Comprehensive solutions for hydrogen industry by ZwickRoell

Dr. Chen Cao
Global Industry Manager Energy

Zwick Roell

Made by ZwickRoell Perspective in Numbers

Headquarted in Ulm

10 YEARS

Min. 10 years spare parts availability guaranteed

85%

in-house production depth

CO_2 neutral since 2014

1. **Hydrogen strategy**

2. **Customer Challenges in Testing in Hydrogen industry**

3. **Testing requirements and solutions**

H_2 – Production and Use
H_2 – Transport and Storage

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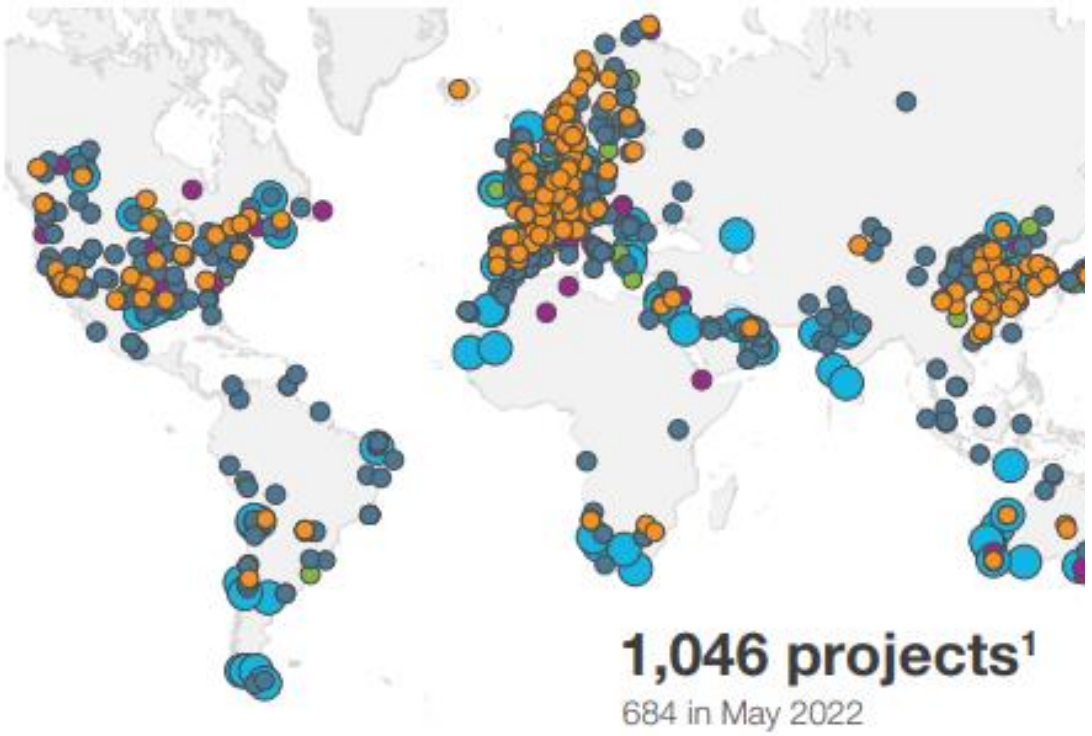
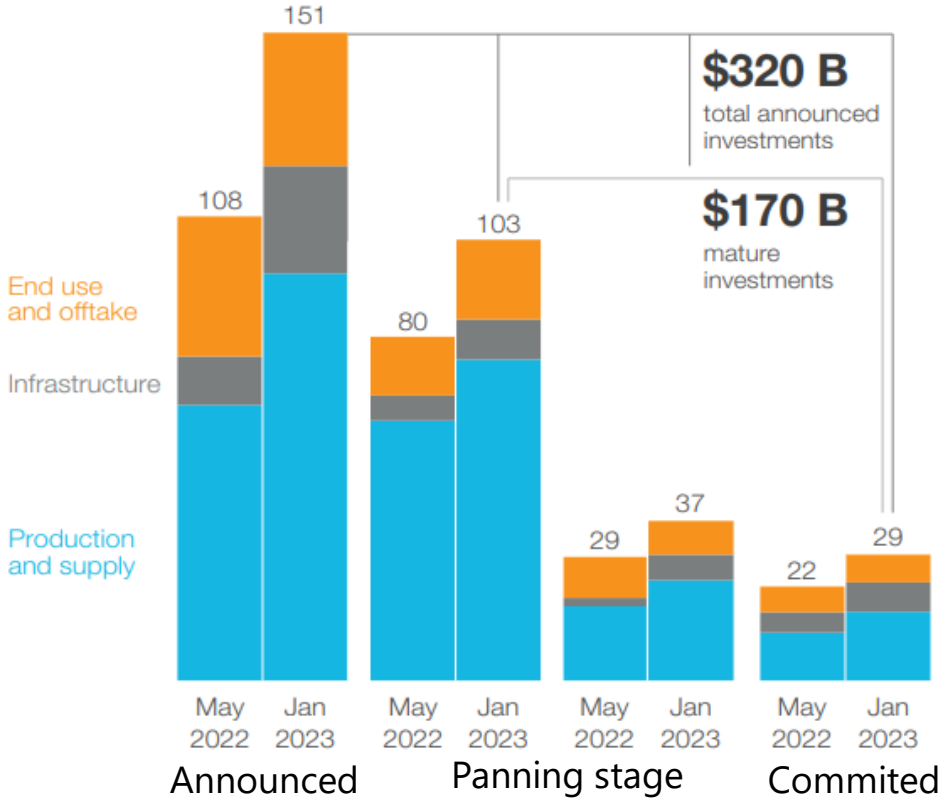
Hydrogen momentum keeps strong but investment decisions are lagging.





Source: Hydrogen Council/Mckinsey

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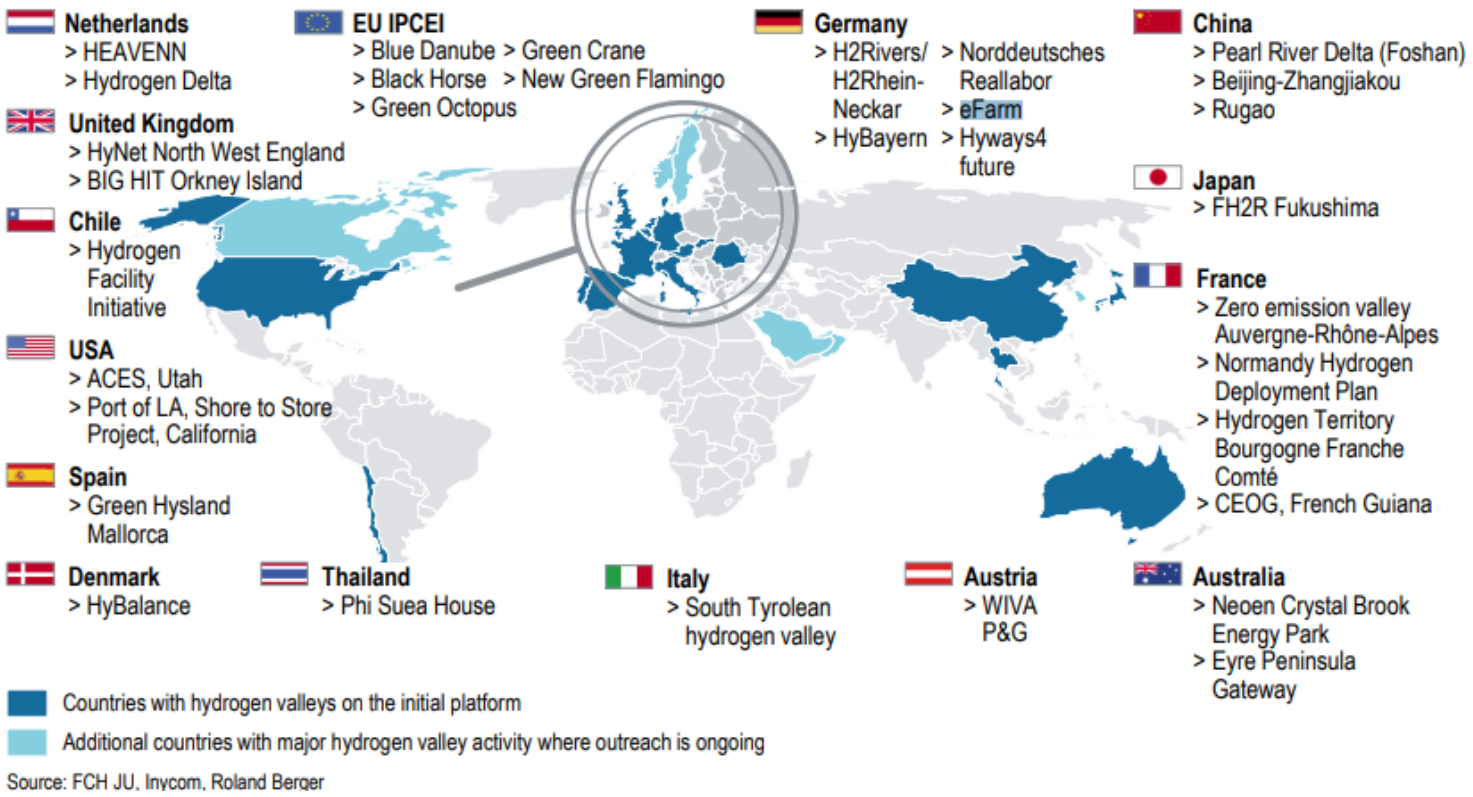
The formation of hydrogen valleys is a global phenomenon as an important step towards technology incubation and a locally integrated hydrogen ecosystem.



Source: Mission Innovation Hydrogen Valley Platform www.h2v.eu

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1. **Hydrogen strategy**

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H_2 – Production and Use
H_2 – Transport and Storage

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Hydrogen industry customers have to cope with a variety of challenges in testing. ZwickRoell offers comprehensive solutions.

1 Complexity

- Sophisticated testing set-ups and infrastructure for all relevant kinds of materials
- Static, dynamic, and creep testing
- Coupling of complex loads and environmental conditions
- Several physical parameters (e.g. electrical/ mechanical/ permeability)

2 Safety

- Ensure safe handling taking into account the high reactivity of hydrogen with oxygen
- Create safe infrastructure concepts
- Safety audits of labs

3 Standardization

- Understanding the standards available today
- Follow the standards that are emerging
- Flexibility to adapt to new regulations (HW/SW)
- Learning the OEMs/endusers quality requirements and guidelines

4 Cost-efficiency

- Determine the necessary complexity of your testing device to meet your objectives

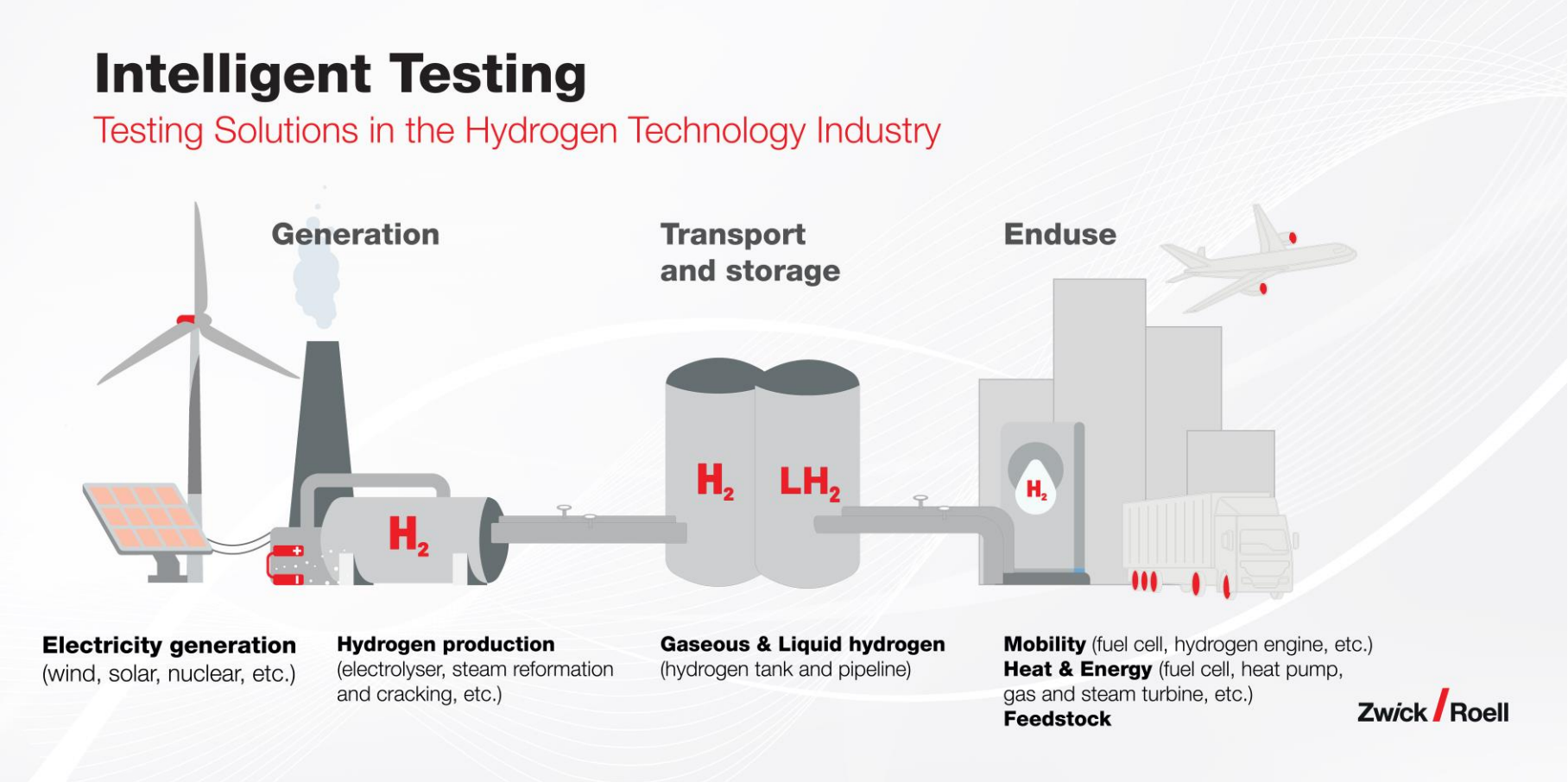
5 Know-how/ State-of-the-Art

- Need for high-skilled, experienced personnel
- Continuous training towards advancements
- Analysis/ interpretation of test results
- Fruitful exchange of findings with other experts

6 Machine lifetime

- Machine and applicances need to be HIC resistant
- Condition monitoring
- Specific maintenance and service
- Upgradeability

ZwickRoell offers a wide range of material testing solutions covering the whole hydrogen value chain.



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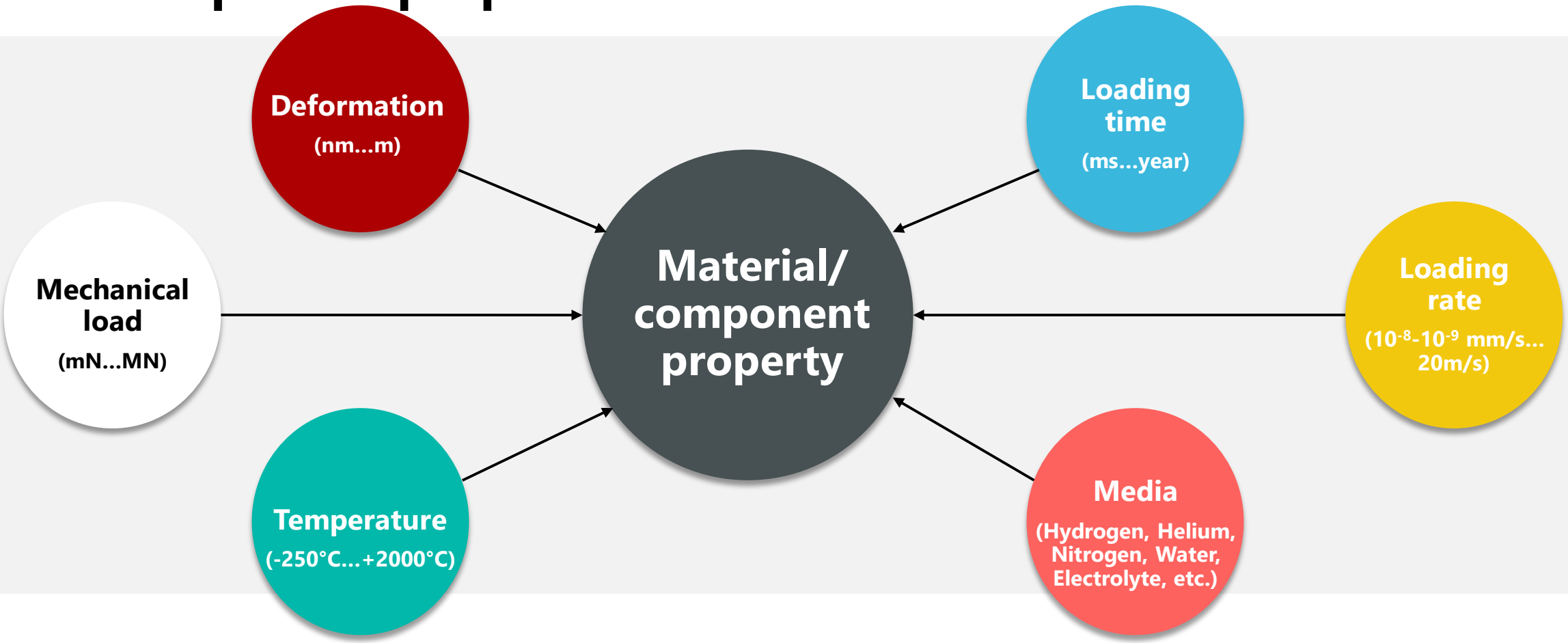
External influences parameters are defining the material and component properties characterization.



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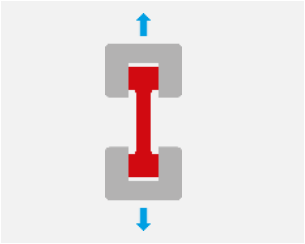
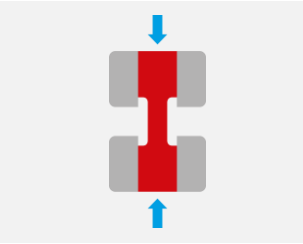
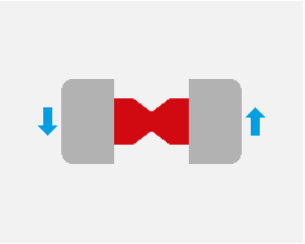


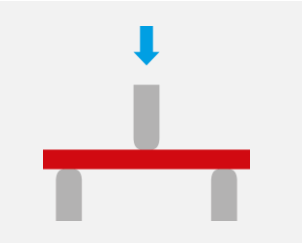
- tensile



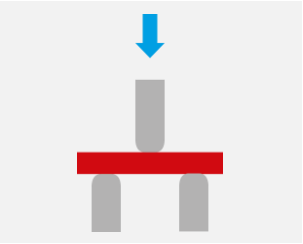
- compression



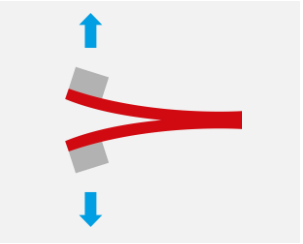
- shear



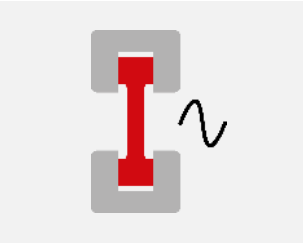
- flexure



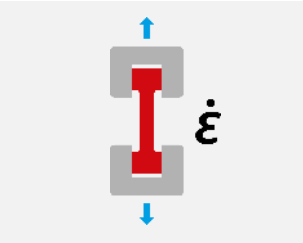
- ILSS



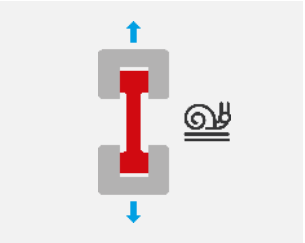
- fracture



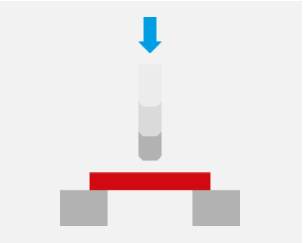
- fatigue



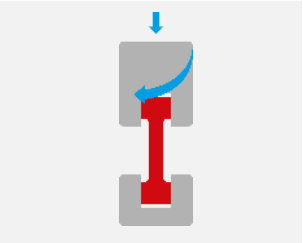
- strain rate



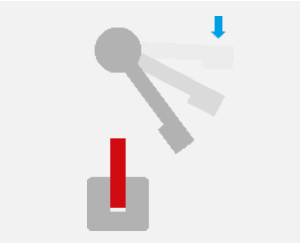
- creep



- impact (drop-weight)



- torsion



- impact (hit)

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H_2 – Transport and Storage

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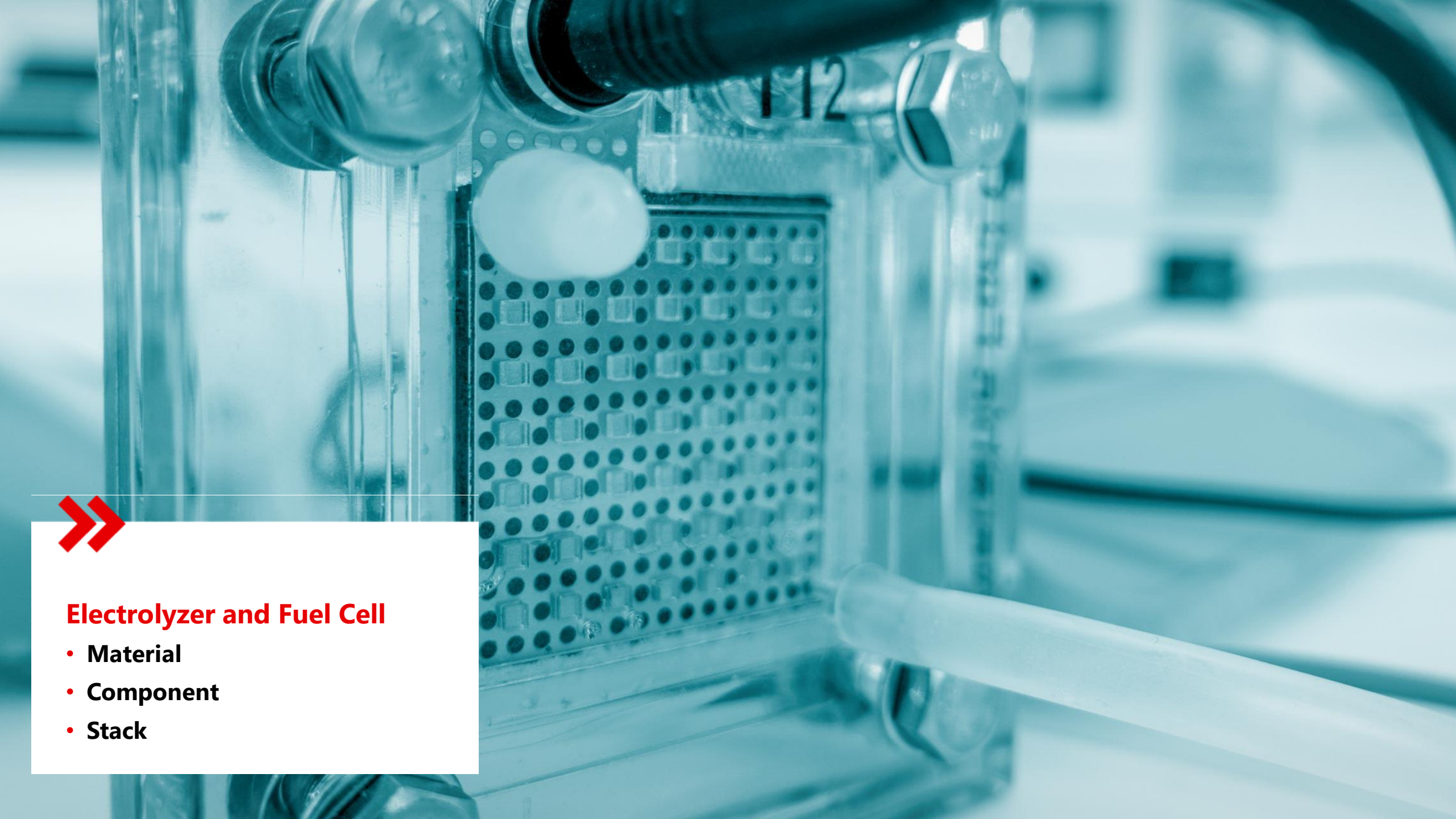
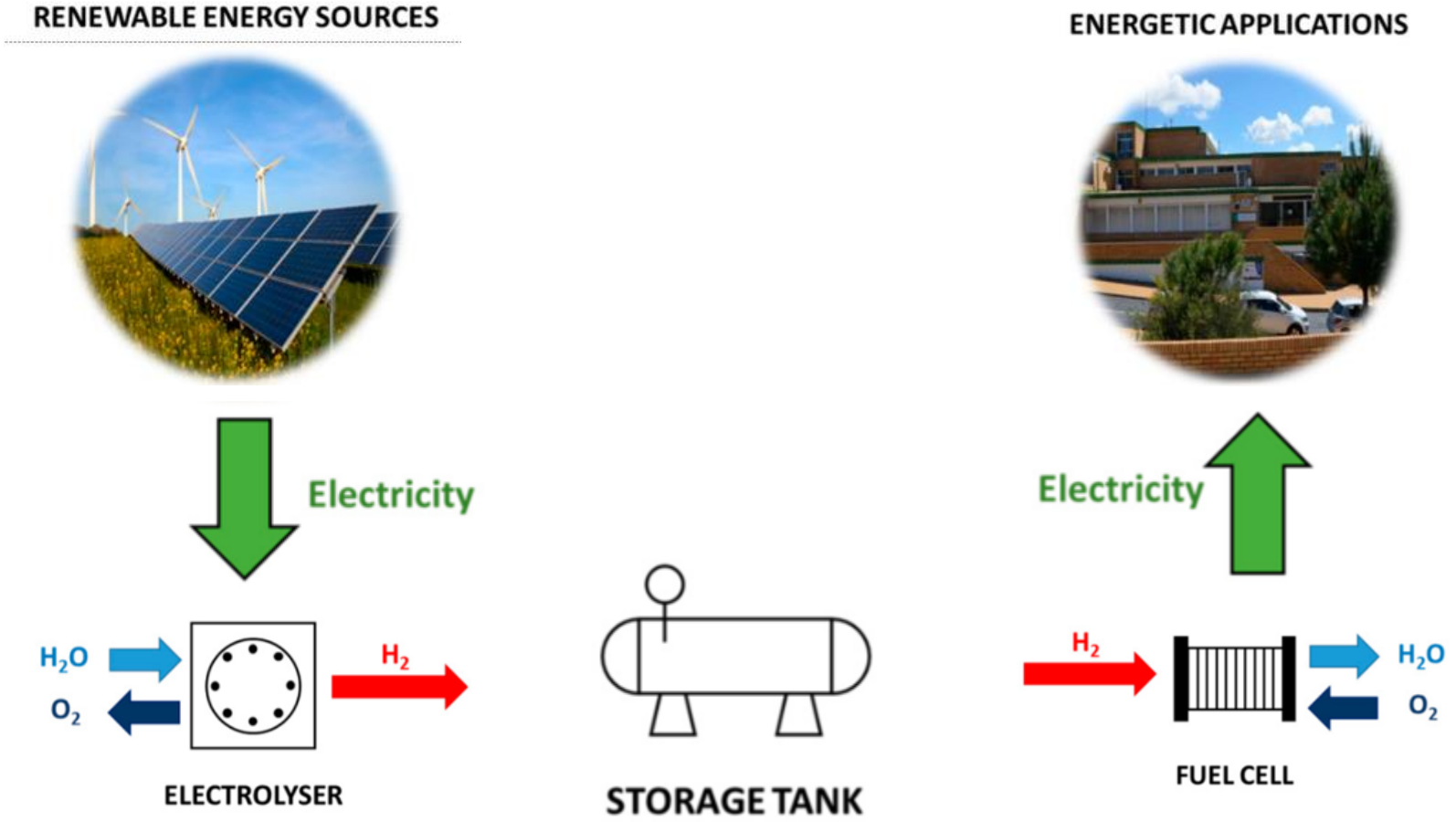


Electrolyzer and Fuel Cell

- Material
- Component
- Stack

An electrolyzer produces hydrogen and oxygen from water and electricity. A fuel cell generates electricity by reaction of hydrogen with oxygen.



Source: Mancera etc. Electronics 2020, 9(5)

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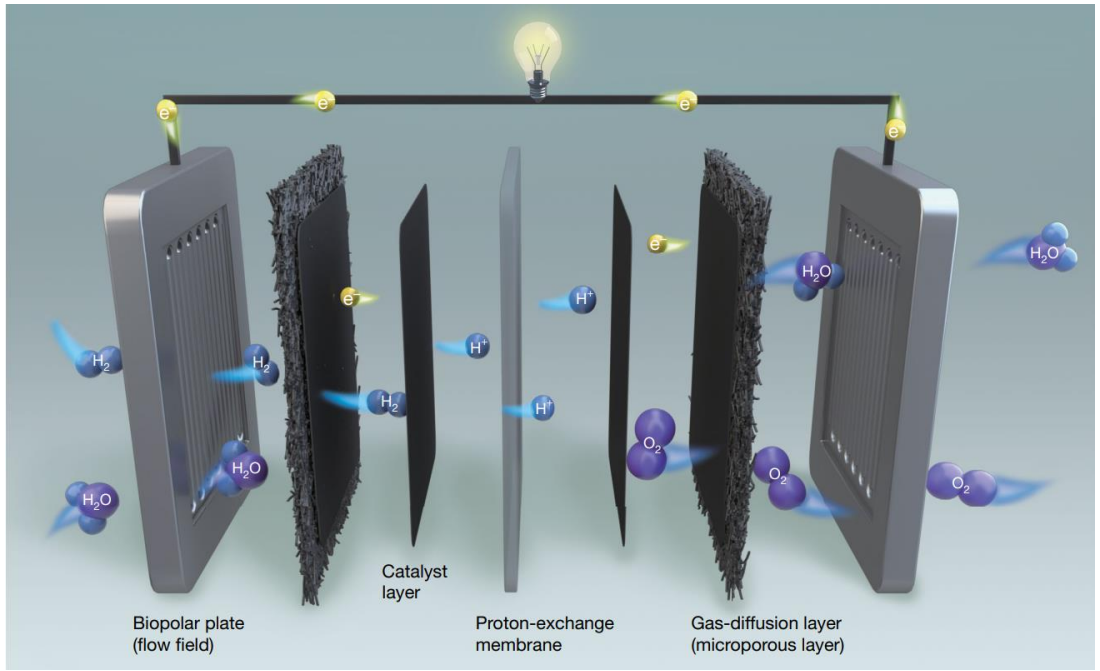
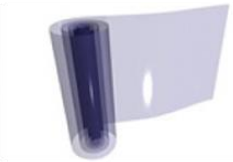
Testing is necessary for all key components of a fuel cell or electrolyzer.



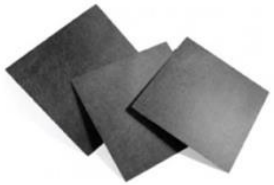
Set up of a PEM fuel cell

Proton Exchange Membrane
(Polymer)

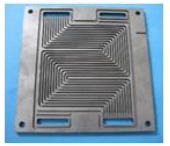


Gas Diffusion Layer
(Carbon paper/cloth/felt)

Gas diffusion layer on the **anode side of Electrolysis is Ti**



Bipolarplates
Gaskets
(Metal/Graphite composite/Polymer)



Assemblies and Cell stacks
(Material combinations)

Source: Jiao etc. sNature 595, 361-369 (2021)

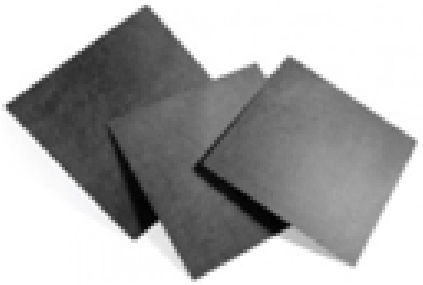
Material testing is crucial for better performance and properties of components in electrolyzers and fuel cells.

Research & Development/Quality Control

Material

Evaluate raw material property

Component



Evaluate the mechanical/functional property

Stack

Assembly the Stacks

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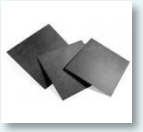
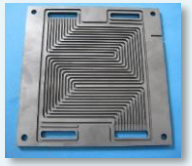
ZwickRoell provides many crucial testing solutions for PEM electrolyzer/fuel cell – without hydrogen.

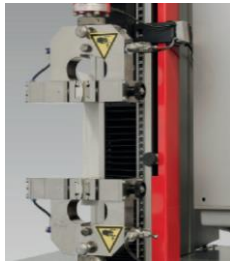


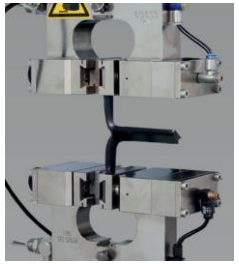
Components for fuel cells



Assembled cell

Tensile strength
Elongation
Peel test
Creep test





Flexure and Puncture tests

Thickness,
Electrical resistance,
Air permeability
measurement under
compression

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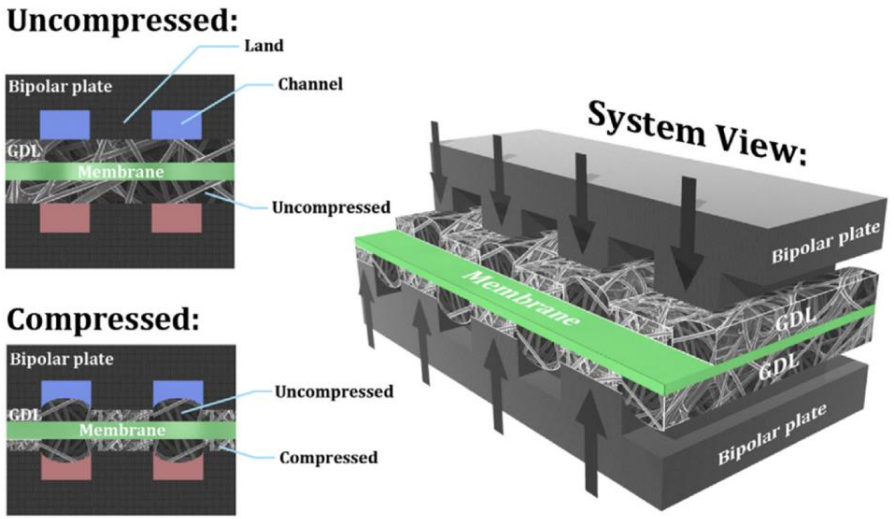
Mechanical loading during assembly/working changes material properties and this impacts the performance of the product.

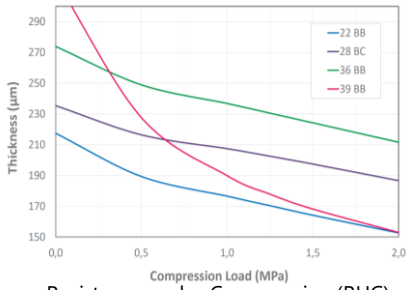


Thickness

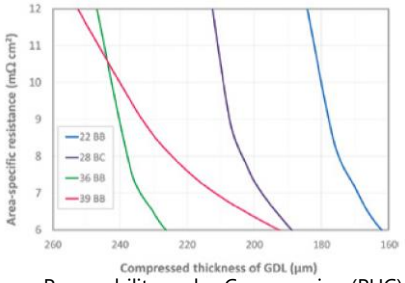
Conductivity

Permeability

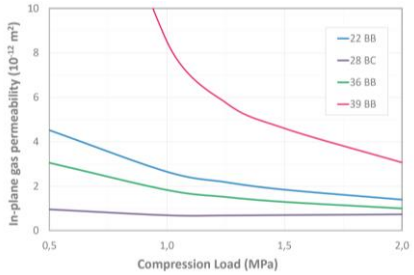
Thickness under Compression (TUC)



Resistance under Compression (RUC)



Permeability under Compression (PUC)



Source: Song etc. Renewable and Sustainable Energy Reviews 153 (2022)

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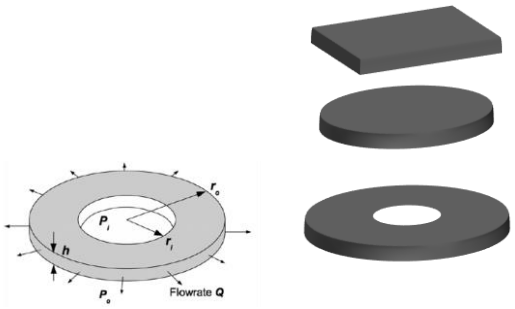
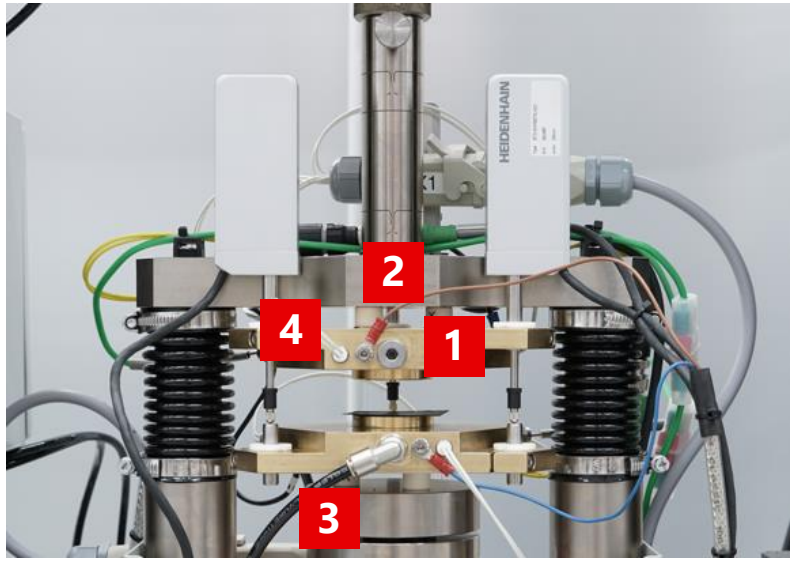
ZwickRoell offers a combined testing solution that measures thickness change, electrical conductivity and permeability at different loading types.

Typical GDL samples



Square-shape sample
Round-shape sample
Ring-shape sample: air permeability measurement

Sample fixture



1 **Function: Compressibility**

2 **Function: Electrical resistance**

3 **Function: Air permeability**

4 **Function: Temperature**

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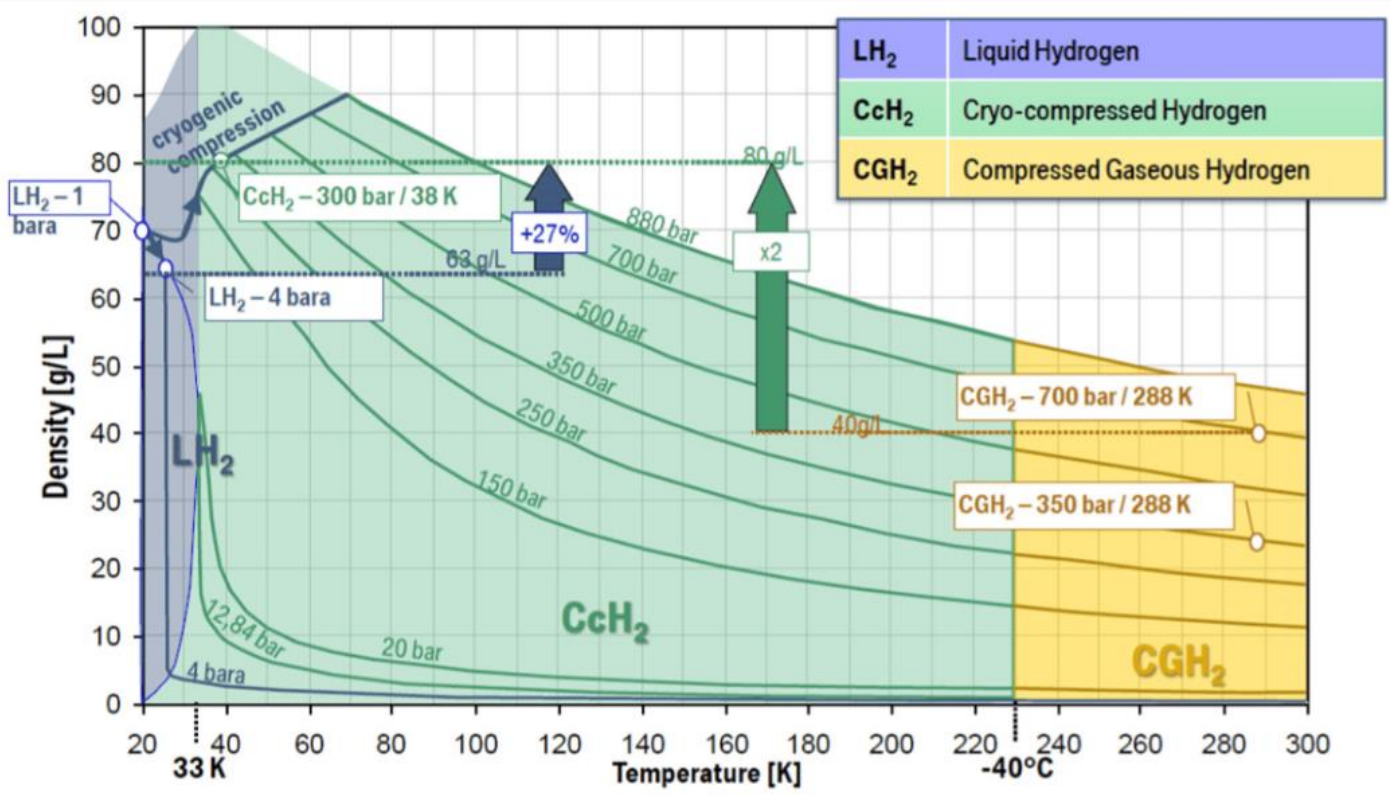
Pipeline and Tank

- Ex-situ solutions
- High Pressure
- Cryogenic temperature

Hydrogen is usually transported or stored at high pressure or under cyrogenic temperatures.



Source: Barthélémy, H. etc., Int. J. Hydrogen Energy 2017, 42, 7254–7262.

For vessels, tanks, tubes, and pipes, predominantly used:

→ **Testing under compressed hydrogen conditions**

For aerospace, space, and special materials

→ **Testing under cryo-liquid conditions**

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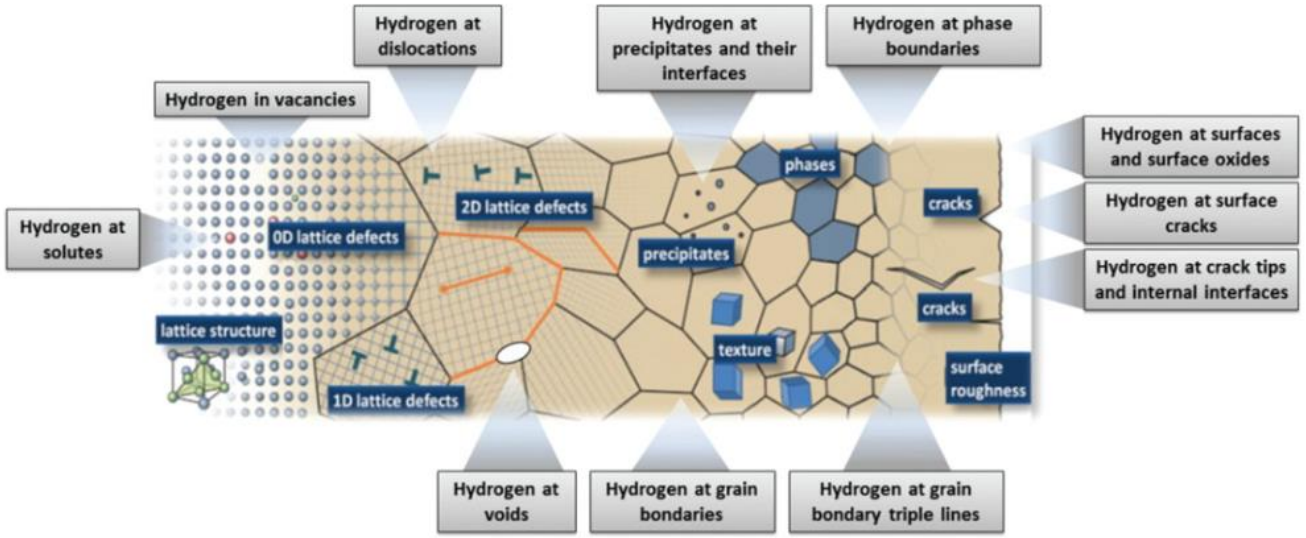
Mechanical testing is able to identify materials compatibility in the suitable application area.



© source: Koyama etc. Matera Sci Technol, 2017, 33(13): 1481-96

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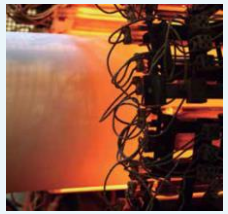
ZR already provides many crucial testing methods for H_2 testing for tubes, pipelines and tanks.



Metals

Composite sPlastics

Tests at ambient pressure and RT

Conventional tests with samples ‚loaded and aged' with hydrogen

Tests under compressed hydrogen

Tensile test, e.g. SSRT

Fatigue test

Fracture mechanics, crack growth

Hardness test

Tests under cryogenic temperatures (down to 20K)

20K with or w/o hydrogen environment

Tensile test, compression test, shear test, flexure test
Fatigue test
Fracture mechanics, crack growth
Pendulum impact test at 15K .. 20K

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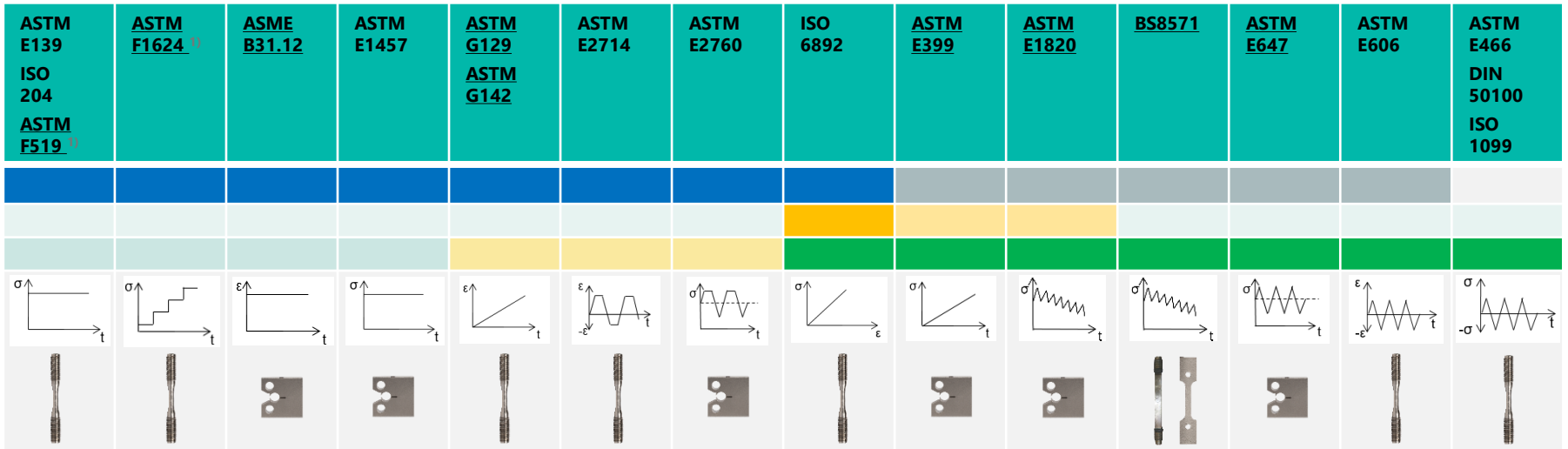
Already, there exist a number of internationally recognized standards for testing in context of hydrogen. Experts of ZwickRoell are involved in the standard committees to support future testing regulations.

Creep

Nanoindentation



1) Specimen H_2 charged

Static

Servo-hydraulic

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There exist already standards relating to the material compatibility in hydrogen environment.

- **GB/T 34524-2** (storage and transportation system for gaseous hydrogen, part 2: test methods for evaluating metallic material compatibility in hydrogen atmosphere)
- **ANSI-CSA CHMC1** (testing methods for evaluating material compatibility in compressed hydrogen environment)
- **ISO 11114-4** (Compatibility of cylinder and valve materials with gas contents)

- Method mentioned in the standards:
  - ISO 11114-4 targeted for gas cylinder: method B in-situ fracture mechanics test with autoclave to measure KIH; method C: constant displacement measurement in autoclave.
  - ANSI-CSA CHMC1 targeted in general material compatibility with compressed hydrogen applications and serves to provide a basic comparison of materials performance.
  - GB/T 34524-2 targeted in general material compatibility with compressed hydrogen applications.

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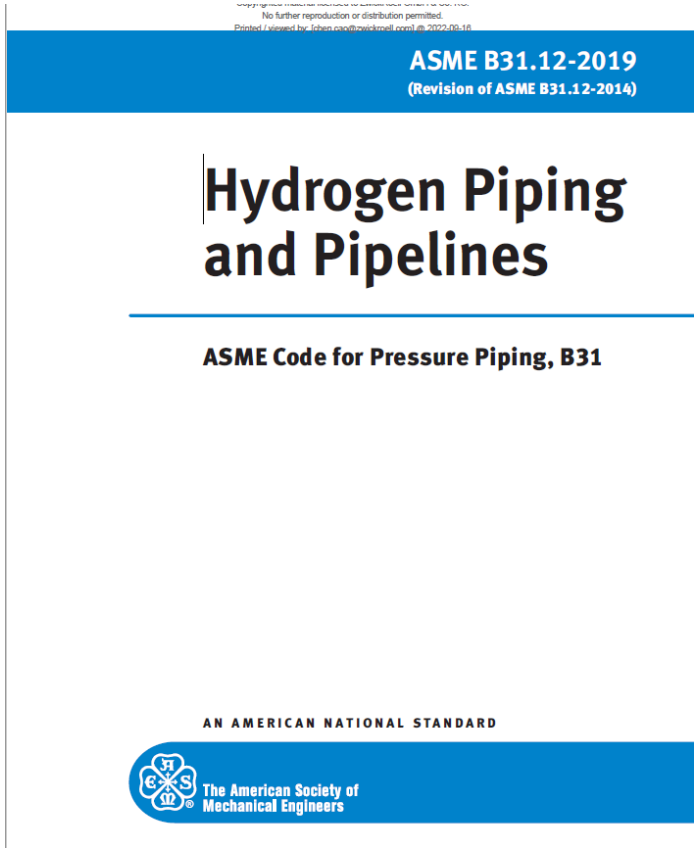
ASME B31.12 plays a central role in materials testing here as the leading standard for tests on hydrogen-carrying pipes and pipelines.

- Material compatibility testing is needed in pipeline design.
- ASME standard defines two methods of design, one is based on the testing and the other is one performance.
  - The performance design is preferred due to a lower design factor, which requires testing based on ASME BVCP Section VIII article KD-10 and ASTM E1820.
  - ASTM E1820 gives the general introduction of the facture mechanics testing but missing the detailed requirements on the testing chambers and hydrogen conditions.


ASME B31.12-2019
(Revision of ASME B31.12-2014)

Hydrogen Piping and Pipelines

ASME Code for Pressure Piping, B31

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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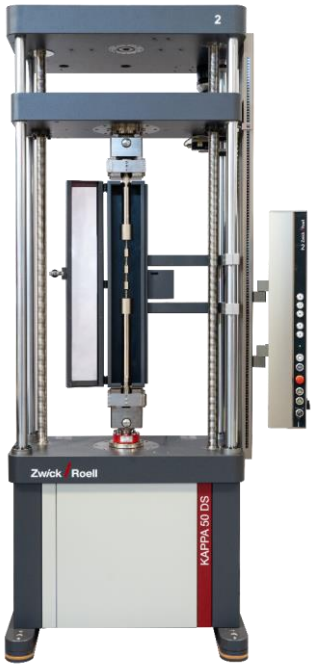
Nowadays the majority of tests are performed with externally charged samples.

Tensile test
- ISO 6892
- ISO 527



Creep test: quality control due to possible hydrogen embrittlement caused by plating/coating processes in steels
- ASTM F519-13
- ASTM 1624

Hardness test: Typical application is pipeline, tubes and tanks. Materials (mostly metal) need to be measured with pre-charged samples.
- Micro hardness test on welded joints (ISO 22826)
- Mapping function on welded joints (ISO 9015)
- ISO 2639: CHD to check the success of the heat treatment

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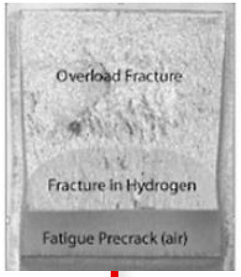
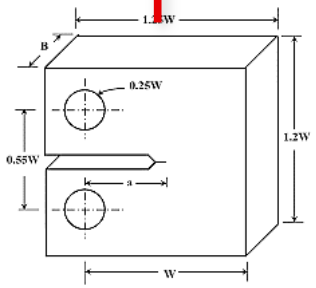
K1H testing according based on ASME B31.12 offers a way of qualifying high-strength line-pipes for H2 transport.

KIH testing system:

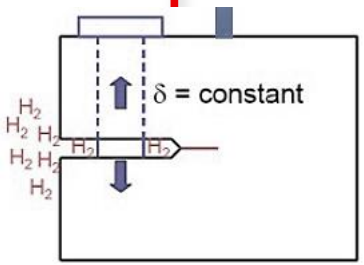
- Constant displacement:
  - No machine → manual loading
  - ClipOn extensometer
- Constant force: Creep testing machine



Machine CT-sample → **Fatigue pre-cracking** → **Apply displacement in glove box** → **Move to test position** → **Expose in HP H2 for 1000hrs** → **Evaluate in SEM/optical**



dyn. mcs. necessary



Source: Tazedakis et al.; Qualification of High-Strength Linepipes for Hydrogen Transportation based on ASME B31.12 Code; Pipeline Technology Journal; Issue 1/2021

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In-situ testing is significant to characterize the material under high H_2 pressure influence.

1000bar system-together with MPA Stuttgart

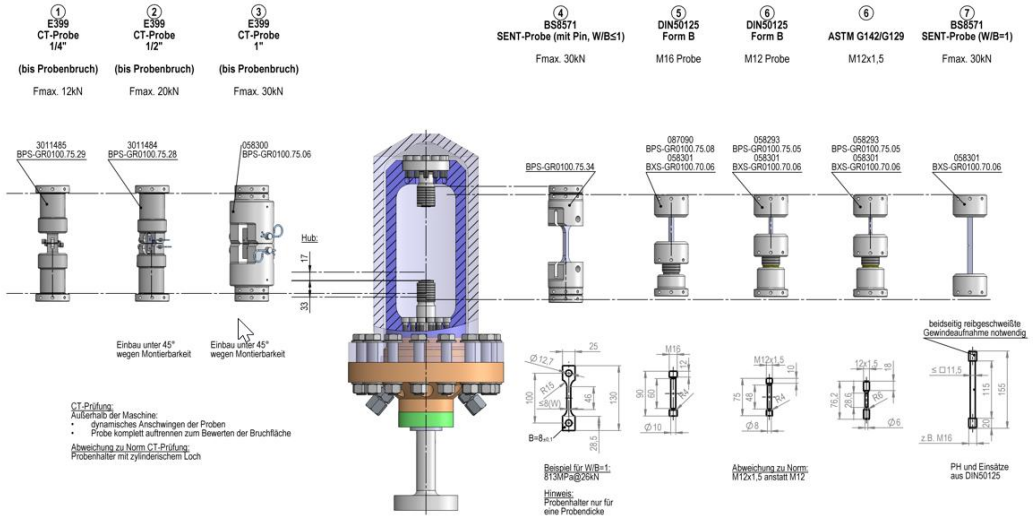
Testing system to perform

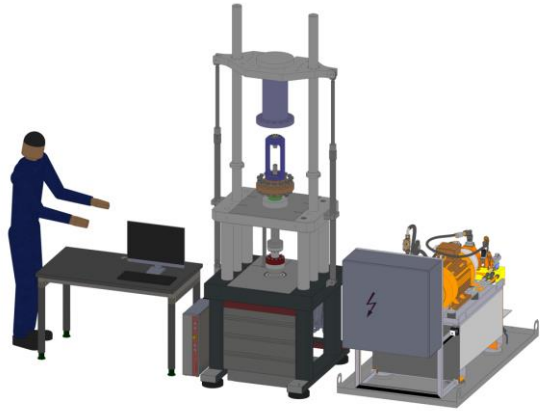
- Tensile tests (Ø 3- 8 mm)
- Fatigue tests (Ø 3- 8 mm)
- Fracture mechanics tests (max. CT25)

Testing in

- Media: H_2 and reference medium
- Temperature range: -85 °C to +150 °C
- Max. hydrogen pressure: 1000 bar
- Fmax: 100 kN
- Max. testing frequence: 70 Hz
- Max. amplitude: 1mm
- Min. testing speed: < 0.01 mm/min

In-situ testing is significant to characterize the material under high H_2 pressure influence.





ZwickRoell 400bar system

Testing system to perform

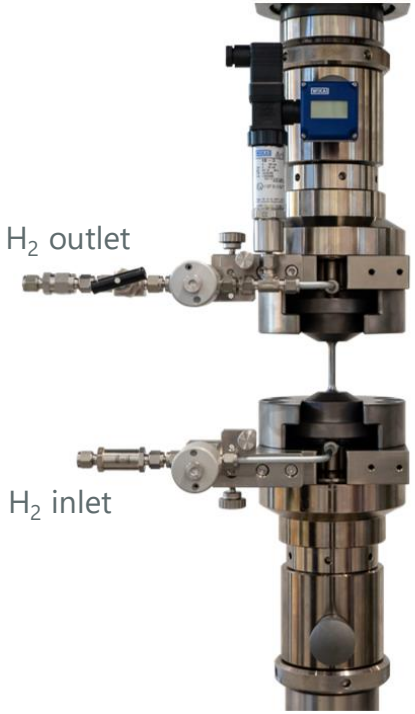
- Tensile tests
- Fatigue tests
- Bending tests
- Fracture mechanics tests

Testing in

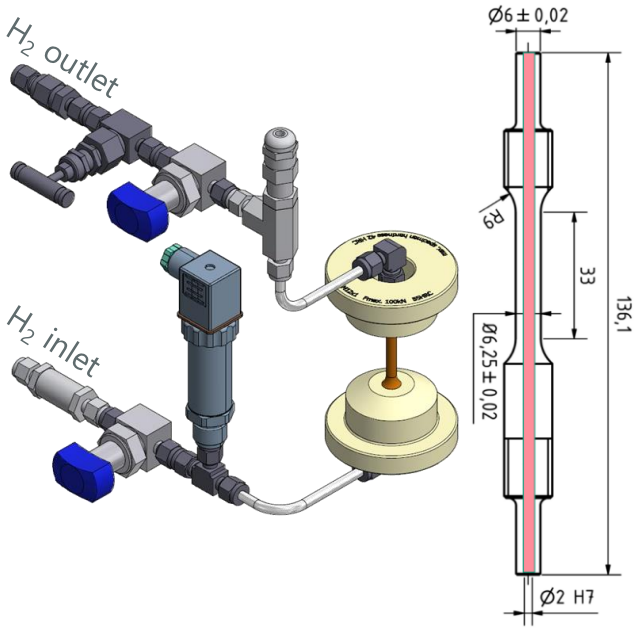
- Temperature range: RT
- Optional: -60°/+100°C.
- Max. hydrogen pressure: 400 bar
- Fmax: 100 kN
- Min. testing speed: 0.01 mm/min
- Actuator stroke: 100mm
- Hydrogen pressure vessel with mechanical pressure compensation and internal load measurement to compensate friction

Zwick Roell

In-situ testing is significant to characterize the material under H_2 pressure influence.



Specimen adapter for testing hollow specimens



Hollow specimen filled with compressed H_2

ZwickRoell Hollow specimen testing system

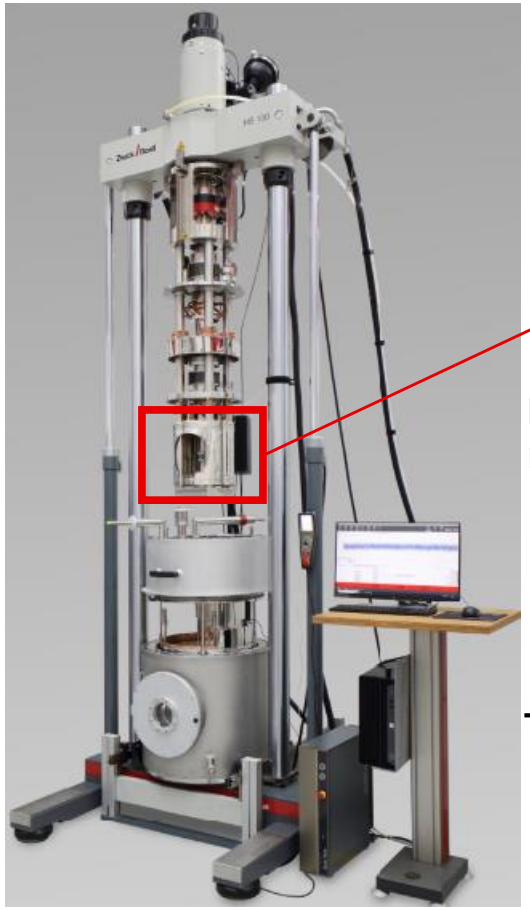
Testing system to perform

- Slow strain rate test
- Creep fatigue
- Compression test

Testing in

- Temperature range: RT
- Max. hydrogen pressure: 200 bar
- Hollow specimen testing system providing an easy handling in-situ compressed hydrogen environment, suitable for a standard lab without special safety measures.

ZwickRoell offers static/dynamic testing machines with continuous flow cryostat.



Flexure test

Fracture mechanics

Tensile test

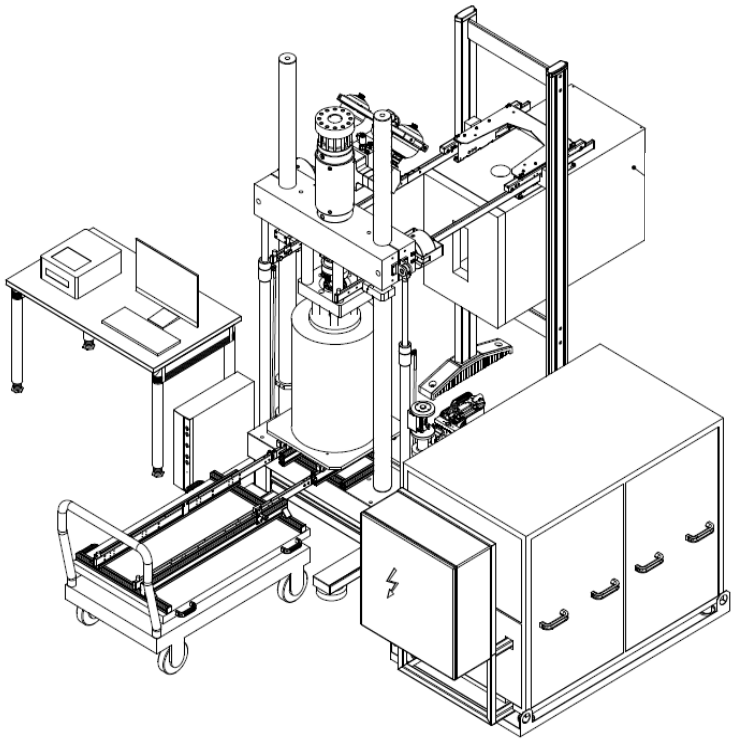
Dynamic/Static testing machine HB100 with Cryostat (LN_2-LHe-LH_2) system

- Tensile tests
- Fracture tests
- Fracture mechanics tests

Testing in

- LN_2/LHe/LH_2 stepless temperature adjustment from room temperature to -258°C/15K .
- Elongation measurement/ Bending unit with measurement of deflection with low temperature clip-on gauges/deflectometers
- pressure: max. 1 bar
- Application of load with special load bridge with alignment unit
- Low temperature grips for tensile-, fracture mechanics and bending tests
- Optional: H_2-environment

ZwickRoell offers static/dynamic testing machines with cryostat and additional temperature chamber.



Static/Dynamic testing machine Z100 with Cryostat (LN_2) system

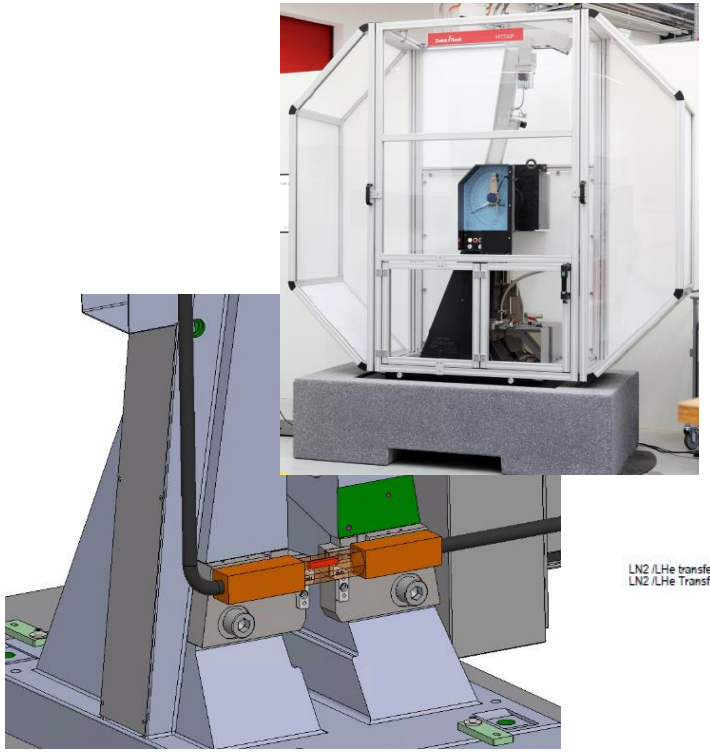
- Tensile tests
- Bending tests
- Fatigue tests
- Fracture mechanics tests
- For static and dynamic tests at 77K with composite specimen, plastics and other materials.

Testing in

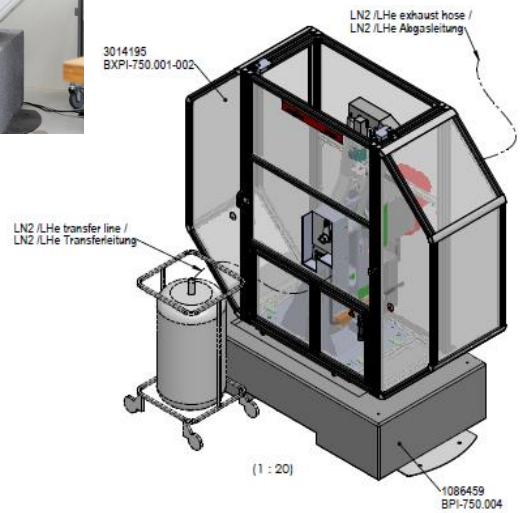
- LN2 immersion cryostat down to 77K
- Pressure: max. 1 bar

Metals can be tested at low temperatures down to 15K with a pendulum impact tester HIT750 (max. 300J).

- Pendulum impact test according to DIN EN ISO 148 and ASTM E 23 at low temperatures at min. 15K
- Instrumented fin according to ISO 14556
- Charpy specimen dimensions 10x10x55mm
- Direct LHe/LN2 cooling system with specimen mounted in testing position



detail



Zwick Roell

From idea to realization: our cooperation allows customers to successfully build advanced hydrogen testing labors.

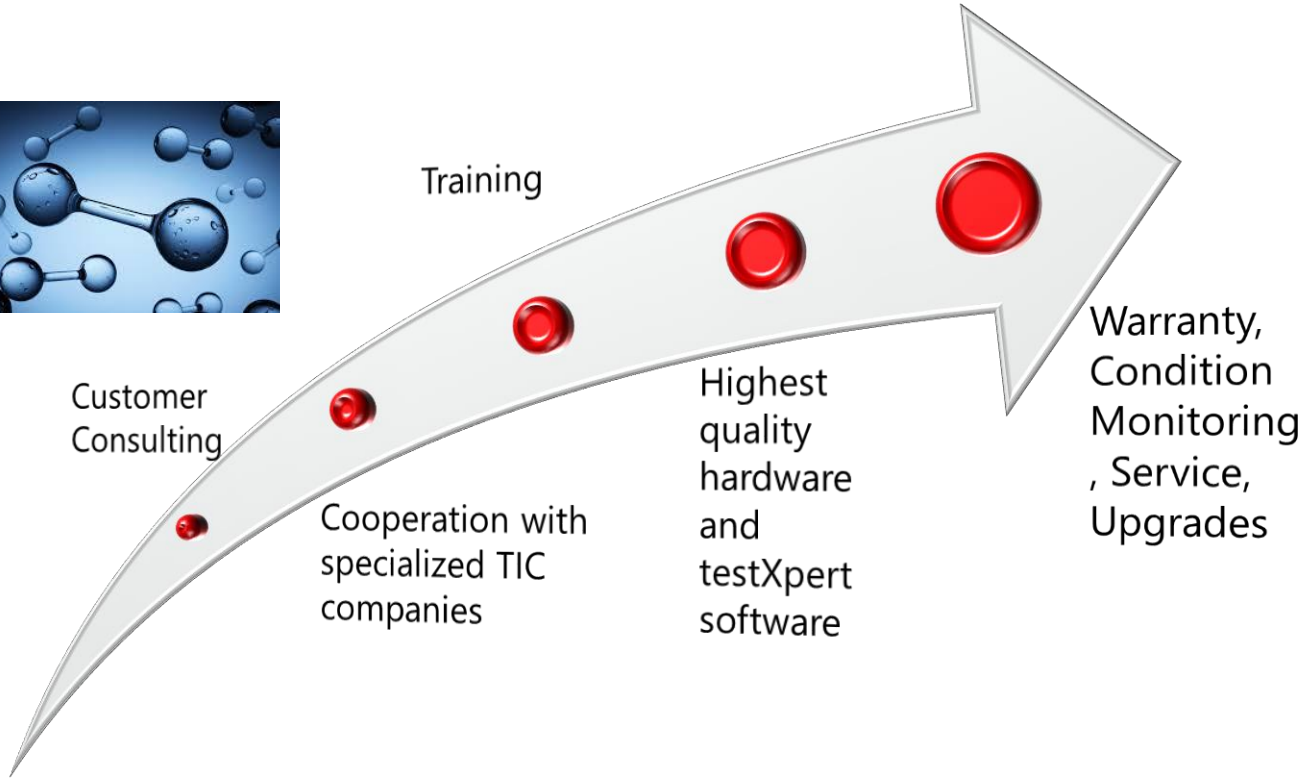
Application: Pipeline
400 bar system

Application: Transport and storage
Cryogenic temperature solution-
20K

Application: Aerospace
Cryogenic temperature solution-
77K, 20K

Application: Fuel cell
compressibility-electrical resistance-
permeability solution

ZwickRoell provides a holistic customer support from first ideas to successful operation of the hydrogen testing lab.



Zwick Roell

Hydrogen center

Area 1:

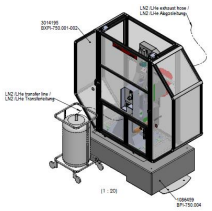
- Focus application in generation/enduse: Electrolyser and Fuel cell

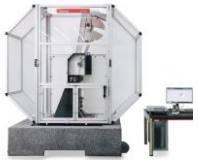
Area 2:

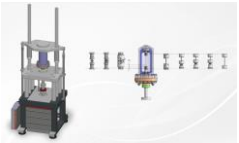
- Focus application in Transport and Storage: In-situ solution and ex-situ solutions.

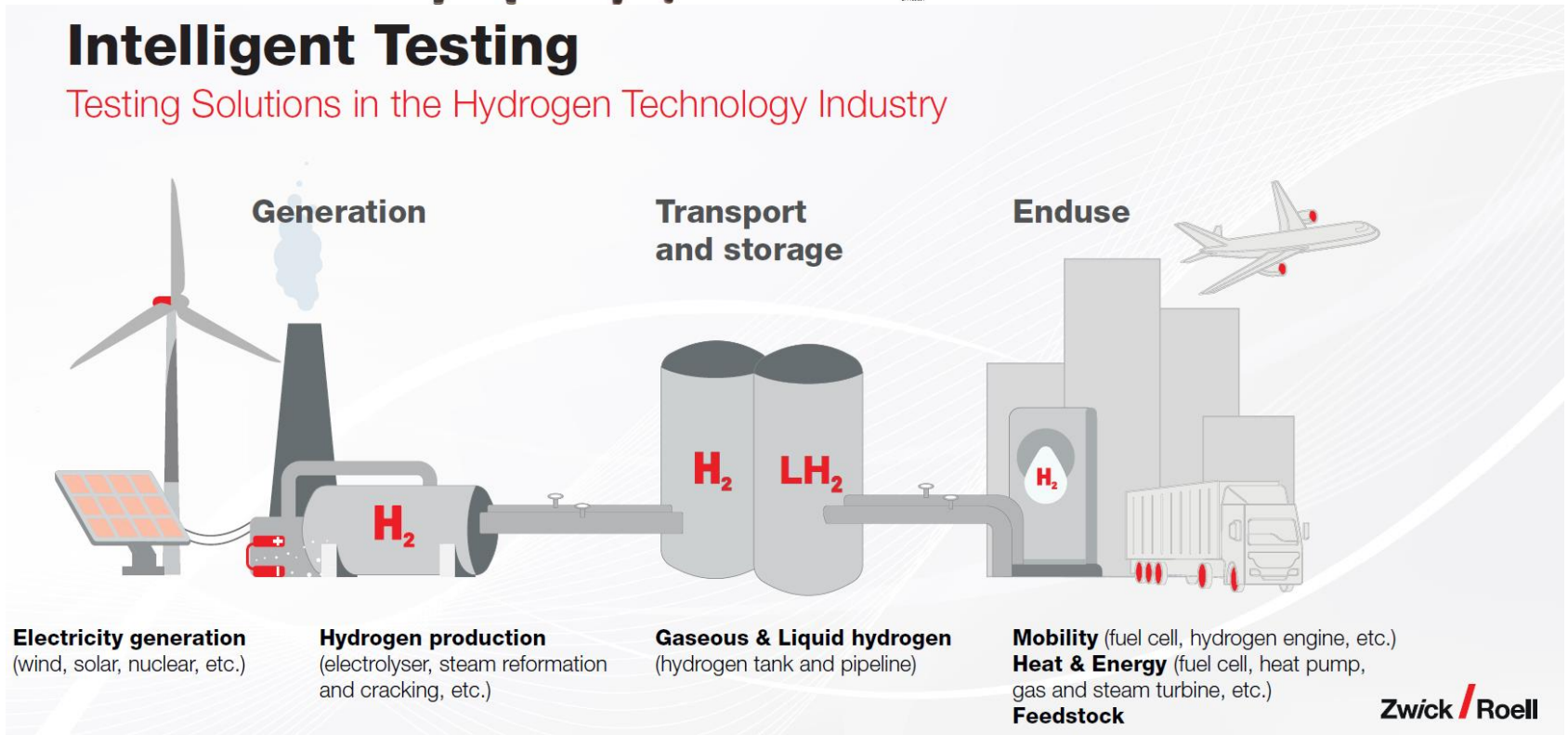
Zwick / Roell

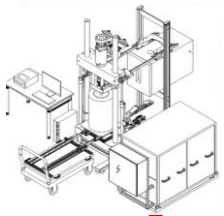
ZwickRoell offers testing solutions covering the whole hydrogen value chain.











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