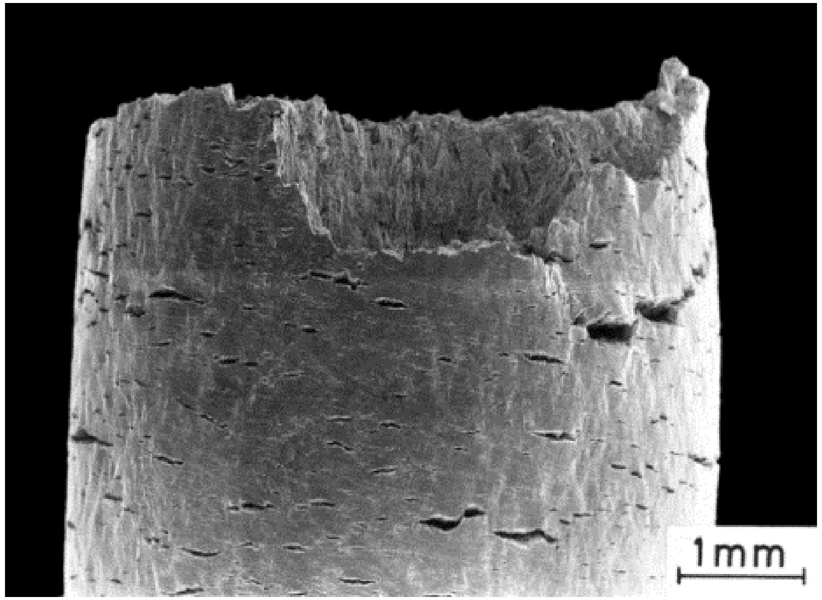
Intelligent Testing

Challenges and Solutions in Materials Testing under Hydrogen Influence

testXpo 2021



Hydrogen is a promising energy source for emission-free mobility

www.airbus.com

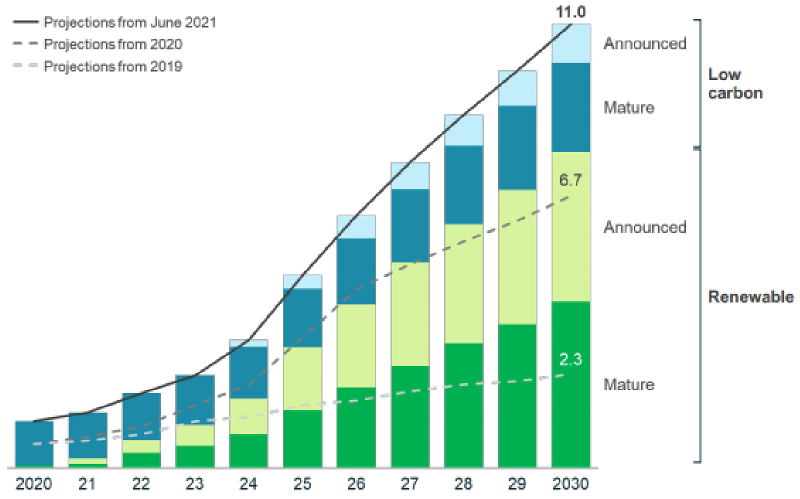
Source: Webseiten: Nikola Motors, Toyota, Airbus, Siemens, DFDS

Considerable growth in hydrogen usage expected

Zwick Roell

Exhibit 2: Announced clean hydrogen capacity through 2030

Cumulative production capacity, Million tons p.a.



>60%
increase in capacity
announced in the past 5 months

69 GW
clean hydrogen capacity
by 2030 announced

+7.7 Mt
additional capacity
(low carbon and renewable)
announced for post-2030

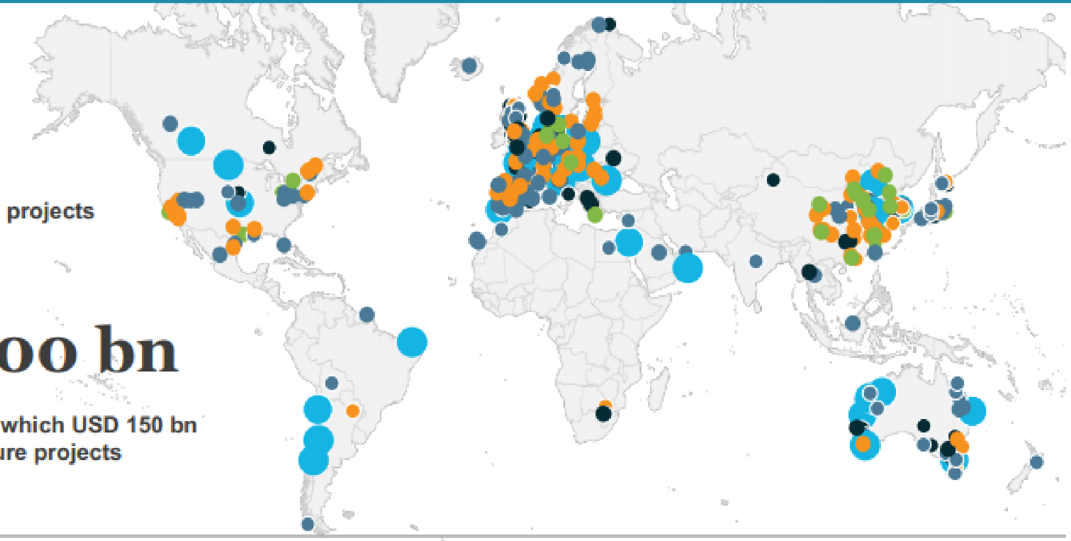
Exhibit 1: Global hydrogen projects and investment across the value chain

359

Announced large-scale projects

~USD 500 bn

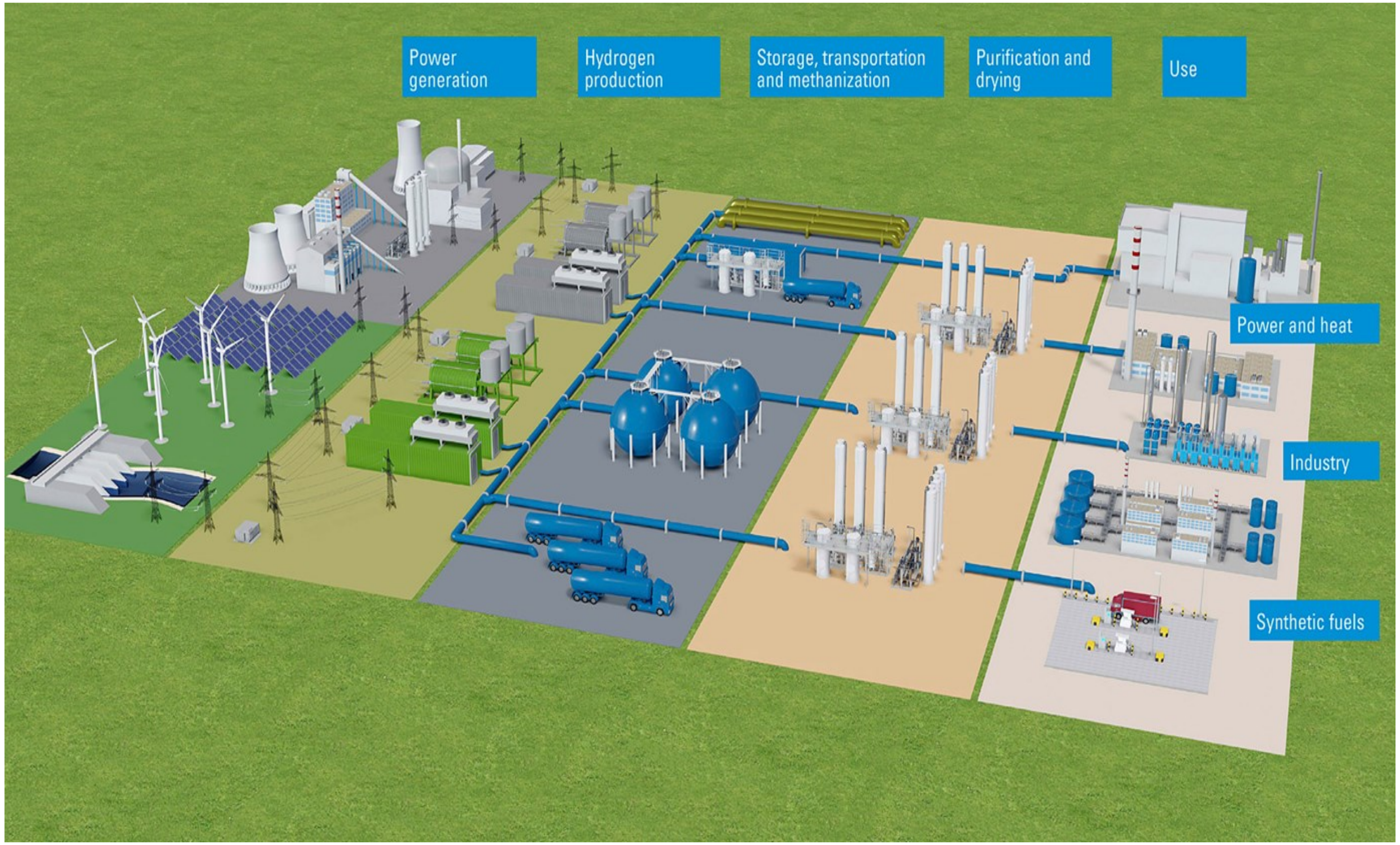
investment by 2030, of which USD 150 bn is associated with mature projects



28	141	96	56	38
Giga-scale production	**Large-scale industrial usage**	**Transport**	**Integrated hydrogen economy**	**Infrastructure projects**
Renewable hydrogen projects >1 GW and low-carbon hydrogen projects >200 ktpa	Refinery, ammonia, methanol, steel, and industry feedstock	Trains, ships, trucks, cars, and other hydrogen mobility applications	Cross-industry and projects with different types of end uses	Hydrogen distribution, transportation, conversion, and storage

Source: Hydrogen Insights Report 2021, Hydrogen Council & McKinsey, Update 15.07.21

Value chain of hydrogen industry & material challenges



Source: Bilfinger website 08/2021

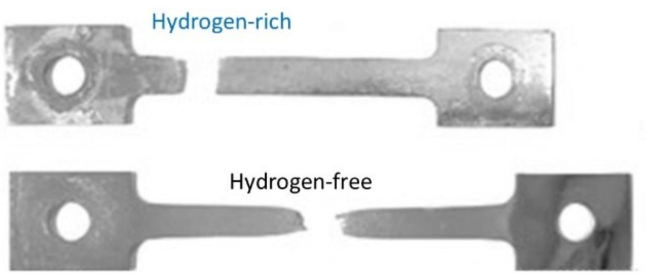
Production
Electrolyzers (Components,…)
-> Metals, various components

Storage
Stationary & Mobile storage
-> Metals, Composites, Plastics

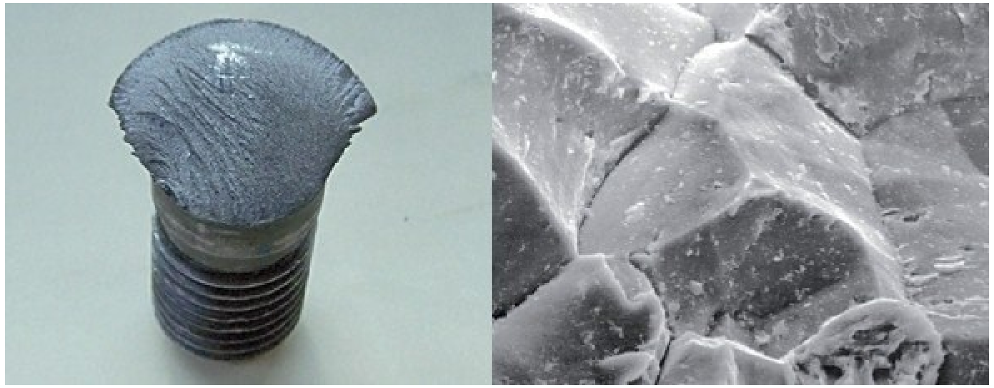
Transportation
-> Pipelines, Pipes, Vehicle
(Liquid, Pressurized)
-> Metals, Plastics

Transformation & Use
-> Energy & Heat (Fuel Cell, Combustion Eng.)
-> Chemical Industry (Equipment, …)
-> Mobility (Fuel Cells, Tanks, Synth. Fuels…)
-> Various components

Examples of hydrogen embrittlement



Hydrogen-Induced Cracks (HIC)



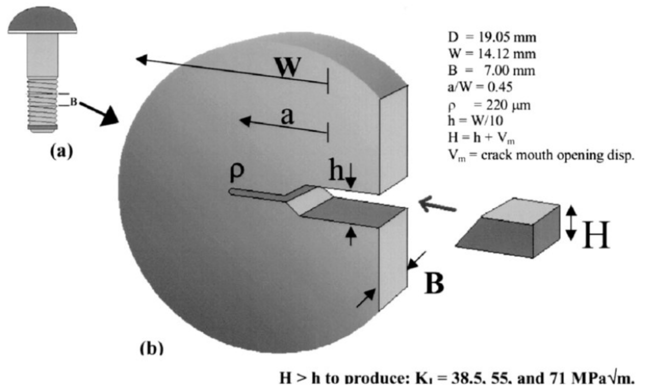
Source: Wikipedia

Applications for Tubes and Pipes

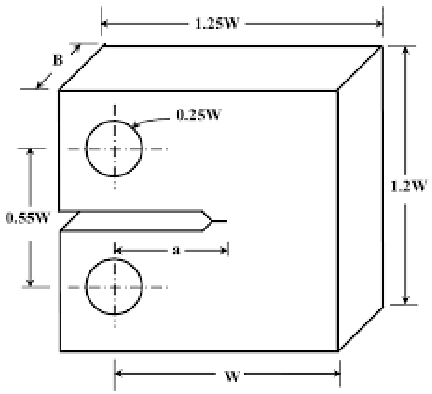
ZwickRoell

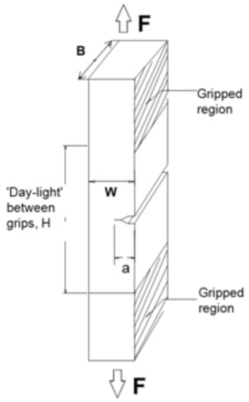
For H2 applications streel grades need to be further investigated concerning durability.

- **Fracture toughness** in hydrogen environment KIH:
  - **WOL specimen;**
  - **As per ASME B31:12 Option B (ASME BPVC Sec. VIII, Division 3, article KD-10 (ASTM E1681, constant displacement configuration, 1000 h of exposure);**
  - **K-rate: 0.005** $MPa{\cdot}\sqrt{m}/s$**;**
  - **Total 3 (three) specimens;**
  - **Deliverables: KIH value & fracture surface analysis**



Schematic representation of the standard specimens machined from the bolts for mechanical testing.



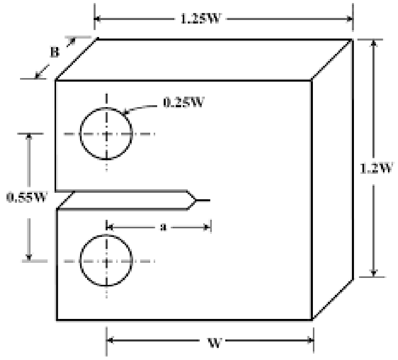


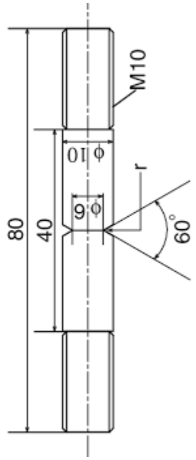
- **Fracture toughness** in hydrogen environment KJICH:
  - **C(T) specimens or SEN(T)**
  - **As per ASTM E 1820 "Standard Test Method for Measurement of Fracture Toughness";**
  - **K-rate: 0.005** $MPa{\cdot}\sqrt{m}/s$**;**
  - **Total 3 (three) specimens;**
  - **Deliverables: KJICH value & J-Da curve & fracture surface analysis**

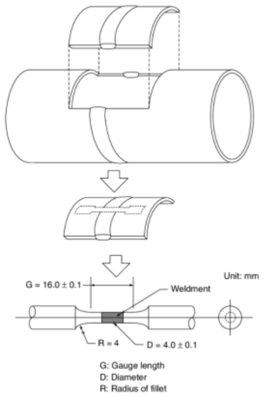
Applications for Tubes and Pipes

For H2 applications streel grades need to be further investigated concerning durability.

- **Fatigue crack growth rate** tests:
  - **C(T) specimens;**
  - **As per ASTM E 647;**
  - **Test frequency <=0.1 Hz;**
  - **Load ratio R = 0.5;**
  - **Total 3 (three) specimens;**
  - **Deliverables: Paris curve & fracture surface analysis**

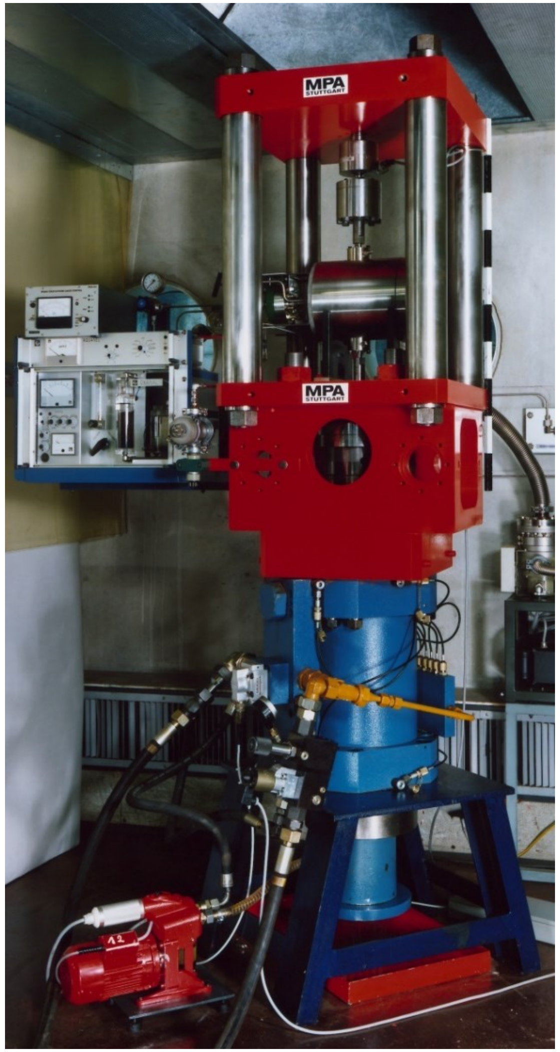


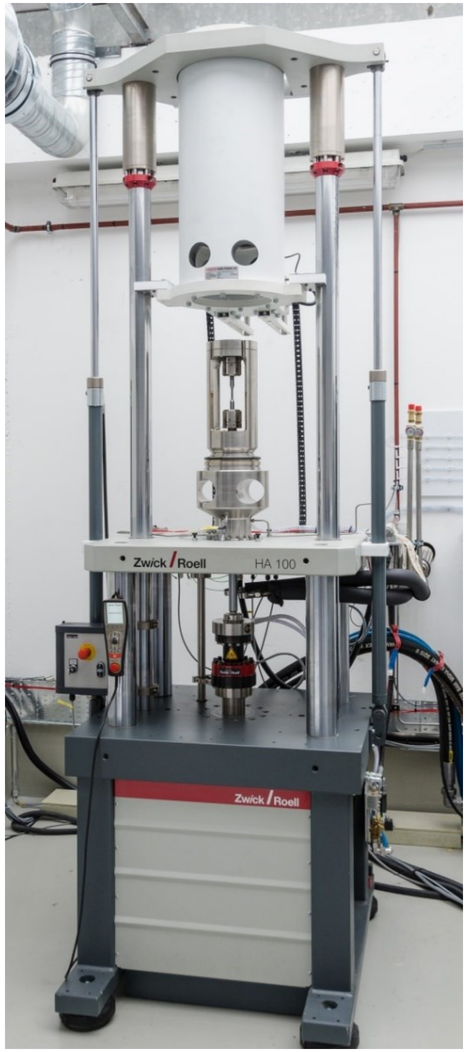




- **Slow Strain Rate Tests** (SSRT):
  - **Round specimens;**
  - **As ASTM G142 at low strain rate (10^{-6} s^{-1} as per ASTM G129);**
  - **Total 3 (three) specimens;**
  - **Deliverables: Tensile curves & fracture surface analysis**

Overview Test Systems at MPA Stuttgart





Creep testing applications

- Mechanical testing of 4 specimens per test
- Investigation of plating/coating processes that can cause hydrogen embrittlement in steels
- Form fitting grips for tests at ambient temperatures
- Safety device to avoid injuries
- Ambient temperature , test time up to 200h
- No extensometer needed – only force measurement
- High modularity of Kappa 50 DS covering all requirements of ASTM F519-13 and ASTM 1624

Load line with
4 specimens

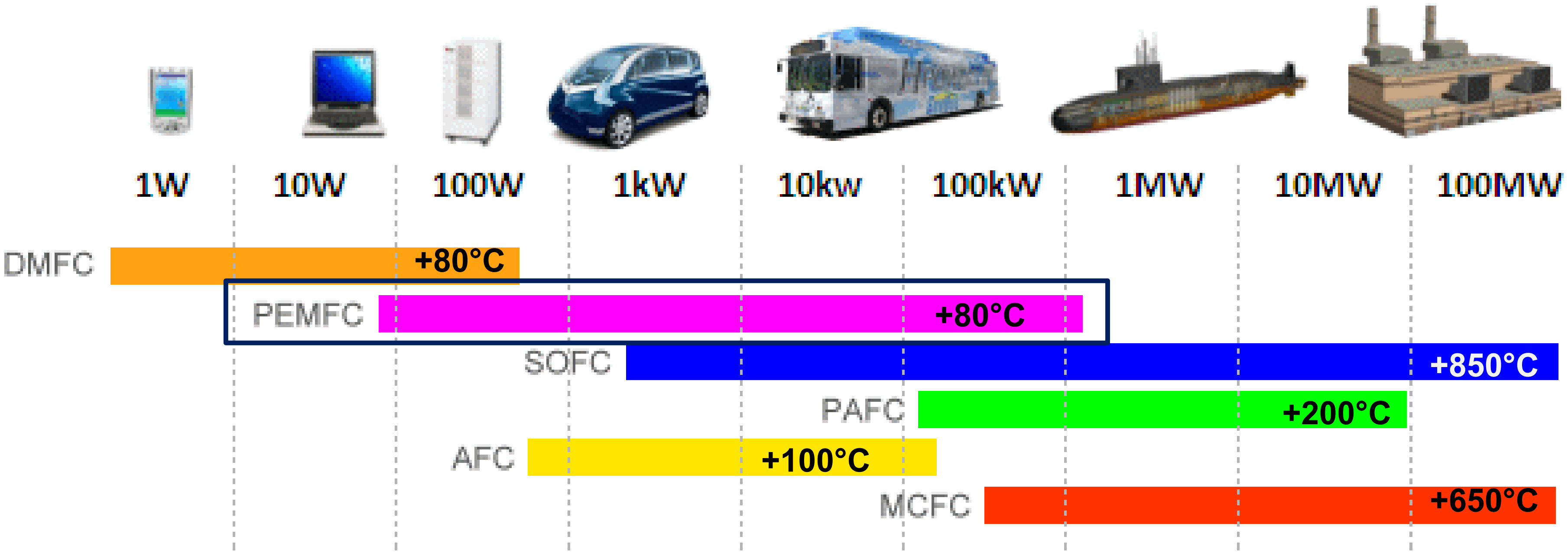
Tensile test acc. ASTM E8
→ NFS (notched fracture strength)

Mechanical testing of CFRP for H2 applications

- **Static composite standard tests are necessary, typically at cryogenic temperatures:**
  - Tensile test according to ISO 527-4.5 or ASTM D3039
  - Compression test according to ISO 14126 or ASTM D3410, D6641, D695
  - In-plane shear test according to ISO 14129 or ASTM D3518
  - Interlaminar shear strength (ILSS) according to ISO 14230 or ASTM D2344
  - Flexure test according to ISO 14125 or ASTM D7264
  - Lap shear for bonded joints according to EN 1465 or ASTM D3164
  - Interlaminar Fracture Toughness Mode II according to ASTM D7905

- **Composite fatigue tests at cryogenic temperatures:**
  - Tensile test according to ISO 13003 or ASTM D3479
  - Bending test according to ISO 13003 Annex A

Types of fuel cells and material challenges



Fuel cell material requirements:

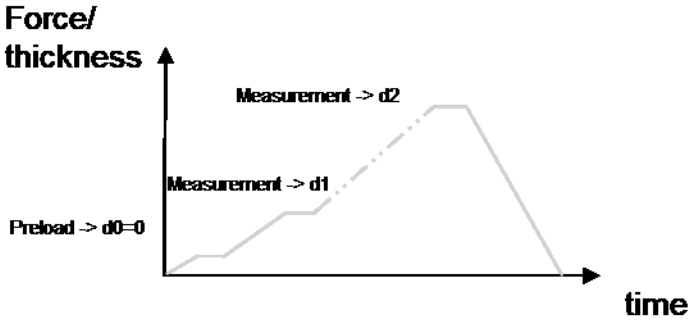
- Uniform temperature distribution
- Corrosion resistance
- H2 resistance
- Permanently high conductivity
- Low deformation
- High creep resistance
- Zero leakage

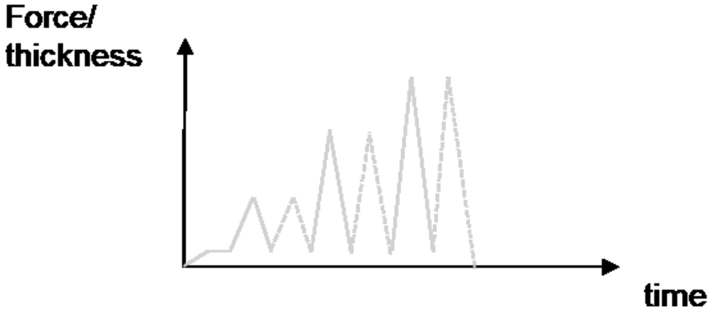
- High Temperature Components: Durability?

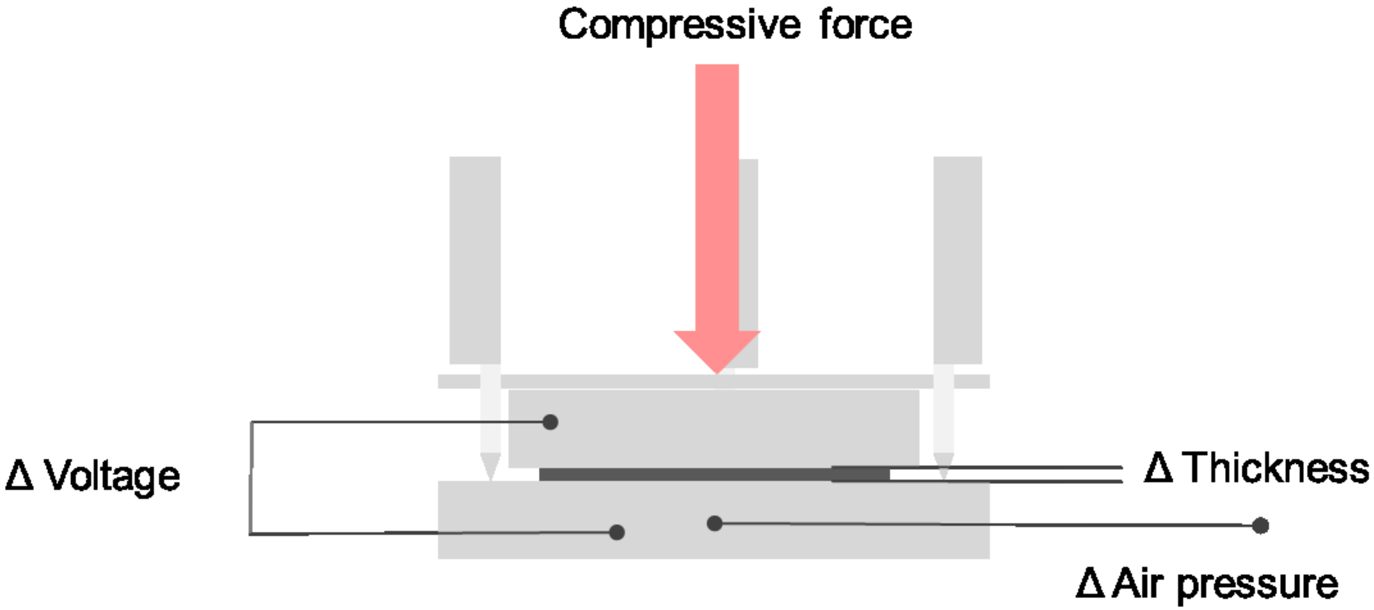
Source: http://www.antig.com/technology/technology_fuel_cell_types.htm
Roth, W, Benz, J, Ortiz, B, Sauer, Dirk, Steinhüser, A, 2003/09/25, Fuel cells in photovoltaic hybrid systems for stand-alone power Supplies; 2nd European PV Hybrid and Mini Grid Conference, Kassel

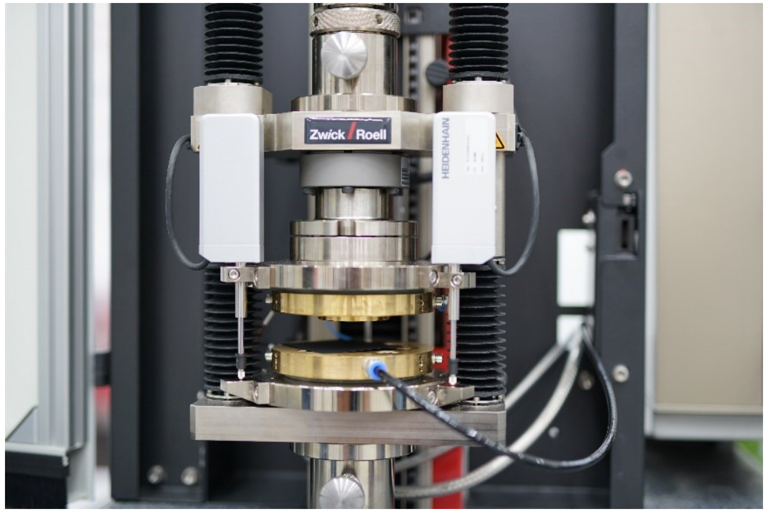
Example: TUC/RUC/PUC Testing of Gas Diffusion Layer

Typical GDL samples





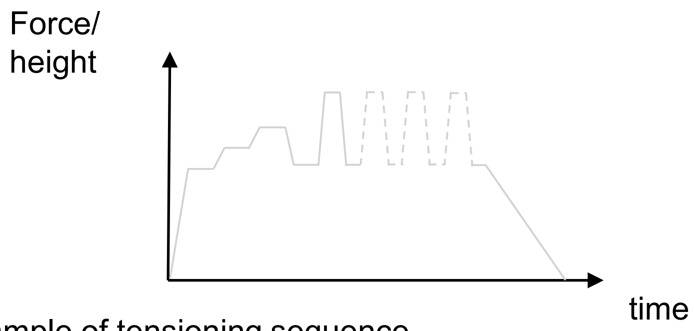




Example: Solution for tensioning of fuel cell stacks

Fuel Cell Stack Compression

Source Fuel cell: ElringKlinger article



Example of tensioning sequence

High Precision Compression Machine
with Fuel Cell Stack compression tool