre glass
- Automated fibre placement for carbon fibre
- Rotational moulding or blow moulding for polymer liners
- Advanced composite layup techniques, including in situ consolidated thermoplastic composites. Specialised manufacturing

Pipelines

- Welding (BS 4515-1)
- Steel manufacture
- Steel machining
- Polymer pipeline manufacture and fabrication (extrusion)
- Protective coatings for metals (corrosion protection)

There will also be supply chain opportunities for companies with experience in installation and the ongoing maintenance of tanks, pipelines and compressors, taking into account hydrogen unique physical properties, for instance paying attention to leak free manifolding during installations. Maintenance may involve periodic inspections and non-invasive testing of pipelines, welds, valves, etc.

We would like to thank TÜV SÜD for providing input on hydrogen standards and content on hydrogen metering

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