



THE STRONGEST LINK.

STAHL

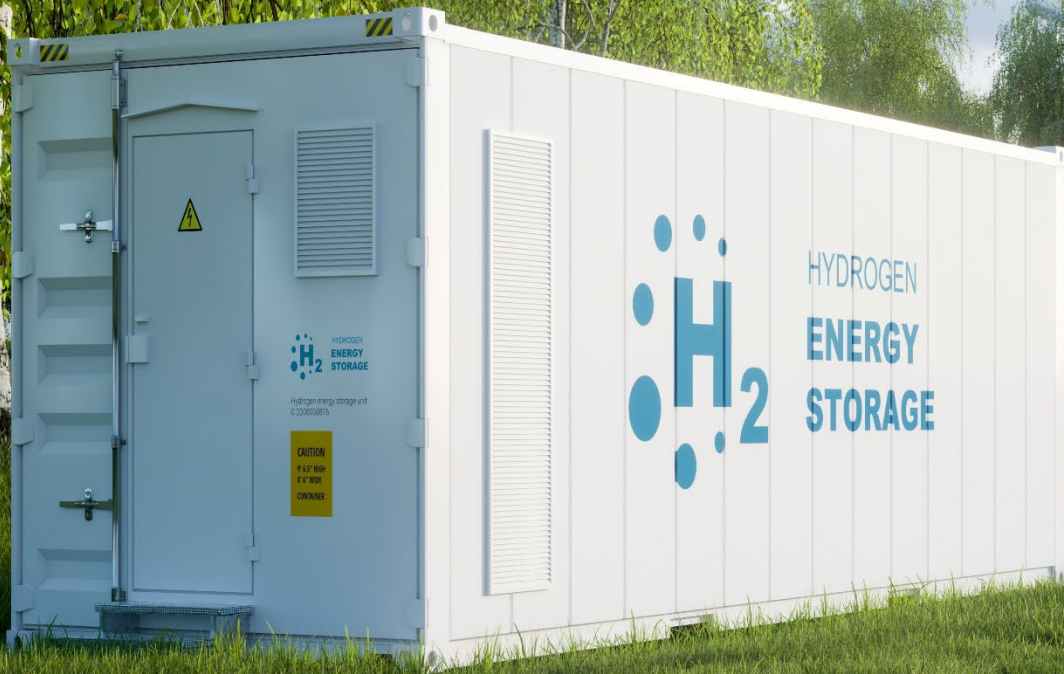
STANDARDS AND INTERNATIONAL CERTIFICATION SCHEME FOR EQUIPMENT USING HYDROGEN TECHNOLOGIES

Prof. Dr. Thorsten Arnhold – R. STAHL AG Germany



“water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable”

Jules Verne in The Mysterious Island



To usher in the hydrogen economy, South Korea passed the world's first hydrogen law. It centers on the development of an ecosystem for a hydrogen economy and expanded public access to the alternative fuel.....

....Most importantly, the hydrogen law tackles the **safety issues that had long remained in a regulatory blind spot**. Previously, hydrogen equipment – electrolyzers, portable fuel cells and hydrogen extractors – and fuel cell facilities that directly used hydrogen weren't subject to periodic government safety checks. **Now, safety assurance will be carried out in three steps -- technological safety at the design stage, an on-site examination upon completion of a facility, and annual safety checks....**



CANADIAN H2 STRATEGY: AWARENESS FOR SAFETY ISSUES IS CURRENTLY LACKING

AWARENESS

There is currently a lack of awareness about the opportunities for hydrogen and around safety issues, both by the public, as well as within industry and government.

Limited domestic hydrogen deployments have further resulted in a lack of tangible case studies to increase awareness and support long-term planning and buildout. For example, mine safety and reliability must be successfully proven in the pilot stage before technology can be fully adopted.



THERE ARE MANY MISUNDERSTANDINGS IN THE MARKETS...

ABC Inc.

Home Products ▾ Development ▾ Career ▾ Company ▾

10 important questions about hydrogen

01 | What is hydrogen? +

02 | How does the energy density of hydrogen compare to conventional fuels? +

03 | How dangerous is the use of hydrogen? +

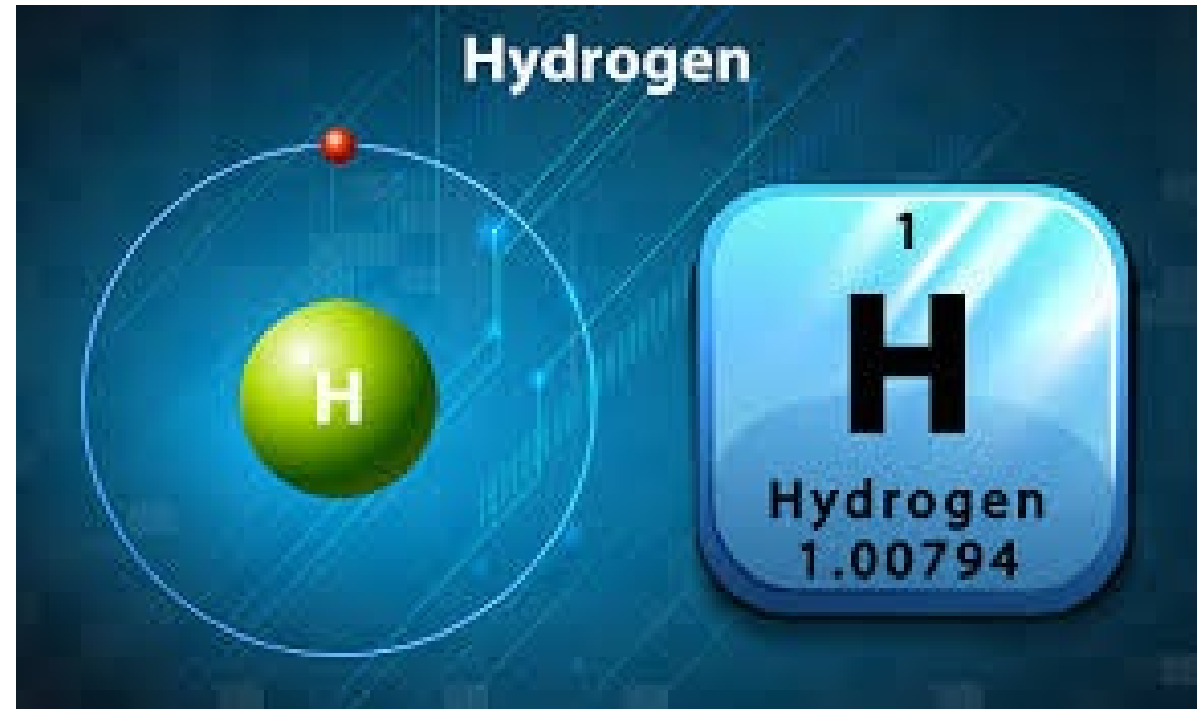
04 | Is hydrogen explosive? -

No. Hydrogen-air mixture is combustible, but does not explode. A mixture of hydrogen and pure oxygen (oxyhydrogen) is explosive.

SOME HYDROGEN SPECIFIC INFORMATION

TECHNICAL REPORT ISO/TR 15916: 2015

- Overview of hydrogen applications
- Basic properties of hydrogen
- Safety considerations for the use of gaseous and liquid hydrogen
- Team approach and education/training needed for the safe use of hydrogen
- Mitigation and control of hazards and risks
 - Deflagration and detonation
 - Oxygen enrichment
 - Gas detection (ISO 26142); fire detection
 - Many other aspects



IMPORTANT US REGULATIONS REGARDING HYDROGEN SAFETY

ANSI/AIAA G-095A-2017
(Revision of AIAA G-095-2004)

Guide

American National Standard

Guide to Safety of Hydrogen and Hydrogen Systems

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Order Number: 92324791
Sandia National Laboratories
87185 and Livermore, California 94550
Revised for Review 2022-11-23 15:05:44 UTC

*This report contains an overview
of the regulations that apply to hydrogen*

SANDIA REPORT

SAND2021-2955
Printed March 2021



Federal Oversight of Hydrogen Systems

Austin R. Baird, Brian D. Ehrhart, Austin M. Glover, Chris B. LaFleur

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico
87185 and Livermore,
California 94550



Hydrogen Technologies Safety Guide

C. Rivkin, R. Burgess, and W. Buttner
National Renewable Energy Laboratory

*National laboratory of the U.S.
Department of Energy*

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

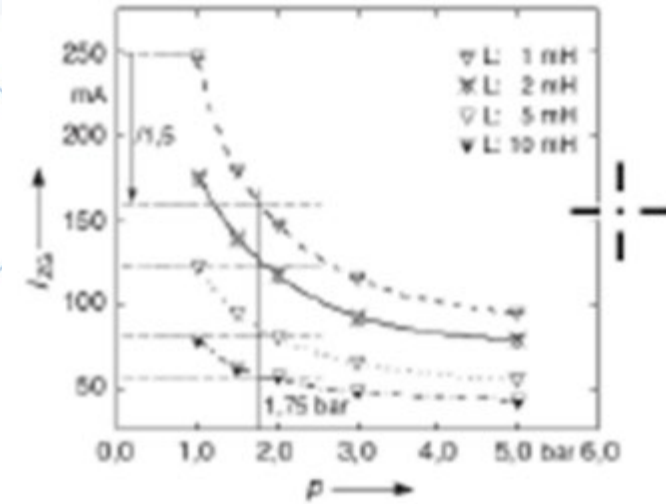
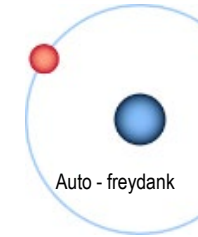
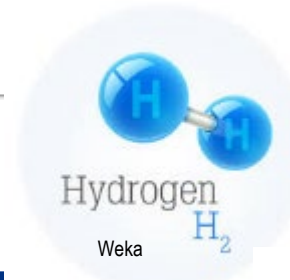
Technical Report
NREL/TP-5400-60948
January 2015

Contract No. DE-AC36-08GO28308

KEY CHARACTERISTICS OF GASEOUS HYDROGEN

Hydrogen is flammable, non-toxic and non-corrosive. It is colorless, insipid and odorless. It can suffocate people.

	Hydrogen (H ₂)	Methane (CH ₄)
Density [kg/m ³]	0.08388	0.7175
Molecule size [nm]	0.276/0.106*	0.324
Ignition temperature in air [°C]	585	540
Diffusion coefficient cm ² /s in atm air	0.768	0.215
Max. flame speed [cm/s]	346	43
Ignition range in air [vol%]	4 to 73	5 to 14
Heat conductivity [W/(m x K)]	0.18339	0.0341
Minimum ignition energy [mJ]	0.02	0.28



Zündstrom für ein Wasserstoff-Luft-Gemisch (Verh. 21/79) in Abh. vom Druck

E. Brandes; M. Thedens: Kenngrößen des Explosionsschutzes bei nichtatmosphärischen Bedingungen PTB Mitteilungen 2003

*ionised

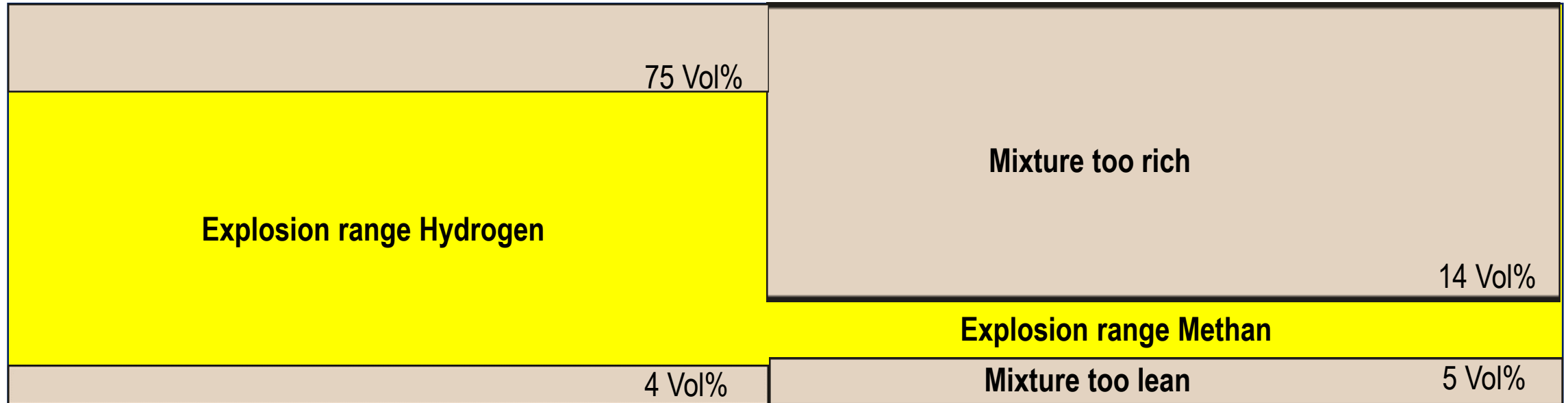
HYDROGEN IS 14 TIMES LIGHTER THAN AIR!

- Outdoors, the extremely low density allows released hydrogen to escape quickly into the atmosphere.
- If there are obstacles in the way (e.g. covers or roofs) or if it is released in rooms, the extremely high buoyancy of the hydrogen creates very large concentration differences between the exit point and the area under the ceiling in a very short time.
- The turbulence that arises in the hydrogen flow can easily lead to detonation transitions.



WorldPress

EXTREMELY BROAD EXPLOSION RANGE !



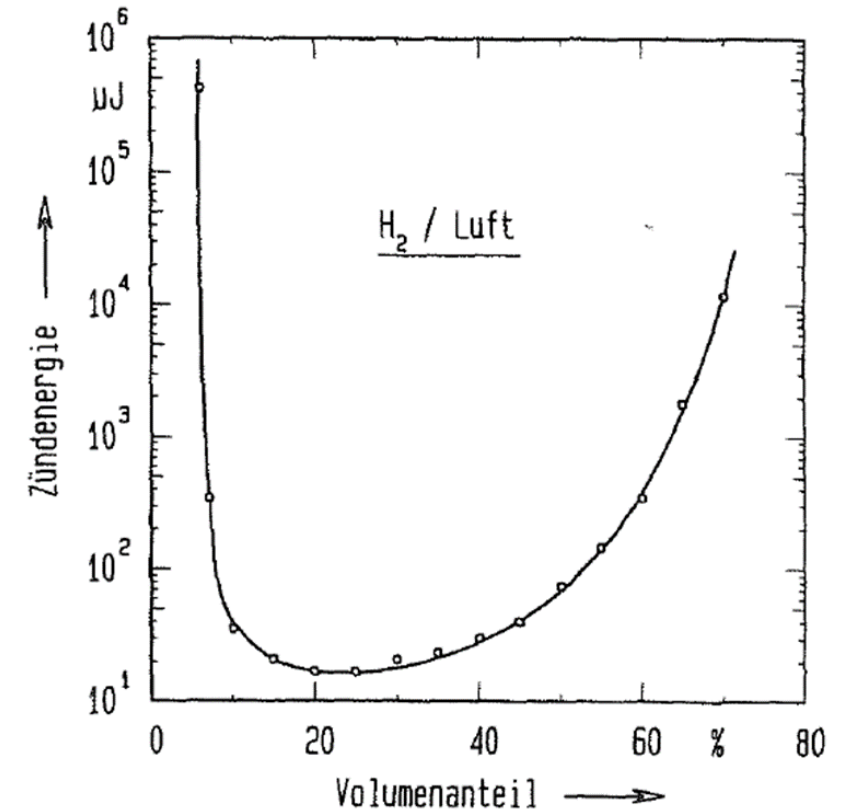
Pressure dependence of the hydrogen explosion limits

The behavior of the UEL is in comparison with other fuels atypical!

Pressure / bar	1	10	100
LEL in Vol-%	4,3	4,9	5,8
UEL in Vol%	78,5	72,4	74

MINIMUM IGNITION ENERGY

The ignition energy is extremely low over a relatively wide concentration range of 10...50%: below $10^2 \mu\text{J}$



Source: Reichelt Chemietechnik; Explosion protection manual

VISCOSITY

- Viscosity is the internal resistance of a fluid to shear stress.
- Due to its small molecule size, hydrogen has a very low viscosity.
- **As a result, the flow rate is relatively high if the gas escapes through leaking (porous) areas of seals, conduits, etc.**
- GRAHAM effusion law
 - Average molar mass of air: 29 kg/kmol
 - Average molar mass of H₂: 2 kg/kmol
 - Average molar mass of CH₄: 16 kg/kMol
- **Airtight does not mean hydrogen-tight!**



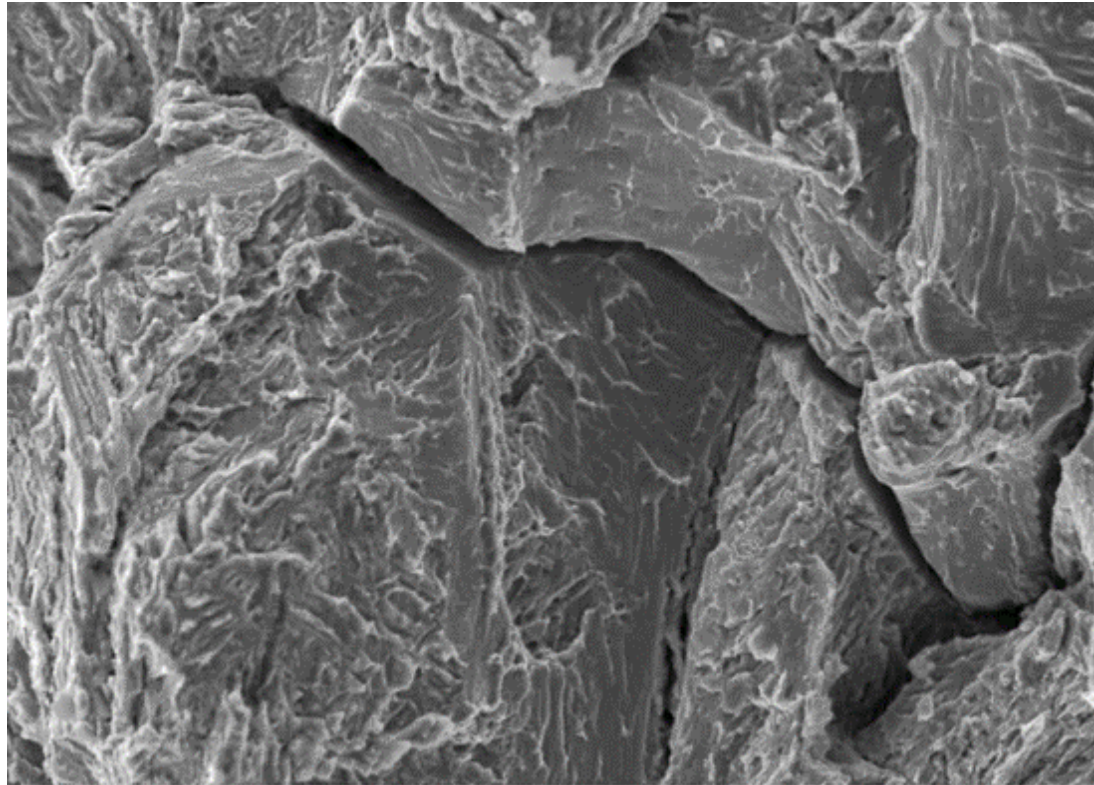
Grahams Effusion law

$$\frac{v_1}{v_2} = \sqrt{M_2/M_1}$$

$$v_{H_2} = 3,8 \cdot v_{Air}$$

Source: HAZ/TU Clausthal Regenerative Energiequellen WS 2007/2008

HYDROGEN EMBRITTLEMENT



typischer H-induzierter Bruch an 300M, 15kV, X1846, WD5mm

10 μm

Steinbeis

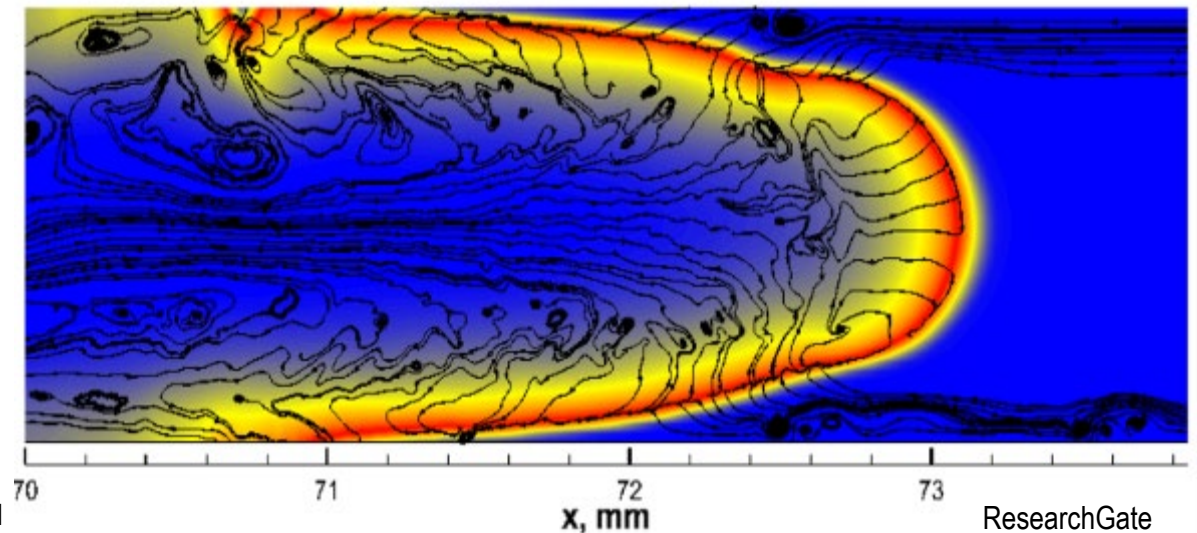


VauQuadrat

COMBUSTION SPEED: LAMINARE BURNING VELOCITY

Fuel	V_{flame} in cms^{-1} nach 1)	V_{flame} in cms^{-1} nach 2)
Acetylen	173	155
Methan	36,4	44,8
Wasserstoff	320	325

Laminar burning velocity: movement of the flame front in a homogeneous gas-air mixture per unit of time perpendicular to the flame front in the unburned mixture.



- 1) Mannan S. (2005) Lees`loss prevention...3. Auflage Elsevier, Amsterdam
- 2) Center for chemical process safety (1994) Guidelines for evaluating the characteristics of vapour cloud explosions...American Institute of Chemical Engineers, New York

TECHNICAL RISKS WHEN HANDLING HYDROGEN

...result from:

the physical and chemical properties of hydrogen

the influence of hydrogen on the material properties

the uncontrolled release in accident situations (pressure)

the low temperatures of liquid hydrogen

Technikfolgen-Abschätzung für den Deutschen Bundestag

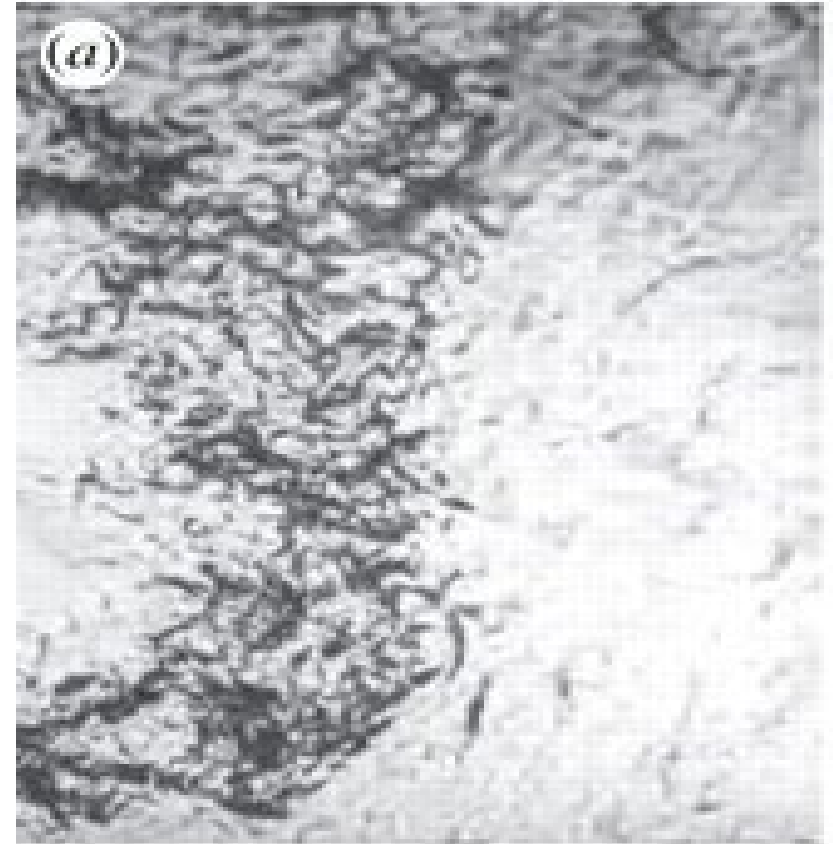
Das TAB – Erfahrungen und Perspektiven
wissenschaftlicher Politikberatung



HYDROGEN EXPLOSIONS DEFLAGRATION AND DETONATIONS RESULTING HAZARDS

HYDROGEN DEFLAGRATION AND DETONATION

- Expansion due to diffusion of heat and radicals
- Combustion speed of hydrogen is between 2 and 3 m/s, therefore 10 times higher than that of hydrocarbons!
- The visible spread (flame speed) is even higher due to the additional force from hot combustion products
- Blockages in the direction in which the flames spread can significantly increase the pressure and flame speed (8 to 10 bar)
- The upper limiting value is the speed of sound in a stoichiometric H₂/air mixture



Geraint Thomas: Some observations on the initiation and onset of detonations;
The Royal Society publication 2012

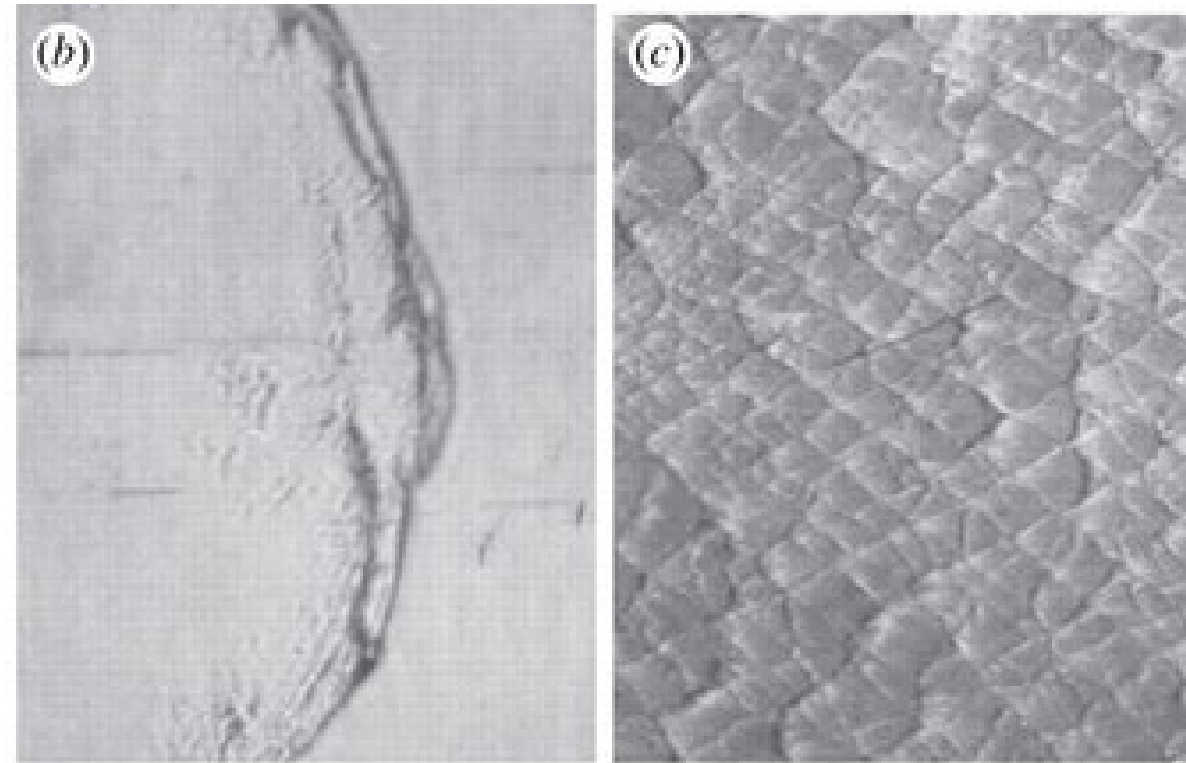
DEFLAGRATION TO DETONATION TRANSITION (DDT)

- Reason: closed rooms and obstacles in the way the flame spreads
- Pipes, containers, walls can significantly increase the flame speed
- Above a certain speed, turbulence and instability occur, which ultimately leads to detonations.



DETONATION OF HYDROGEN

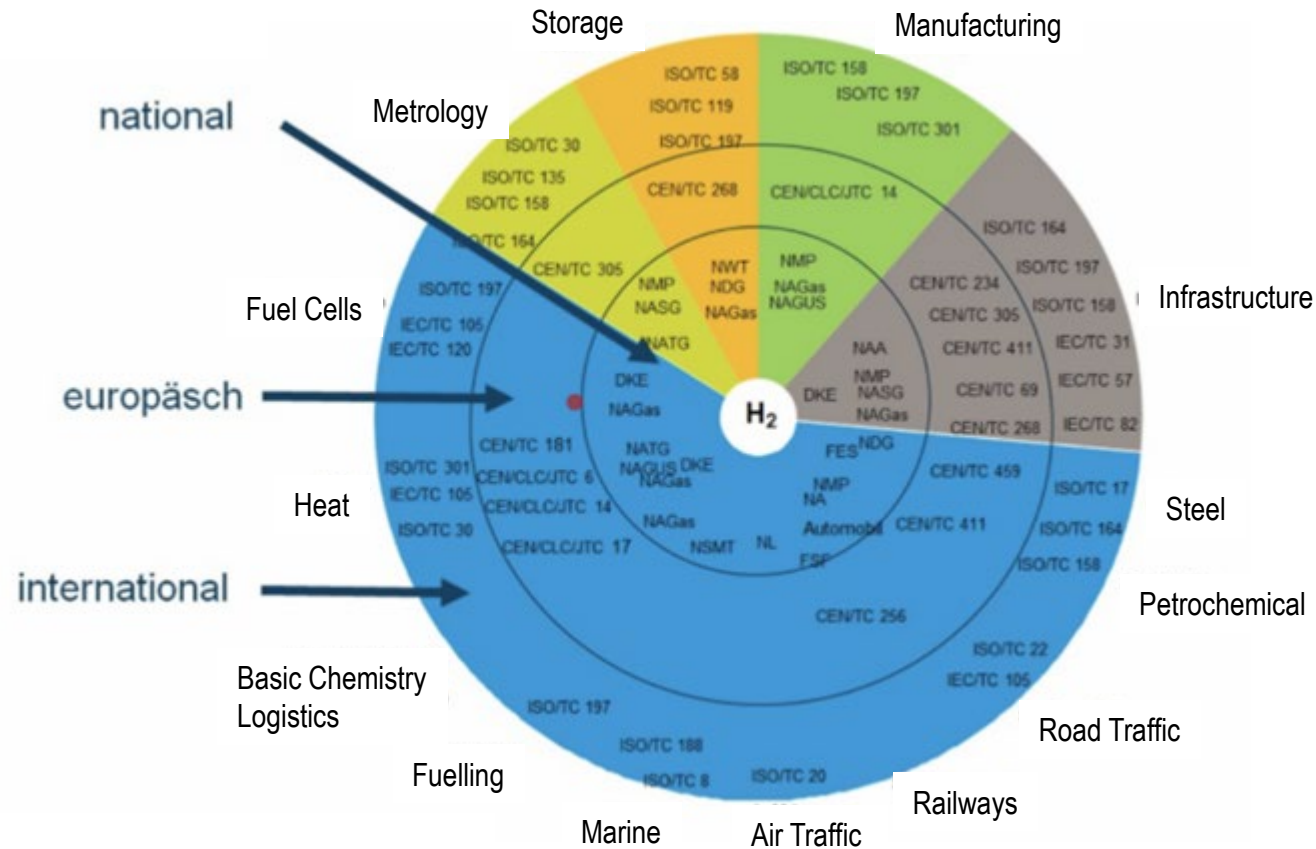
- Spread due to adiabatic heating due to shock waves
- Caused by significant pressure increase in uncombusted mixture and/or very high ignition energy input
- Spread speeds between 1500 m/s and 3400 m/s.
- Detonation pressures between 15 and 20 bar
- Detonation propagation occurs in the form of a spatial wave structure, depending on the concentration, temperature and pressure in the mixture.



Geraint Thomas: Some observations on the initiation and onset of detonations;
The Royal Society publication 2012

BASIC ELEMENTS OF SAFETY CONCEPTS FOR HYDROGEN

HYDROGEN STANDARDS MAP



Source: Fraunhofer

RISC ANALYSIS AS THE STARTING POINT AND THE BASEMENT

- The manufacturer must perform a risk analysis using one or more methods according to IEC 31010, Annex B, i.e.
 - HAZOP, fault tree analysis (FTA), FMEA, Markov analysis
- and/or ISO 12100 "Safety of machines".
- Normal operation and relevant error conditions must be observed during this process
- When planning the system, the requirements of ISO 12100 must be followed.



Source: Sunfire

PRIMARY PROTECTIVE MEASURES TO AVOID EXPLOSIVE MIXTURES:

Tightness => natural ventilation => gas detection => technical ventilation => gas detection => production shut down

- Tightness of the system parts by preferably welded joints as few connections as possible
- Natural ventilation combined with hydrogen concentration monitoring
- Gas detectors according to IEC 60079-29-1 and ISO 26142
- Maximum concentration of released hydrogen is Vol-1%, with the use of gas detectors
- If necessary, switching on sufficient and reliable technical ventilation
- In the event of a failure, shut down gas production.



Chemietechnik.de

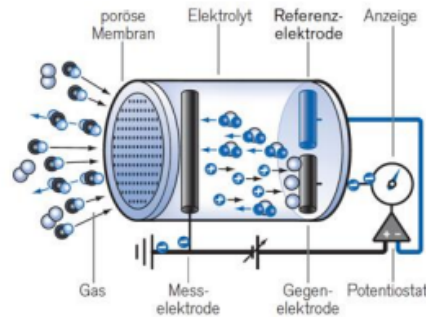
LEAK TIGHTNESS OF THE SYSTEM PARTS: EN 1127-1:2019: ANNEX B

- **Normal leak tightness:** No release is expected during normal operation; if this does occur, it is rare and for a short time.
- **Increased leak tightness:** No release at all is expected, and no explosive atmosphere can form in the surrounding environment
- One potential way to achieve increased leak tightness is the use of continuous gas monitoring with an appropriate degree of functional safety
- **ISO 26142:** Stationary gas warning equipment for H₂



VDI, Trotec

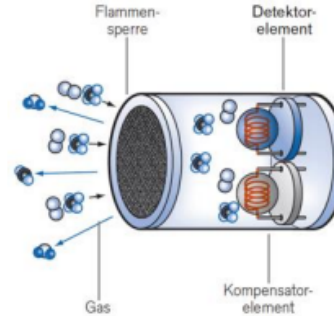
BASIC TECHNOLOGIES FOR GAS-DETECTION



Electrochemical Sensor

work similar to batteries and fuel cells.

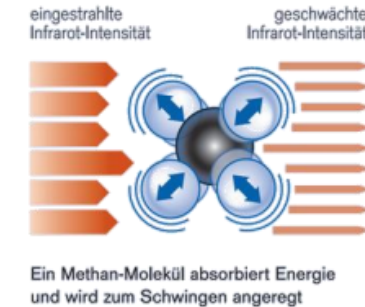
- Target substance reacts **chemically** and creates an electrical charge between two electrodes.
- The **signal strength** is proportional to the gas concentration



Catalytic bead sensor (CatEx)

oxidize combustible gases releasing heat.

- A suitable temperature-controlled catalyst material is used, which is also **heated up** measurably by the heat of reaction.
- This **slight increase** in temperature is a **measure** of the gas concentration.



Infrared sensor (IR)

measure the change in **intensity of infrared radiation** absorbed by target substances.

- Infrared is weakened by C-H but not by H-H bonds.
- - Methane can be measured with an IR sensor, but **not hydrogen**

Informationen und Bilder aus DrägerSensor® & Gasmessgeräte-Handbuch, 4. Ausgabe, 2018 Dräger Safety AG & Co. KGaA

EXPLOSION PROTECTION BY AVOIDING IGNITION SOURCES

- When it comes to Ex protection, zone classification as per IEC 60079-10-1 must be performed and, if necessary, ignition protection methods as per IEC 60079-0 ff. must be implemented.
- The specific Ex conditions in oxygen-rich atmospheres must be observed.
- Appropriate Emergency stop and shut down measures must be installed.



NEL

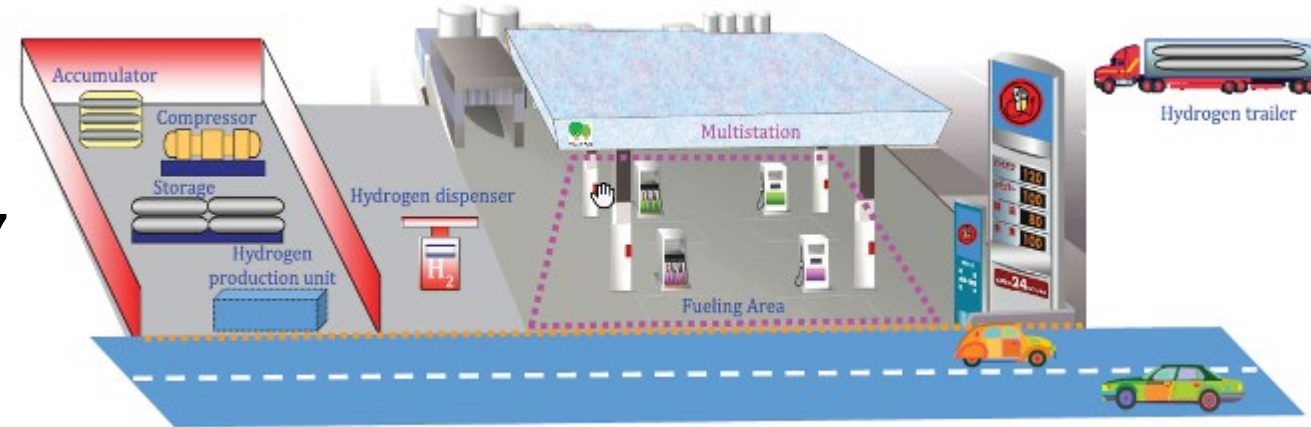
IMPORTANT MECHANICAL REQUIREMENTS

- Material must be suitable for all operationally
 - mechanical
 - thermal
 - electrical
 - chemical loads
- Enclosures must have sufficient fire resistance
- Adequate protection against electrostatic charging
- Pressure bearing components must have the required strength
- Protection against external influences

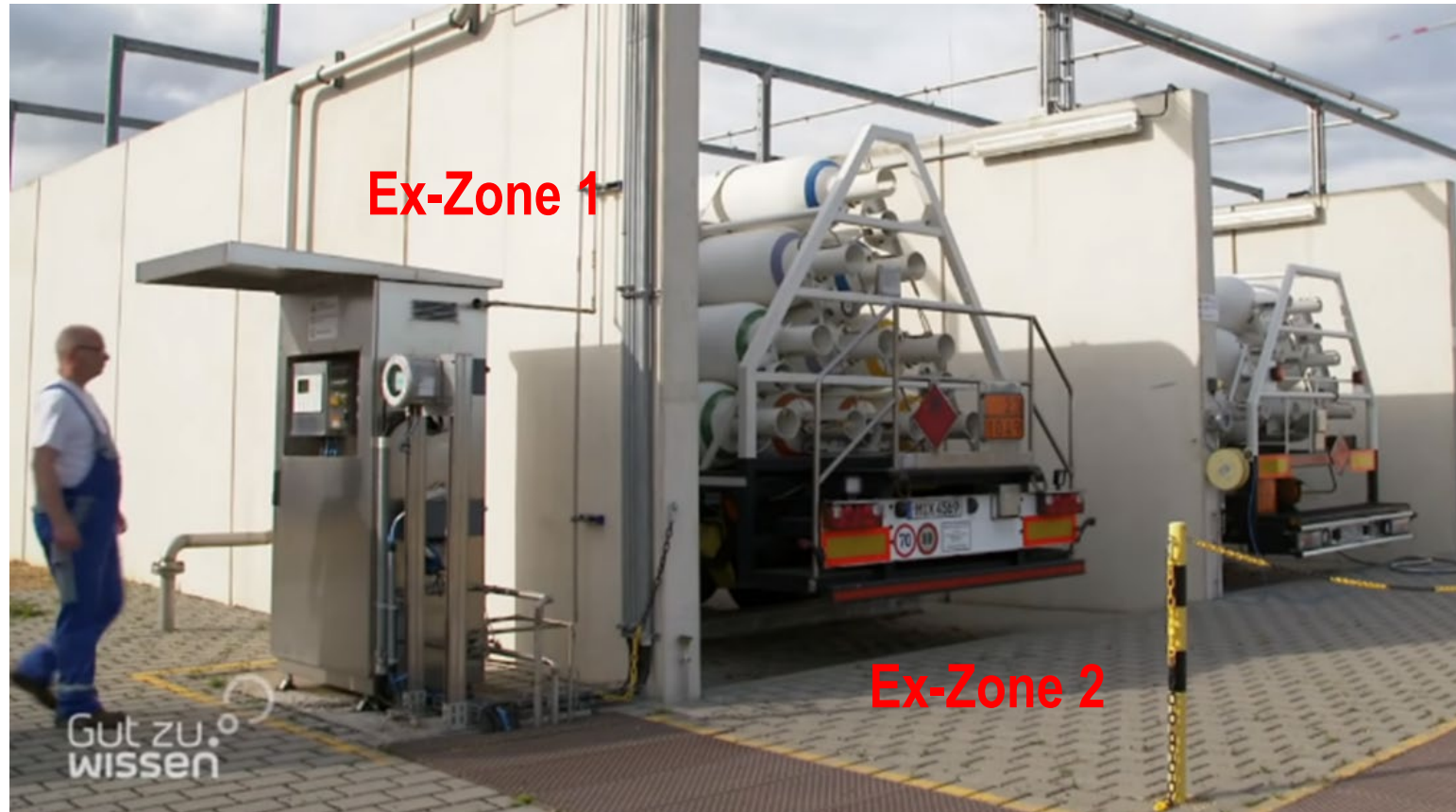


COMPETENCE FOR CORRECT PLANNING, INSTALLATION, OPERATION, INSPECTION AND MAINTENANCE IS REQUIRED!

- Zone classification as per IEC 60079-10-1
- Installation as per IEC 60079-14
- Types of protection with reference to IEC 60079 ff. and IEC 80079-36/37
- Inspection and maintenance as per IEC 60079-17



ZONE CLASSIFICATION FOR HYDROGEN TUBE FUELLING



BR

IS ALL THE EFFORT FOR SUCH A HYDROGEN SECURITY CONCEPT JUSTIFIED? WHAT EXPERIENCES HAVE BEEN MADE SO FAR WITH REGARD TO THE DANGERS OF HYDROGEN APPLICATIONS?

08. August 2023 Graz/Austria

Explosion of a Hydrogen Tank
Close to the Autobahn.

One person injured

Heavy damages in the facility.

STEIERMARK LEBEN SPORT

**KLEINE
ZEITUNG**

GRAZ & UMGEBUNG

 EINLOGGEN

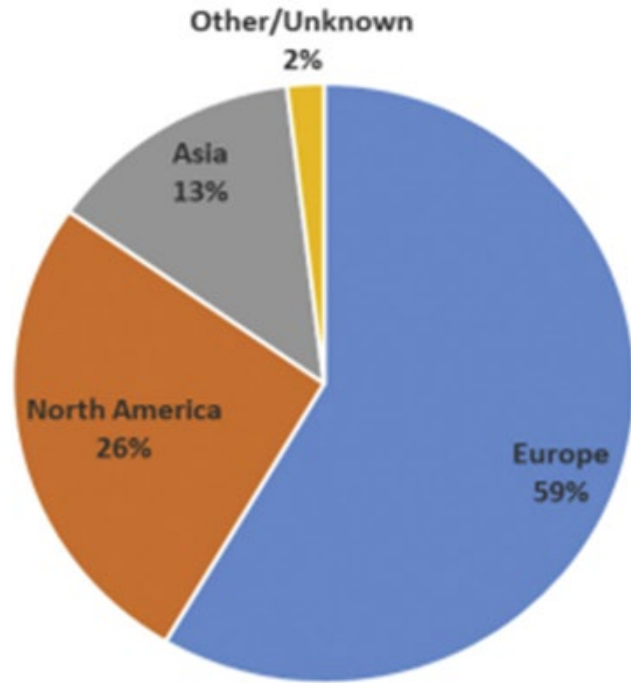
Wasserstofftank neben Autobahn explodiert, Mann (39) verletzt

Auf dem Areal einer Firma in Lebring ereignete sich Dienstagmittag eine Explosion. Ein Mitarbeiter wurde dabei leicht verletzt. Die Polizei gab am Nachmittag Entwarnung, die Gefahr sei aber noch nicht gänzlich gebannt.

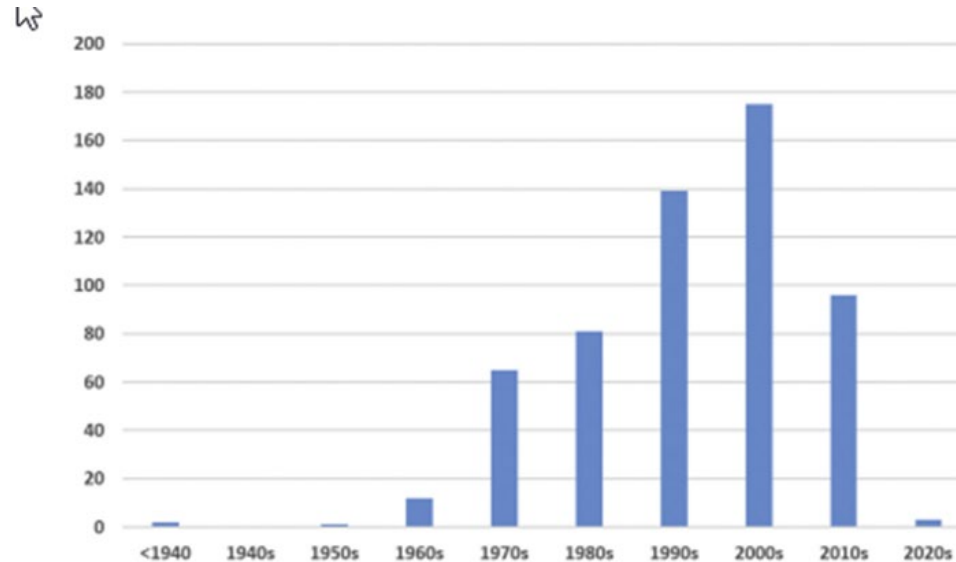


Durch die Wucht der Explosion wurde ein Teil der Anlage schwer beschädigt

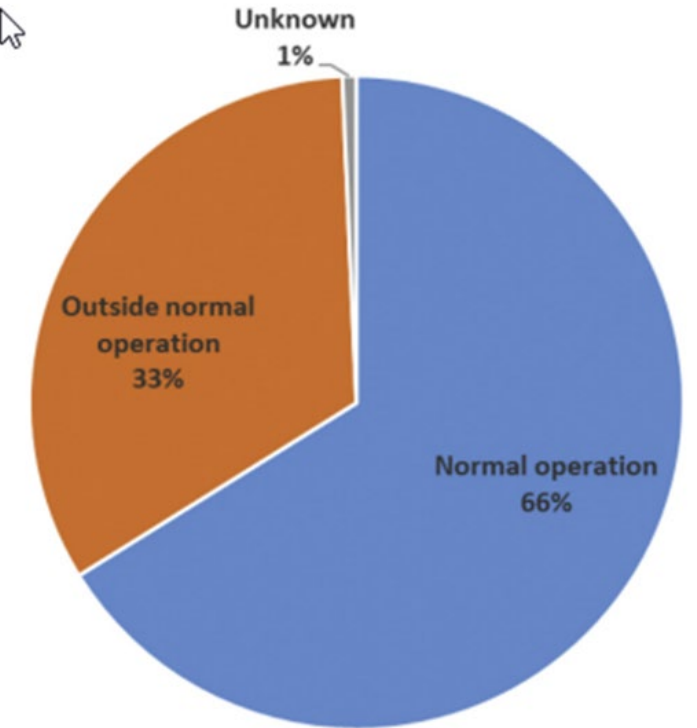
HIAD 2.0 EUROPEAN HYDROGEN INCIDENT AND ACCIDENT DATABASE @ 2022 EUROPEAN HYDROGEN SAFETY PANEL (EHSP)



Regional location of considered events



Number of the considered events per decade

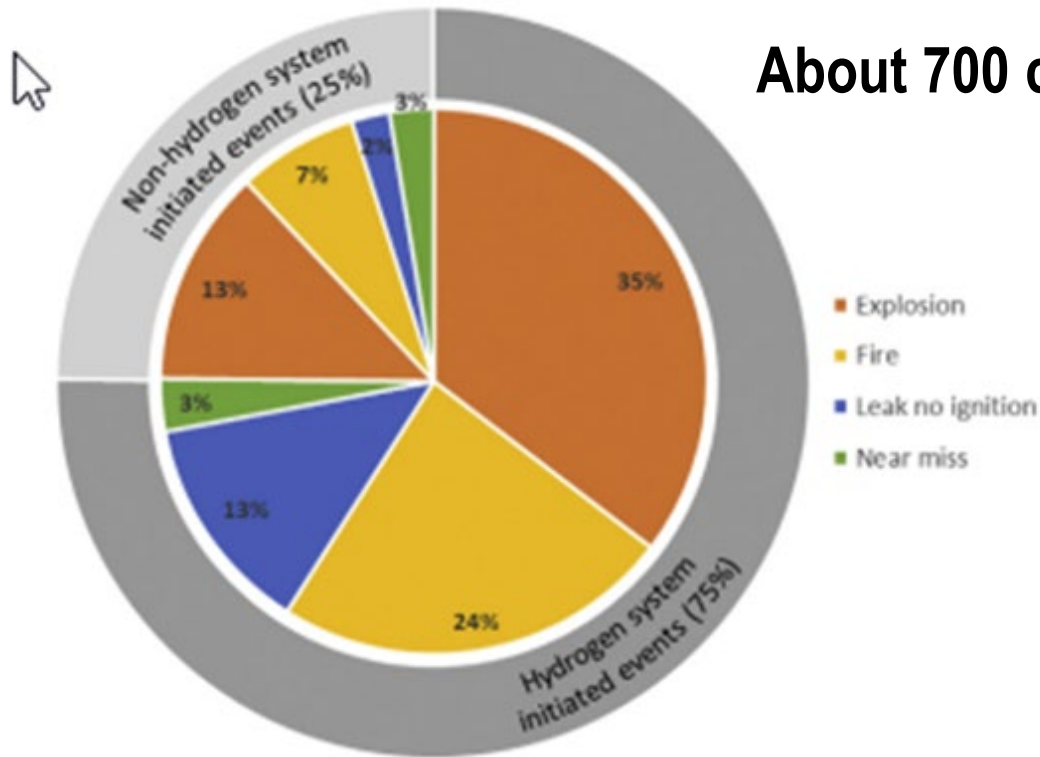


Operational Mode

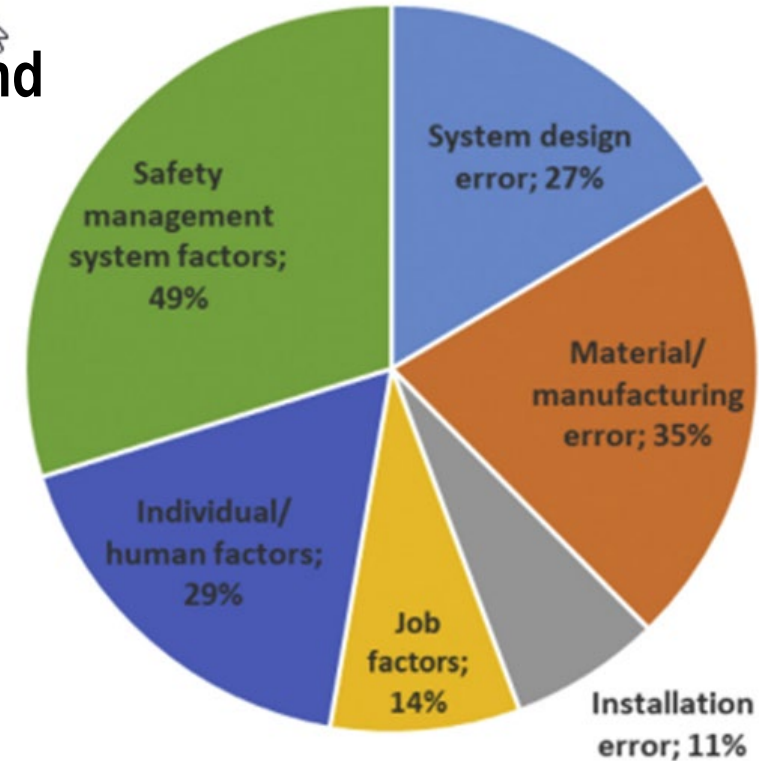
About 700 in total

We., J. X. et al: Statistics, lessons learned and recommendations from analysis of HIAD 2.0 database; International Journal of Hydrogen Energy 47(2022)

HIAD 2.0 EUROPEAN HYDROGEN INCIDENT AND ACCIDENT DATABASE @ 2022 EUROPEAN HYDROGEN SAFETY PANEL (EHSP)



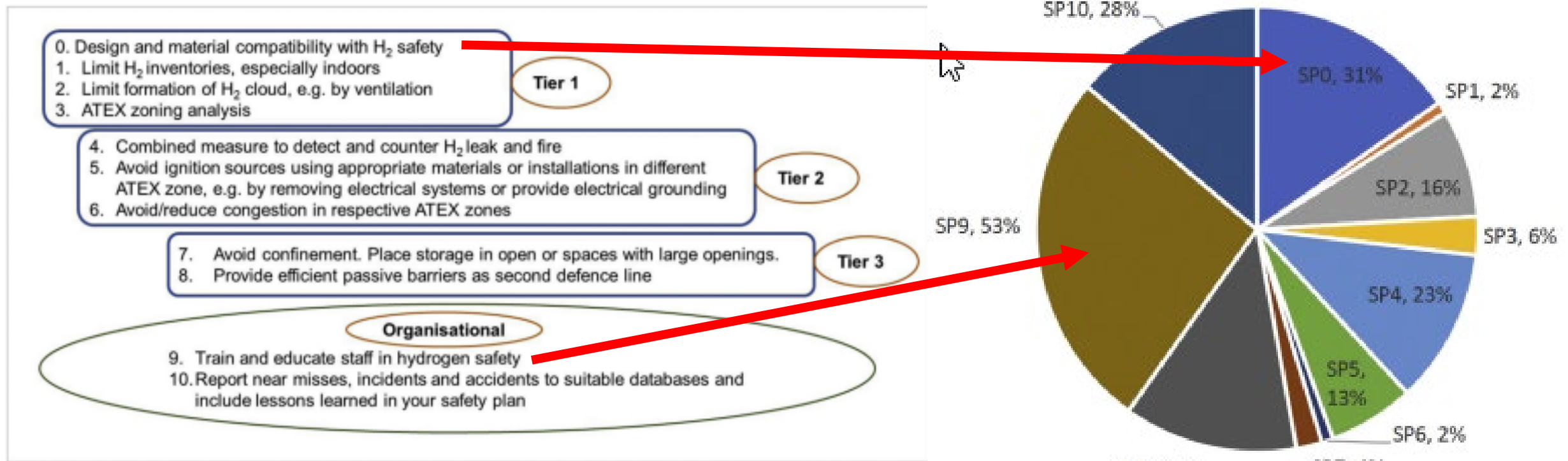
Percentages of the events initiated by hydrogen or non-hydrogen systems (outer circle) and those related to different consequences (the inner circle)



Percentages related to the causes of the events considering multiple causes per event

We., J. X. et al: Statistics, lessons learned and recommendations from analysis of HIAD 2.0 database; International Journal of Hydrogen Energy 47(2022)

HIAD 2.0 EUROPEAN HYDROGEN INCIDENT AND ACCIDENT DATABASE @ 2022 EUROPEAN HYDROGEN SAFETY PANEL (EHSP)

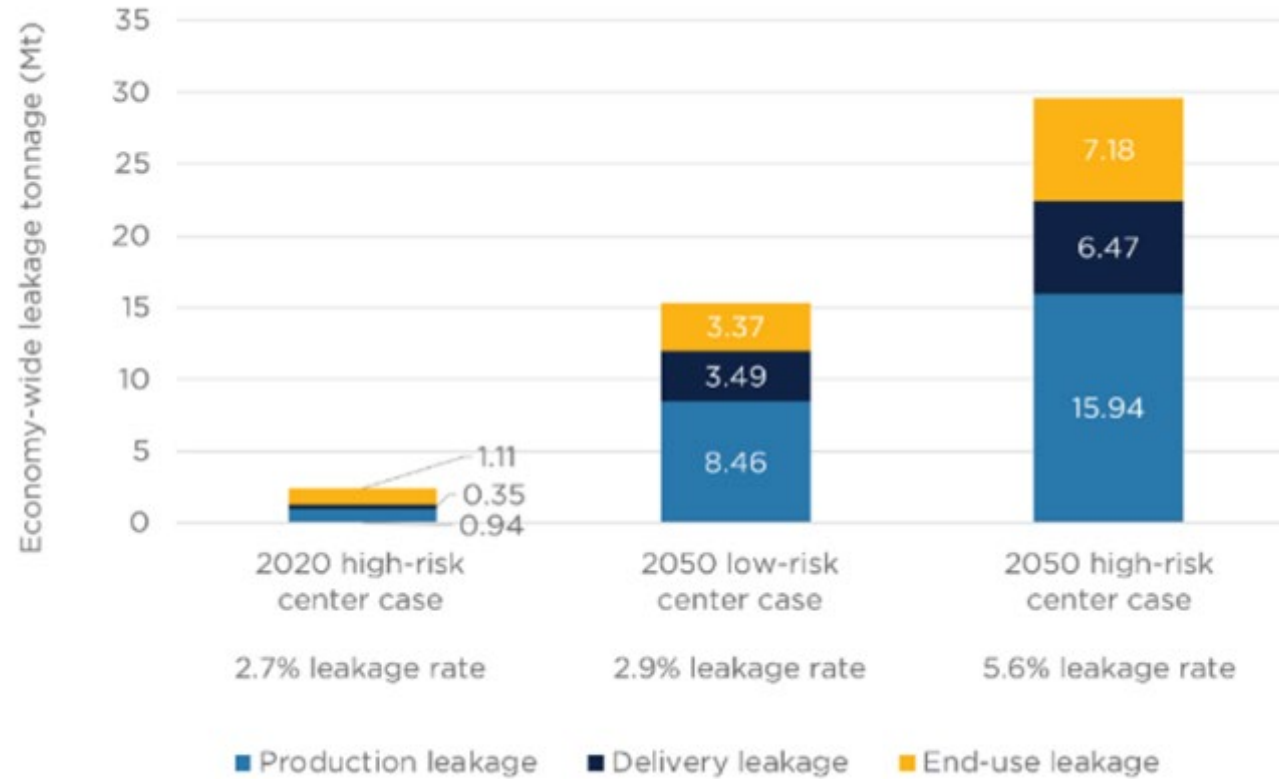


Hydrogen safety principles (SP#) (European Hydrogen Safety Panel, 2021).

Percentages of events related to the 11 Safety Principles (SP#)

We., J. X. et al: Statistics, lessons learned and recommendations from analysis of HIAD 2.0 database; International Journal of Hydrogen Energy 47(2022)

ESTIMATED H2 RELEASE AMOUNTS (LEAKAGE) DUE TO THE INCREASED H2 PRODUCTION (100MT - 500MT)

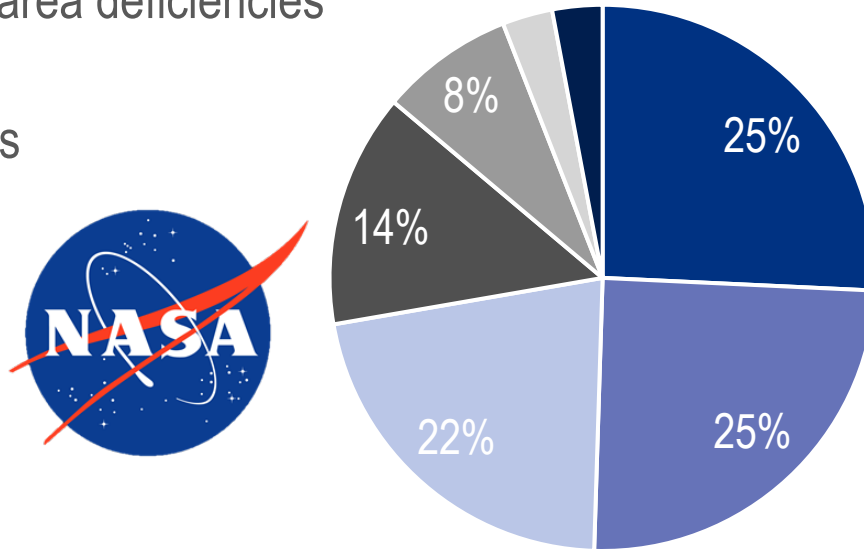


Fan,Z; Sheerazi,H.;Bhardwaj,A.;Corbeau,A.-S.;Longobardi,K.;Dr.Woodall,C. M.;Agrawal,M.;dr. Friedmann,J.:
Hydrogen Leakage: A potential Risk for the Hydrogen Economy; Columbia | Sipa Center on Global Energy Policy;
5.July 2022

ANALYSIS OF ACCIDENTS IN HYDROGEN APPLICATIONS

Ordin, P.M.: Review of Hydrogen Accidents and Incidents in NASA Operations 1974

- Operational and work area deficiencies
- Procedural deficiencies
- Design deficiencies
- Planning deficiencies
- Malfunctions
- Material failures
- Material incompatibilities



Two main goals

- Minimize potential human error
=> **Training**
- Develop systems that remain robust in the event of human error



NASA, Der Spiegel;

WHAT DOES IECEX DO TO ESTABLISH A SUFFICIENT LEVEL OF SAFETY FOR HYDROGEN APPLICATIONS?

Goal 1: Minimize potential human error:

- IECEX added Hydrogen specific competence elements to the Recognized Training Provider (RTP) Program and
- Established Unit 11: Basic knowledge of the safety of hydrogen systems
- Unit 11 works in conjunction with two or more standard Units of OD 504
- Unit 11 refers directly to ISO/TR 15916



IECEX OD 504

Edition 5.0 2022-10

IECEX OPERATIONAL DOCUMENT



ards Relating to Equipment for Use in
m)
sonnel competence for explosive
assessment outcomes

AGU

CANADIAN HYDROGEN INSTALLATION CODE – 4.2 INSTALLER QUALIFICATIONS, AND OPERATOR TRAINING

- Only qualified personnel shall be responsible for the installation of hydrogen equipment covered by this code.
- Upon completion of an installation , the installer shall train the system operator on the proper and safe use of all hydrogen equipment covered by this code.
- At a minimum, system operator training shall cover basic hydrogen properties; safety aspects, including the safe handling and operation of hydrogen systems...



WHAT DOES IECEX DO TO ESTABLISH A SUFFICIENT LEVEL OF SAFETY FOR HYDROGEN APPLICATIONS?

Goal 2: Develop systems that remain robust in the event of human error:

- IECEX keeps **35.919 current IIC** – Product certificates in the online database
- OD 290 is the basis for harmonized procedures for IECEX certification of equipment, components and systems **associated with the production, dispensing and use of gaseous hydrogen**

The screenshot displays the IECEX Certificates website interface. At the top, the logo and name 'IECEX Certificates' are visible, along with the full name: 'International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres'. Navigation links for 'Home', 'Search', and 'Export' are present. A search bar contains the text 'IIC'. Below the search bar, there are filter options for 'Issue date' (ranging from 2003 to 2023) and 'Type' (including Certified Equipment, Component Certificate, Equipment Certificate, EXTR, and QAR). The 'Status' filter is set to 'Current' (35,919). The search results section shows '35,919 RESULTS' and lists several 'CURRENT' status certificates, such as 'IECEX BAS 04.0002 Issue 1' and 'IECEX BAS 04.0002 Issue 2', each with a brief description of the equipment and standards.

OD 290 refers closely to the relevant Hydrogen standards like ISO 19880-X and to IEC 60079-46: Equipment assemblies

AGU

CERTIFICATION REQUIREMENTS

5 HYDROGEN EQUIPMENT

5.1 HYDROGEN EQUIPMENT TO BE INSTALLED

Hydrogen-generating equipment for non-process end use, hydrogen utilization equipment, hydrogen-dispensing equipment, hydrogen storage containers, hydrogen piping systems and their accessories shall be certified or approved prior to installation.

7.7 COMPRESSORS AND COMPRESSOR PACKAGES

7.7.1 General

Only compressors that are designed for hydrogen systems shall be used.

Compressors that are an integral part of certified or approved hydrogen-generating equipment need not comply with the provisions of Clause 7.7.

shall be certified

7.8.1.3 Subject to the approval of the AHJ, stationary containers for compressed gaseous hydrogen storage originally intended for transportation and onboard use shall be certified to one of the following documents:

- a) CSA B51, Part 2;
- b) ISO 11119;
- c) ISO 19881;

Dispensers shall comply with the requirements of the document CSA/ANSI HGV 4.1. Dispenser validation testing for light-duty vehicles shall be performed in accordance with the document CSA/ANSI HGV 4.3.

NOTE — The document CSA HGV 4.9 focuses on hydrogen key fuelling station components and protocols by setting requirements and referencing appropriate standards, e.g., documents SAE J2601 for hydrogen fuelling protocol, SAE J2799 for communication with a hydrogen-fuelled vehicle, CSA/ANSI HGV 4.1 for hydrogen dispensers and CSA/ANSI HGV 4.3 for hydrogen dispenser validation testing.

This copy is available on the BNQ Web site for personal use. Copying, distribution or installation on a network is forbidden.

BNQ
Bureau de normalisation
du Québec

CAN/BNQ 1784-000/2022
Canadian Hydrogen Installation Code

SCC CCN

STANDARD

THE STRONGEST LINK.

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