Flagship Project
TransHyDE

Kickstarters for a hydrogen economy

Innovations and innovative services out of the TransHyDE Projects

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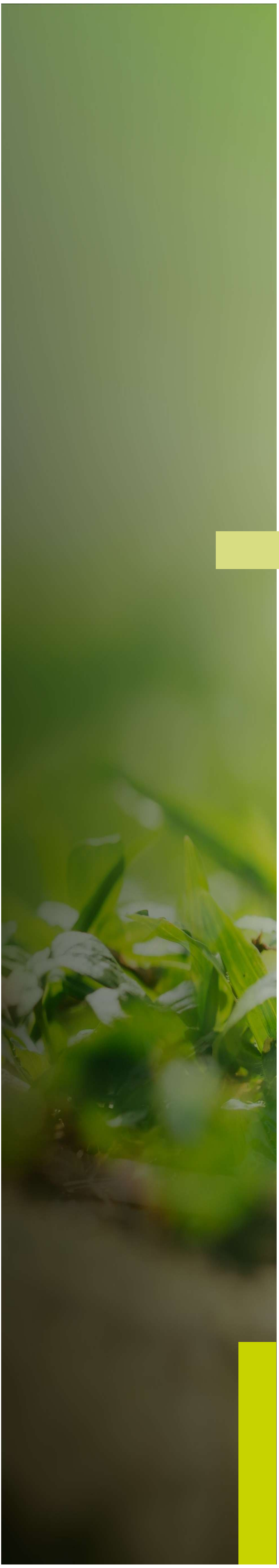

TransHyDE

Transport and storage infrastructure for green hydrogen

This brochure gives you an overview of concrete results that our TransHyDE partners have produced during the project period so far. These can be, for example, techno-economic innovations or innovative services for a hydrogen economy. The brochure is to be regarded as a dynamically evolving document that will be supplemented to as the project progresses.

Key data

Funding: approx. 145 m. euro
Partners: 89
Associated partners: 20
Project duration: 04.2021 – 03.2025

Background of the hydrogen flagship project TransHyDE

The National Hydrogen Strategy (NWS) envisages security of supply through intra-European production as well as diversification and securing international imports of hydrogen. This inevitably results in the need for a supra-regional transport and storage infrastructure for the energy carrier.

At this point, TransHyDE, as one of the three hydrogen flagship projects funded by the Federal Ministry of Education and Research (BMBF) (alongside H_2Giga - series production of electrolysers; and H_2Mare - green offshore hydrogen and power-to-x production from wind turbines), makes a key contribution to the implementation of the NWS.

A total of 109 partners and other associated partners are working on ten projects to overcome the technological and economic obstacles that are currently hampering the efficient transport and storage of green hydrogen. The BMBF's funding for TransHyDE totals around 145 million euros over a period of four years. The technical focus of TransHyDE is on four different transport options: gaseous hydrogen (gH_2), liquid hydrogen (LH_2), ammonia (NH_3) and liquid organic hydrogen carriers (LOHC). TransHyDE also analyses the regulatory framework and makes recommendations for an accelerated ramp-up of the hydrogen economy.

TransHyDE Projects

Research Projects

1

System Analysis deals with the systemic analysis of transport solutions for hydrogen. The core task is the representation of the spatial and temporal development of the transport infrastructure for hydrogen from the perspective of the energy-intensive industry as well as the optimisation of economic costs. The roadmap developed in the project summarises the scientific-technical project progress, the systemic classification of the transport technologies and the resulting statements.

2

Safe Infrastructure develops and demonstrates materials and engineering principles to ensure the safe operation of a hydrogen pipeline network. This involves modifying component designs, enhancing material mechanics and metrology, allowing for the testing of existing natural gas pipelines for H_2 suitability and safe utilisation in H_2 applications. Additionally, Safe Infrastructure also focuses on developing new products suitable for hydrogen applications.

3

AmmoRef investigates and develops an application oriented, industrially feasible, safe and cost-effective technology for ammonia reforming, that is the recovery of pure hydrogen, in order to ensure an environmentally friendly, economical and safe solution for the future energy supply.

4

AppLHy! analyses and applies various technologies for the supply, efficient storage and transport of liquid hydrogen (LH_2). The works include hydrogen liquefaction, contactless level measurement and pumping, synergetic transport (LH_2 and superconductivity) and utilisation of cold.

5

Standardisation collates a status quo of technical standards and develops a needs analysis and recommendations for action to close gaps in standardisation and certification.

6

LNG2Hydrogen develops a scientifically sound collation of data and formulates recommendations as a basis for decision-making to enable sustainable and long-term usage of LNG terminals as logistic hubs for hydrogen and its derivatives (H_2 transport vectors). Additionally, further research and development needs are identified.

TransHyDE Projects

Implementation Pillars

A

Mukran investigates storage and transport of gaseous hydrogen in order to supply consumers who are not connected to a H_2 pipeline network. Moreover, spherical storage vessels are being developed that are characterised by an optimal compromise between load- and material-appropriate geometry as well as low manufacturing and operating costs and thus enable efficient transport with a high payload ratio.

B

GET H_2 TransHyDE supports the development of pipeline-based transport infrastructure for hydrogen, essential infrastructure and operational issues are being addressed. In this regard, scientific and technical work objectives are being pursued along the entire transport chain from feed-in of green hydrogen to feed-out.

C

CAMPFIRE develops the entire ammonia (NH_3) value chain, from production to storage, transport and usage. This includes stationary and mobile applications, fuelling stations, logistics and infrastructure as well as regulatory framework and acceptance.

D

Helgoland researches a ship-based hydrogen supply chain from the offshore area in the Schleswig-Holstein coastal sea to the hydrogen consumers on the mainland. In this supply chain, the example of Heligoland will be investigated as a model location for safely storing hydrogen via hydrogenation in LOHC (Liquid Organic Hydrogen Carriers) based on the thermal oil benzyl-toluene, and Hamburg as a location for releasing hydrogen from this LOHC via dehydrogenation.

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Innovations and innovative services regarding gaseous hydrogen

TwinLoop – the innovative test bench

RMA Rheinau GmbH & Co. KG

Partner of the TransHyDE project Safe Infrastructure

RMA high-pressure test bench with hydrogen

Contrary to common belief, gas is not simply gas. Hydrogen in particular behaves differently from conventional gases such as natural gas when it comes to gas volume determination. This is exactly where the H_2 test bench comes into play: As a specially designed high-pressure gas test bench for flow meters, it enables the precise determination of hydrogen gas quantities. The hydrogen test bench can now be used to calibrate gas meters with flow rates of up to 6,500 m^3/h of pure hydrogen at 51 bar pressure. Together with the natural gas test bench, the hydrogen test bench forms the new twin pair, the TwinLoop.

Our path to hydrogen

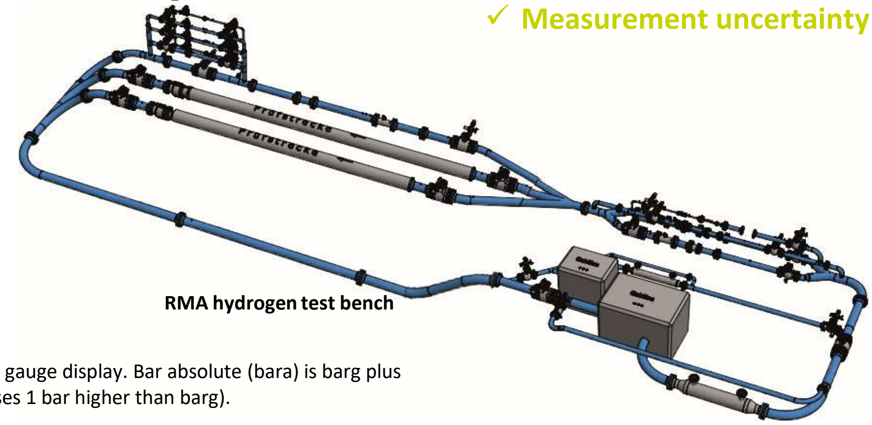
RMA recognised the importance of hydrogen for a successful energy transition at an early stage. Since the climate conference in 2015, we have been working continuously to adapt our product portfolio to the requirements of hydrogen technology. In 2019, this resulted in the development of "H_2-Ready" fittings and the conception of the H_2-Loop.

Together for a secure future

As coordinator of the TransHyDE project Safe Infrastructure, we are part of a national strategy to develop and demonstrate technologies for hydrogen transport. In addition to the development of safe components for a hydrogen infrastructure and sensors for monitoring hydrogen storage facilities, pipelines and connection points, our central goal was the development and commissioning of a calibratable hydrogen test bench.

THE FACTS

- ✓ **Calibratable hydrogen test bench**
- ✓ **Continuous verification of the H_2 purity**
- ✓ **Calibration of gas meters**
- ✓ **Flow rate: 5 – 6,500 m^3/h**
- ✓ **Pressure[3]: 8 - 51 bara**
- ✓ **Nominal sizes from DN 50 to DN 300**
- ✓ **2 measuring sections 11 m each**
- ✓ **Measurement uncertainty: 0.2 – 0.3 %**



RMA hydrogen test bench

[3] Bar display (barg) is the pressure gauge display. Bar absolute (bara) is barg plus atmospheric pressure (in most cases 1 bar higher than barg).

H_2 test bench

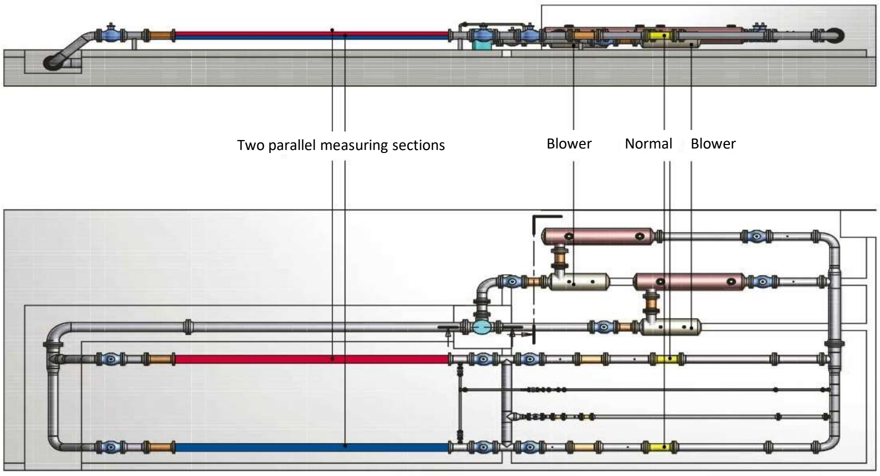
Natural gas test bench

With our test equipment the following devices can be measured and calibrated:

- ✓ **Volumetric gas meters**
  - Rotary displacement gas meter
- ✓ **Flow gas meters**
  - Ultrasonic gas meter
  - Vortex gas meter
  - Turbine gas meter
- ✓ **State volume corrector and additional devices**

THE FACTS

- ✓ Calibratable natural gas test bench
- ✓ Constant gas quality
- ✓ Gas meter calibration
- ✓ Flow rate: 3 – 13,000 m^3/h
- ✓ Pressure: 1 - 51 bara
- ✓ Nominal sizes from DN 50 to DN 500
- ✓ 2 Measuring sections 12 m each
- ✓ Measurement uncertainty: 0.25 % – 0.30 %



RMA natural gas high-pressure test bench

RMA high-pressure test bench with natural gas

As a long-standing and reliable supplier and partner for gas supply and industry, we offer a wide range of products and services. Our “state-approved test center for measuring instruments for gas” is a central component in our claim to be able to offer our customers a complete system. In addition to a test bench with air and hydrogen, we also have a state-of-the-art high-pressure test bench for gas measuring instruments.

This high-pressure test bench is used to adjust and calibrate. In addition, this test equipment can also be used for demanding measurement series as part of a product development or type examination.

Due to the state recognition of our test facility, the measuring equipment is subject to regular monitoring by the responsible weights and measures office, which works in close cooperation with the National Metrology Institute (Physikalisch-Technische Bundesanstalt, PTB) in Braunschweig.

National standards and other transfer standards are the basis of our test bench. This ensures a high level of safety as well as reliable measurement accuracy.

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Endress+Hauser
People for Process Automation

Real-time quality measurements by laser-based photoacoustic spectroscopy

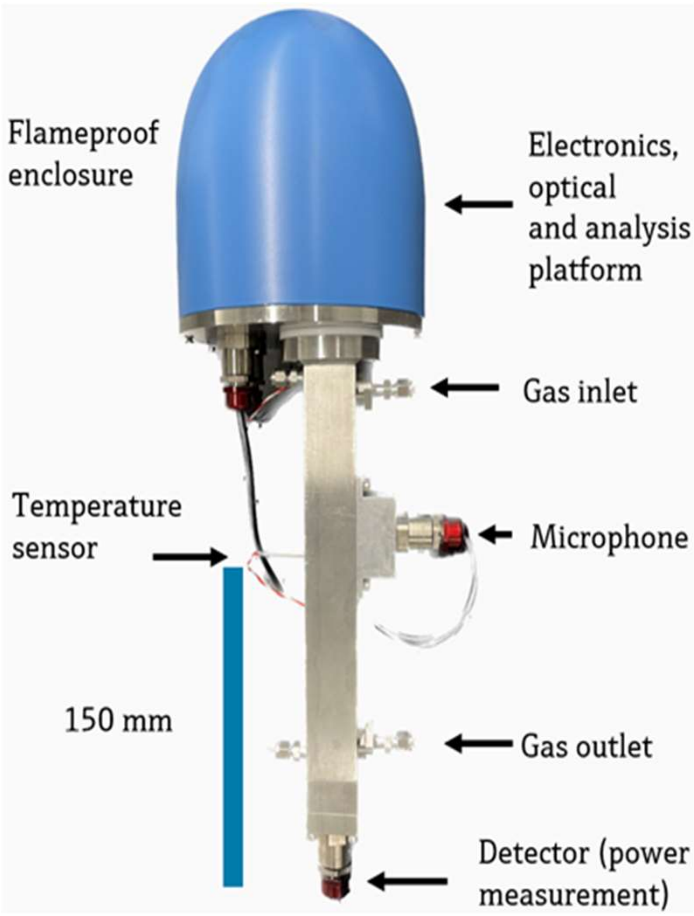
Endress + Hauser Digital Solutions (Deutschland) GmbH

Partner of the TransHyDE project Safe Infrastructure

As part of the TransHyDE joint project Safe Infrastructure, Endress + Hauser's Sensor Automation Lab is developing measurement technology for gas quality analysis and leakage detection.
The project focuses on the prerequisites for converting natural gas infrastructure (components, pipelines and storage facilities) for hydrogen use. Among others, components will be tested in pure hydrogen and a test pipeline as well as a calibratable H_2 test loop will be installed. The aim is to understand which materials are suitable and how the existing infrastructure can continue to be used and operated safely. We also investigate the influence of transport and storage on hydrogen purity.

The hydrogen used today comes from a variety of different sources

The origin of hydrogen is titled with different colors: green hydrogen is produced exclusively from renewable energy sources, and turquoise hydrogen is produced by methane pyrolysis, in which methane is broken down into solid carbon and hydrogen in a thermochemical process. In the case of gray hydrogen, production takes place using fossil energy sources. If the resulting CO_2 is stored using carbon capture storage (CCS) technology or is further processed in industry, it is referred to as blue hydrogen. Hydrogen also occurs as a by-product in the chemical industry, e.g. in chlorine production. In order to be able to check the quality of the hydrogen after or during its transport, regardless of its origin, new measurement technology is necessary. Our focus is on the measurement of the components carbon monoxide (CO) or ammonia (NH_3) and moisture in hydrogen.



Prototype of the photoacoustic gas analyser

Advantages at a glance

- ✓ Precise, repeatable and fast measurements
- ✓ Low maintenance efforts, low cost
- ✓ Reliable, even in harsh environments
- ✓ Real-time measurements with smallest quantities
- ✓ No cross-sensitivity
- ✓ Simultaneous measurement of two impurity gases in one instrument

CO, NH_3 and H_2O impurities in hydrogen

Fuel cell catalysts are sensitive to impurities such as carbon monoxide, which can be produced by steam reforming during manufacture. If the carbon monoxide content is too high, the efficiency of the fuel cell decreases. With regard to aging CO also has a negative effect on its stability.

In contrast, too high humidity content can among others promote corrosion of the infrastructure. Therefore, the maximum permitted humidity concentration is limited to 5 ppm (parts per million[1]). Humidity contamination can occur during electrolysis, storage or transport.

If hydrogen is to be reconverted from NH_3 (as H_2 transport medium), ammonia may remain as a contaminant. NH_3 is highly corrosive and toxic. It may only be present in H_2 at a maximum of 100 ppb (parts per billion[2]). The required measurement accuracy here is 5 ppb. The corresponding standard for H_2 as a fuel (ISO 14687) specifies limits for various impurities. For CO this limit is 200 ppb, for moisture 5 ppm and for NH_3 100 ppb. With our photoacoustic analyser we can measure these impurities online with the necessary accuracy.

H_2-quality-analyser prototype

Photoacoustic spectroscopy (PAS) can be used to detect gases very precisely and selectively. The basic measurement principle was described by Alexander Graham Bell in 1880. When the gas sample to be examined is illuminated by a pulsed light source in the measuring cell, the gas molecules absorb the light and heat up as a result. At a constant volume size of the measuring cell, an acoustic wave is generated with a frequency corresponding to the modulation frequency of the light source. These acoustic waves or opto-acoustic signals are transmitted to acoustic transducers (for example commercially available MEMS micro-phones). The signal amplitude then correlates with the intensity of absorption which provides information about the gas concentration in the measuring cell.

Based on this measurement principle, we have developed a prototype of a hydrogen purity sensor. The prototype is able to detect two impurity-gases in hydrogen at a time, CO or NH_3 in addition to H_2O. In order to avoid ignition in case of a leakage, the prototype is equipped with an explosion proof housing. The analyser is able to perform autonomous online measurements.

Our prototype is currently been tested in field campaigns of partners within the TransHyDE consortium.

Target gases	CO, NH_3 and H_2O
Carrier gas	H_2
Measurement principle	Photoacoustic spectroscopy (PAS)
Measurement range	CO: 0 to 100 ppmv H_2O: 0,05 to 5,000 ppmv
Reproducibility	CO: ±5 ppbv or ±1 % of reading H_2O: ±15 ppbv or ±1 % of reading
Limit of detection (3σ)	CO: 20 ppbv H_2O: 100 ppbv

Preliminary specification

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[1] The term parts per million stands for a factor of 10^{-6} or one millionth. When supplemented with a v, it refers to the volume.
[2] The term parts per billion stands for the factor 10^{-9} or one billionth. When supplemented with a v, it refers to the volume.

Lifetime assessment of H_2 infrastructure components: materials testing using novel autoclave technologies

Fraunhofer Institute for Mechanics of Materials IWM

Partner of the TransHyDE project Safe Infrastructure

Lifetime concepts for hydrogen products used in hydrogen infrastructure

Safe, reliable and durable components of the hydrogen infrastructure are a prerequisite for the success of the energy transition. Comprehensive lifetime predictions are therefore essential. The Fraunhofer Institute for Mechanics of Materials IWM is one of the world's leading institutions for the multiscale characterisation and evaluation of material properties: from atomistics to the continuum. Based on these findings, first-class modelling and simulation tools are developped for industrial component design, also specifically for hydrogen applications.

Dealing with hydrogen requires new material test methods

Under mechanical stress, steel behaves differently in a hydrogen gas atmosphere than in a natural gas environment. The reason for this lies in the properties of hydrogen. As the smallest atom in the periodic table of elements, hydrogen can penetrate materials as atomic hydrogen under certain conditions and negatively influence their performance under mechanical stress. This phenomenon is called hydrogen embrittlement and can lead to a shortened service life of the affected components in use.

However, the mechanisms of hydrogen embrittlement are still not fully understood and are being intensively investigated. To further research the influence of hydrogen on materials, the Fraunhofer IWM has co-developed a new type of testing machine, the so-called HypA-1000 high-pressure hydrogen autoclave. The HypA-1000 fulfils all requirements for precise material testing with standard specimens for tensile tests, crack toughness, crack propagation and fatigue tests in a hydrogen atmosphere up to 1,000 bar (100 MPa).

However, the very high pressure and large volume of the HypA-1000 require a high level of technical expertise in order to maintain constant test conditions in terms of pressure and temperature. In addition, strict safety regulations must be adhered to in order to prevent the formation of explosive oxygen-hydrogen gas mixtures due to leaks. This requires an enormous technical effort and causes higher costs compared to tests under standard laboratory conditions.

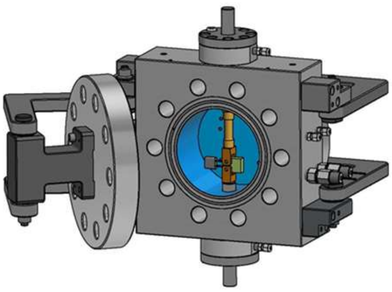
However, fast and cost-effective measurements are a prerequisite for the rapid implementation of a hydrogen infrastructure in order to successfully master the energy transition in the coming years. Testing technologies for materials that are adapted to the new market requirements are therefore urgently needed in order to minimise analysis costs and maximise output at the same time. The Fraunhofer IWM has recognised this need and is implementing it as part of the TransHyDE hydrogen flagship project.

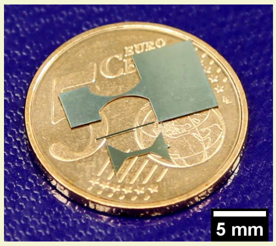
Accordingly, two new, precision-fit systems are currently being set up to investigate the influence of hydrogen on materials under mechanical stress: the HypA-200FCG high-pressure autoclave, which operates at up to 200 bar (20 MPa) and was specially developed for carrying out fatigue crack growth (FCG) tests. And the HypA-100µ, a low-volume autoclave for characterising material properties at a very local level (e. g. weld seams) using samples in the micrometre range. Both systems benefit from the reduction of the internal volume of the autoclave. This leads to the use of smaller quantities of hydrogen and thus to a significantly lower safety risk. These machines can therefore be used in standard laboratory environments with greatly reduced safe ty precautions.

New testing machines for fast and cost-effective recording of material data

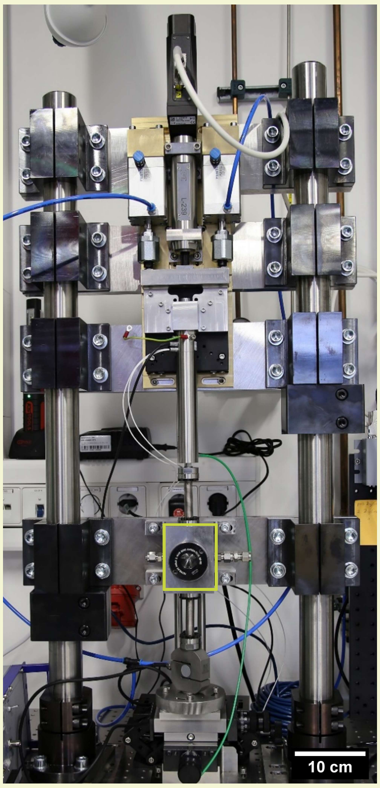
All systems, the HypA-1000, the HypA-200FCG and the HypA-100µ, enable customised product development, provide data for lifetime assessment of existing components and enable product safety through better knowledge of material performance.

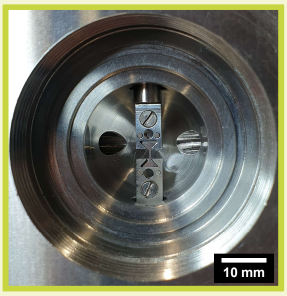
The HypA-200-FCG was developed as part of the TransHyDE project Safe Infrastructure to perform fast and cost-effective crack growth tests by limiting the safety-relevant hydrogen volume to less than 200 bar*litres. The HypA-100µ provides quasi-static tensile, fatigue and fracture mechanics testing in-situ at up to 100 bar hydrogen pressure. Microsamples are used to characterise material properties on a small length scale. The HypA-100µ is funded by two hydrogen flagship projects of the BMBF: the H_2Mare project H_2Wind and the TransHyDE project Safe Infrastructure.





Size comparison of a microsample





The HypA-100µ setup for H_2 in-situ tests on microsamples Zoom: Microsample mounted in specimen holders.

The HypA-200FCG and its specification

- ✓ Electro-mechanical test machine
- ✓ Hydrogen pressure up to 180 bar
- ✓ Room temperature
- ✓ Fracture mechanics and fatigue crack growth testing
- ✓ Optimised for 0.5T CT (CT25) specimens
- ✓ Cyclic frequency up to 1 Hz

Why analyse microsamples?

Micro specimens, i.e. tensile specimens with a cross-section of less than 1 mm², are ideal for characterising small components (e.g. springs, membranes, electronic parts) and for analysing local mechanical properties of larger components (e.g. weld seams). Thanks to high-precision extraction techniques, local measurements can be taken in critical areas with high spatial resolution.Due to the small sample volume and the high-resolution imaging of the sample surface, microsamples provide new insights into mechanical failure mechanisms, even under the influence of hydrogen. The results collected on microsamples complementary to macrosamples thus contribute to the material models and service life concepts developed at the Fraunhofer IWM.

Funding with the right focus

The TransHyDE project Safe Infrastructure develops and demonstrates materials and technical principles for the safe operation of a hydrogen infrastructure. This means that components are continuously modified, material mechanics and measurement technology are improved and existing natural gas pipelines are tested for their H_2 suitability. In addition, the project is focussing on the development of new products for hydrogen infrastructure applications. The Fraunhofer IWM is proud to be part of this consortium in order to increase product safety, develop concepts for predicting the service life of materials and components for hydrogen infrastructure and thus use its expertise to help shape the energy transition.

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H_2 quality measurement with process chromatography

Meter-Q Solutions GmbH

Partner of the TransHyDE project GET H_2

The discussions around gas analysis

Energy transition, natural gas crisis, hydrogen - everything is connected, they are more present in the public news today and especially in the natural gas industry. Every new political decision, every step forward raises new questions, including on the subject of hydrogen. Little is clear, except that hydrogen will continue to gain significantly in importance as an energy storage and energy carrier in the near future.

Where it will go - mixed gas, natural gas and hydrogen in parallel or just hydrogen - nobody knows for sure today. Nor does anyone know what the hydrogen will be used for: for heating, for hydrogen engines or fuel cells, for the chemical industry or for methanisation. But one thing is certain: measuring devices are needed that can analyse the hydrogen.

For gas analysis, meterQ's speciality, this means: The eternal debate as to whether a process gas chromatograph (PGC) should be able to measure 5 %, 10 % or 20 % hydrogen in natural gas is outdated. In today's transition phase, devices are needed that can cover the entire range from 0 to 100 % hydrogen. This means devices that can measure the hydrogen quality, whether from an electrolyser or other hydrogen source, whether to assess how transport in a pipeline affects the gas composition, or whether the customer can be sure of getting the quality they need and pay for.

Today, many different parties are discussing limit values. Limit values for production, for transport, for utilisation and, of course, for the entire billing. Does this already make sense today? For the entire hypothetical hydrogen infrastructure, there is a lack of experience as to how the individual parts behave, what purity can be achieved with what effort, what impurities play a role - in short, there are no measurements! And there is a lack of measuring equipment to carry out such measurements as soon as the first pilot projects are up and running.

Work in the TranshyDE project GET H_2

As meterQ, we are part of the hydrogen flagship project TransHyDE, which aims to research and evaluate the options for transporting hydrogen in the required quantities and over the required distances.

We are involved in the TransHyDE project GET H_2, which focuses on investigating the conversion of natural gas infrastructure (i. e. pipelines and storage facilities) for the use of hydrogen. A test pipeline is being set up for these investigations. The aim is to understand which materials are suitable, how well and safely such facilities and pipelines can be operated, what impact transport has on hydrogen purity, and much more.

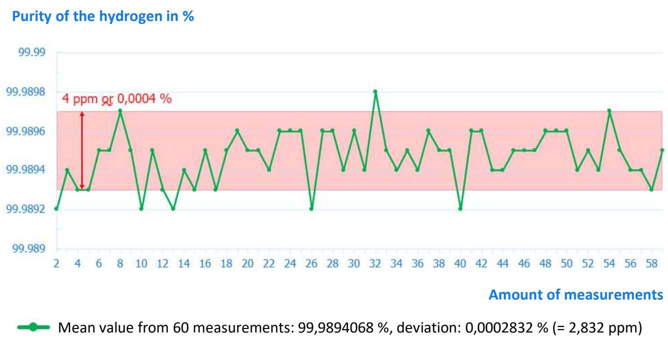
Innovation - a high-precision measuring device

As experts in gas analysis, we can make a fundamental contribution to this. With our new development, the $MGC^{hydrogen}$, we are supplying the first measuring device that can measure hydrogen quality in the same way as natural gas. The primary aim is not to measure an officially approved calorific value, although the $MGC^{hydrogen}$ can of course also fulfil this task, but to measure the purity of hydrogen as accurately and reliably as possible. With the $MGC^{hydrogen}$, we have created an analyser that can measure the expected impurities from production, transport and storage in the sensitivity range down to 1 ppm.

„We measure impurities up to 1 ppm.“

Dr. Achim Zajc

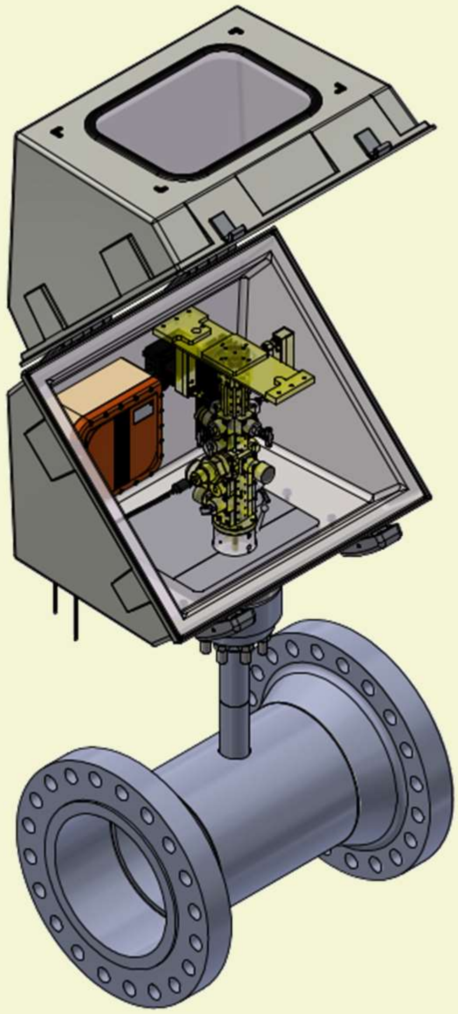
This makes it possible to track the hydrogen quality for all aspects of the hydrogen economy with a single reference device and to evaluate the respective influence. This applies not only to our TransHyDE project GET H_2, but also to the TransHyDE projects that deal with other transport media such as LH2 (liquid hydrogen), ammonia and LOHC (liquid organic hydrogen carriers). This is precisely what we at meterQ see as our challenge: to supply measuring devices that can reliably and independently carry out the required hydrogen quality measurements and deliver precisely the data needed to define limit values for production, transport and billing.



Results from hydrogen analysis with the MGC^{hydrogen}

With the MGC^{hydrogen}, we have the right tool for this. As a state-of-the-art gas chromatograph, it is robust, stable over time, can detect many components, offers a detection limit in the 1 ppm range and is easy to operate and transport.

The Technical Guideline (TR) G 19 and the Technical Rule G 260 clearly show that the determination of the calorific value of "pure" hydrogen will be regulated by custody transfer, even if not all rules exist today. The MGC^{hydrogen} can fulfil all the requirements of TR G 19 (error limit of 0.05 % (500 ppm) for hydrogen) and G 260 for continuous monitoring of hydrogen quality and the custody transfer calorific value calculation in accordance with ISO 6976. The MGC^{hydrogen} is currently undergoing a suitability test at the National Metrology Institute in accordance with TR G 19 (2/2023).



MGC^{hydrogen} for the measurement of hydrogen quality

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02.

Innovations and innovative services regarding liquid organic hydrogen carrier benzyltoluene (LOHC-BT)

LOHC value chain: tanks, materials and coatings

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

Partner of the TransHyDE project Helgoland

Founded in 1968 and integrated into the Fraunhofer-Gesellschaft in 1974, the roots of Fraunhofer IFAM lie in material science with an emphasis on metallic and polymer materials. This is complemented by a strong focus on manufacturing technologies.

At the seven sites in Bremen, Dresden, Stade, Wolfsburg, Brunswick, Helgoland and Cuxhaven, research is carried out on the following core competences: metallic materials, polymer materials, surface technology, bonding, moulding and component production, automation and robotics as well as energy storage and converters.

Both fundamental scientific issues and industry-related tasks with a short, medium or long-term perspective are dealt with as part of bi- or multi-lateral consortia. The Fraunhofer IFAM feels particularly committed to future challenges with regard to climate neutrality, resource conservation and the circular economy.

In TransHyDE, Fraunhofer IFAM is working on thirteen very different topics in the context of hydrogen transport technology development. The core aspect of the issues being addressed is the interaction of liquid organic hydrogen carriers (LOHC) with materials. The results achieved so far form a basis for specific R&D services for industry and for participation in future research projects with public funding.

Innovative LOHC tank concept

If LOHC is to be used as a hydrogen carrier, hydrogenated LOHC and dehydrogenated LOHC (perhydro-benzyltoluene, LOHC+, and benzyltoluene, LOHC-) are always present side by side in both the hydrogenation plants and the dehydrogenation plants. Conventionally, two storage tanks are required for this, which are both space and cost-intensive. Thanks to an innovative tank concept, the necessary tank volume and space requirement can be halved by using only one tank and equipping it with a movable intermediate cover. This means that LOHC+ and LOHC- can be stored together in one tank.

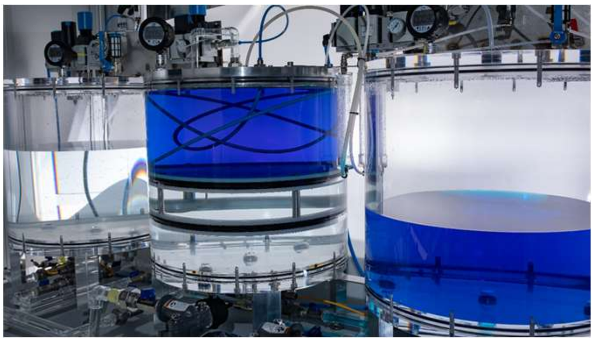

Figure 1: Tank demonstrator with movable false ceiling shows the feasibility of the tank concept for halving the space requirement

The tank demonstrator was used to test this concept and prove its functionality. By using chemically resistant elastomers as sealing materials, the two media LOHC+ and LOHC- can be stored separately from each other. The operation of the tank system has shown that neither the two media are mixed nor that there are any significant signs of wear on the elastomer seal. By coating the elastomer seals with plasmapolymer coatings, the abrasion of the elastomer seal was once again reduced and the sliding properties significantly improved. The tank concept is ready for use in industrial environments and can also be transferred to other applications, such as the separate storage of fresh and waste water.

Figure 2: Parts of the Fraunhofer IFAM test infrastructure on Heligoland. In addition to the outsourcing stands visible here, IFAM operates the Test Centre for Maritime Technologies on the island.

Material suitability for LOHC tanks and LOHC systems

For LOHC transport, materials are required that not only fulfil the requirements of the operating temperature range and mechanical stresses, but also have sufficient long-term resistance in contact with the LOHC.

The resistance to the LOHC used in the project has so far been systematically investigated on steels, glass fibre reinforced composites (GRP) and thermoplastics, sealants and adhesives. Materials were identified that are very well suited for safe, long-term use in LOHC tanks or LOHC systems. Through the exemplary design of various tanks, the materials were also assessed for their suitability for this application, and differences between material alternatives in terms of sustainability were determined through a life cycle analysis. Furthermore, suitable concepts were developed for the joining of add-on parts using adhesive bonding.

The Fraunhofer IFAM offers material selection and qualification for LOHC technology as a service. Thermal, physical and mechanical properties can be determined for this purpose. Specific ageing tests in the maritime field or in the laboratory by ageing samples in different media such as LOHC or salt water are carried out according to customer requirements or corresponding standards (e. g. DIN EN 13121-2).

Coatings for the protection of pipelines

In the TransHyDE project Helgoland, biocide-free anti-fouling coatings were developed and emissions from anti-corrosion coatings were analysed. Field tests are of crucial importance for the evaluation of coatings. Various test rigs were set up on Helgoland, at the Fraunhofer IFAM Test Centre for Maritime Technologies, including the marine exposure of coatings in accordance with ASTM-D3623-78a (2020) with subsequent evaluation in accordance with ASTM-D6990-20. Another test rig enables the evaluation of anti-fouling coatings under dynamic conditions. A fenced test area in the southern harbour area is used for atmospheric weathering tests in accordance with DIN EN ISO 12944 C4 and C5. Furthermore, a storage rack allows the zonal mounting of samples in different environmental zones. The Fraunhofer IFAM also offers extensive laboratory tests in order to gain in-depth insights and contribute to technological optimisation. Practical testing of underwater robotics, especially for maintenance and inspection tasks, is also possible. The flexibility of individual test scenarios guarantees the fulfilment of customer-specific requirements.

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Hydrogenious LOHC

H_2 storage in LOHC-BT: Solutions on Heligoland as blueprint for global projects

Hydrogenious LOHC Technologies GmbH

Partner of the TransHyDE project Helgoland

Founded in 2013, the German company Hydrogenious LOHC Technologies is a pioneer in the field of storing and transporting hydrogen in liquid organic hydrogen carriers (LOHC).

In the process developed by Hydrogenious, hydrogen is safely bonded to the hardly flammable thermal oil benzyltoluene (LOHC-BT) and can be stored and transported over long distances without loss under ambient conditions in conventional and existing liquid fuel infrastructure. In addition, LOHC-BT can be reused hundreds of times for hydrogen storage and transportation. With its technology, Hydrogenious bridges the gap between hydrogen producers in regions with readily available renewable energy sources and energy-intensive industries as consumers of large amounts of hydrogen. Through its international joint ventures and subsidiaries, Hydrogenious offers a secure and flexible global hydrogen infrastructure based on LOHC-BT - from technology licensing to turnkey (de)hydrogenation plants on an industrial scale.

In the TransHyDE Project Helgoland, Hydrogenious is part of several project phases that will be completed by 2025. In 2023, the focus of engineering lay on the development of a LOHC-BT hydrogenation plant for the theoretically considered location of Helgoland. The island is an ideal research location due to its difficult environmental conditions and its proximity to the local population and tourism. Taking these special conditions into account, the TransHyDE project Helgoland is intended to serve as a reproducible and scalable blueprint for LOHC-BT hydrogenation plant locations worldwide. Two aspects in particular have been investigated:

- How does fluctuating hydrogen availability affect the design of the LOHC-BT hydrogenation plant?
- How can the surplus heat from the hydrogenation process be efficiently used for the local heating network?

Design of a LOHC hydrogenation plant under fluctuating hydrogen availability

A key engineering objective was to develop a hydrogenation plant (StoragePLANT) that could handle a fluctuating hydrogen supply and operate dynamically to store hydrogen in LOHC-BT. The green hydrogen to be bound to LOHC-BT for safe storage and onward transportation to the mainland is generated from wind energy, which is subject to natural fluctuations. In order to specify the boundary conditions for such dynamic requirements, the wind data profiles of the island of Heligoland were evaluated in hourly resolution over several years and the design of the planned wind turbines, electrolysis, pipeline and StoragePLANT was assessed from this point of view. From this analysis, the necessary framework conditions for planning the StoragePLANT were derived.

The appropriate size of the hydrogenation plant depends essentially on the number and/or installed capacity of the wind turbines and electrolysers off the island of Heligoland, as well as the length of the pipeline between them. Two electrolysers with a capacity of 10 MW each were considered to follow the wind profile. In addition to the maximum hydrogen storage capacity of the StoragePLANT of 12 tpd (tons per day), there are other variables such as the minimum partial load, the maximum load change rate in relation to the mass flow, and the type of possible operating points (discontinuous or continuous).

In the specific application, it was necessary to check whether the installed output of the wind turbines and the dimensioning of the pipeline matched the capacity of the

StoragePLANT. This was done by evaluating the wind profile and calculating the resulting load change between two data points or within one hour (Figure 1).

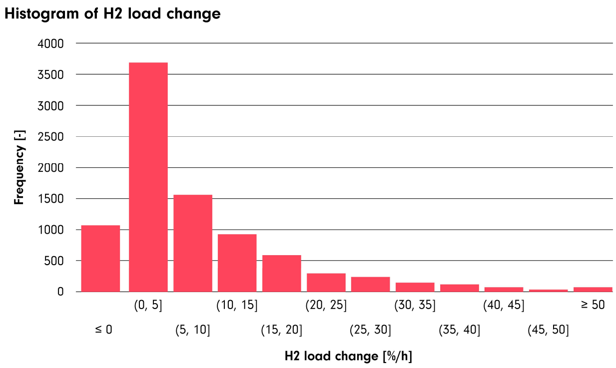

Figure 1: Frequency of the load change of the hydrogen mass flow

Figure 2 presents this data as a cumulative distribution function, which shows that the StoragePLANT must be designed for a load change of at least 30% per hour, based on the input mass flow of hydrogen and unloaded LOHC-BT, to cover 95% of the cases that occur.

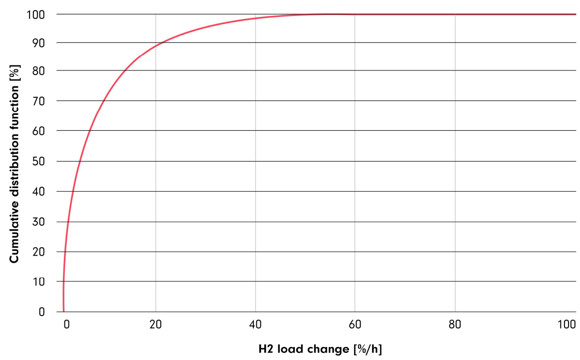

Figure 2: Cumulative distribution function of the load change of the hydrogen mass flow

These requirements were studied as part of the basic engineering. The StoragePLANT was designed to be flexible enough to meet the specified dynamic requirements. The result shows: The LOHC-BT hydrogenation plant can also handle fluctuating hydrogen quantities - an important prerequisite that can also be decisive for other scenarios, e.g. the production of hydrogen using solar energy.

Possible integration of the hydrogenation plant into the heating network on the island of Heligoland

In addition to the supply of hydrogen, the utilisation of surplus heat from a LOHC-BT hydrogenation plant has been examined using the example of integration into the district heating network: When hydrogen is stored in the LOHC-BT, energy is released in the form of heat (approx. 9 kWh/kgH_2 - corresponding to temperatures of 200 - 250°C), which can be used on site in the form of steam or bound to a heat transfer oil. The possibility of harnessing this surplus heat from the StoragePLANT to meet the heating needs of the island of Heligoland was investigated.

To evaluate the influence of various factors on the economic viability, different site options on the island of Heligoland and different plant sizes were considered: a StoragePLANT with a hydrogen storage capacity of 5 tpd and one with 12 tpd. The heat is to be extracted via a steam cycle and fed into a heating network. This is shown schematically in Figure 3. Based on the available data and framework conditions, the study for Heligoland shows that the heat network operator would have an economic incentive to invest in heat coupling with the StoragePLANT.

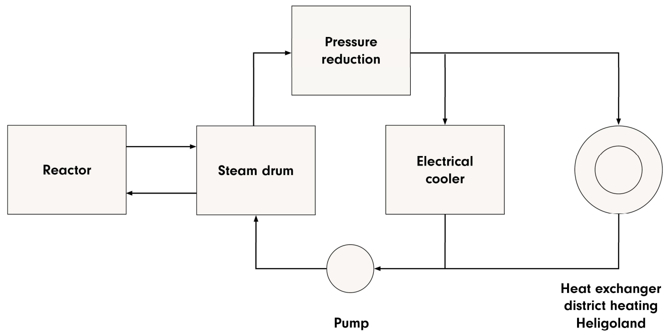

Figure 3: Steam cycle and integration into the heating network

In addition to the economic viability, the heat demand coverage was also examined based on hourly wind profiles for several years. The StoragePLANT was assumed to follow the wind profile. This results in large fluctuations in LOHC-BT heat production over the year (approximately 1,500 MWh to 2,500 MWh). Despite these fluctuations, a large part of the annual heat demand of the island of Heligoland could be covered by the excess heat from the hydrogenation process alone, depending on the size of the plant:

- approx. 70% annual heat demand coverage by LOHC-BT surplus heat with a 12 tpd StoragePLANT
- approx. 50% annual heat demand coverage by LOHC-BT surplus heat with a 5 tpd StoragePLANT

LOHC offers great potential for global hydrogen availability

Both aspects of the TransHyDE Project Helgoland show the strengths and possibilities of LOHC-BT as a transport medium for the supply of green hydrogen. The flexible handling of load fluctuations from renewable energy sources, which is a major challenge for many other technologies, as well as the economic and profitable utilization of by-products - in this case the surplus heat from the hydrogenation process - can be fully implemented with the StoragePLANT design.

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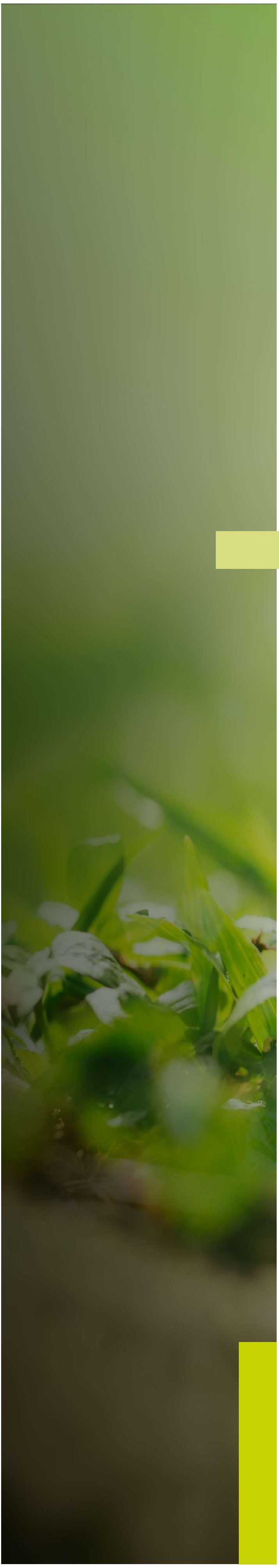

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