CHALMERS
UNIVERSITY OF TECHNOLOGY

Project members:
David Randby, Simon Svensson Qvistberg, Mayur Sharma
Supervisors:
Marcus Runefors, Björn Wickman
Division of Fire Safety Engineering, Lund University

TRA105 Fuel Cell Systems

Assesment of fuel-cell-specific risk

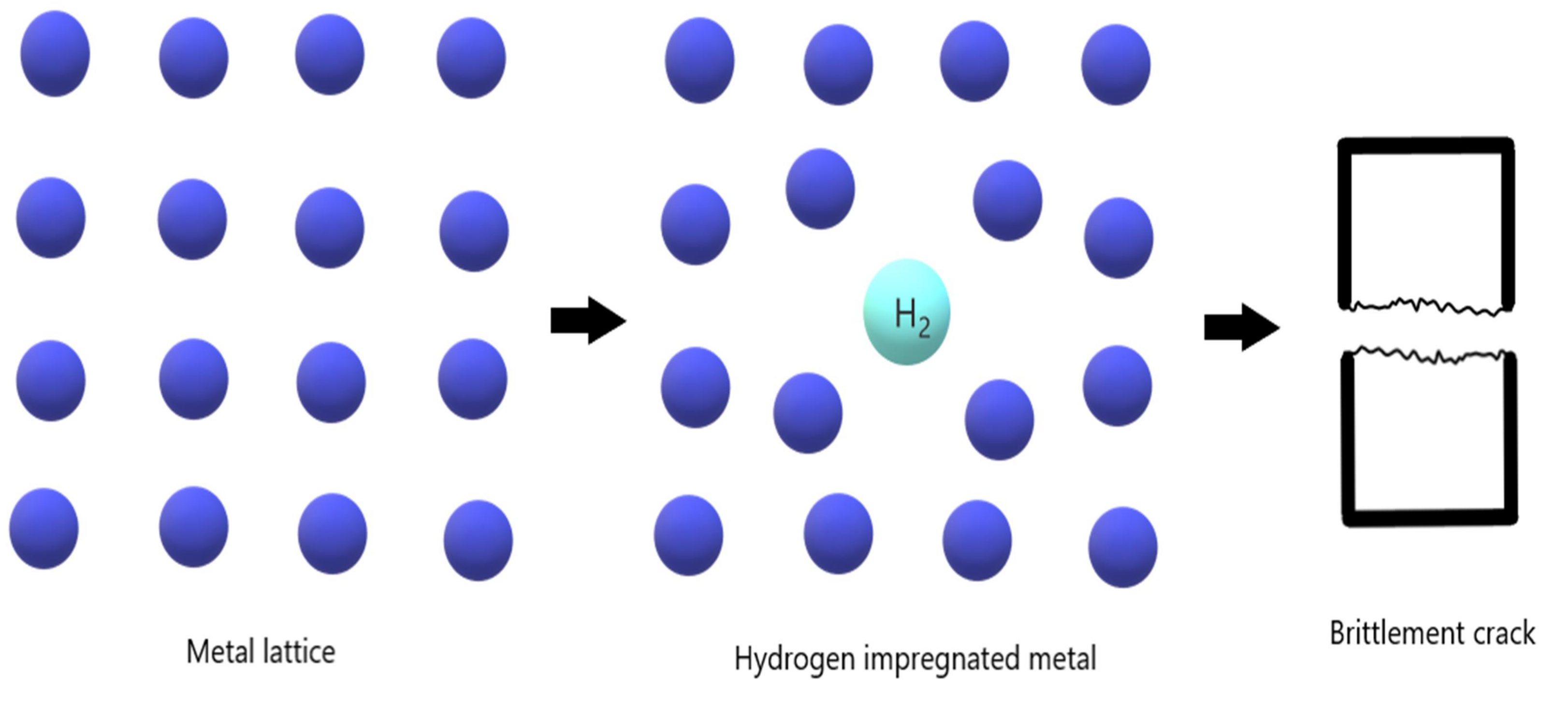
Background

The safety aspect of fuel cell application is very important, especially when the fuel cell is operating on hydrogen. Hydrogen is susceptible to gas explosion being easily ignitable in comparison to other fuels. The hydrogen fuel cell safety risks are often divided into two tracks. The first one is the external effect of the fuel cell. That can be a fire in the operating room not caused by the fuel cell. The second is that the system is leaking hydrogen somewhere. This is inevitable due to the properties of hydrogen. Hydrogen has a very high energy per density and very low density to volume which makes the hydrogen spread extremely fast everywhere. This is something that needs to be taken care of when designing the system. Either by making sure there is no leakage or having other external equipment that reports when there is a leakage and prevent it from ignition.

Source: Planet wissen ''Die letzte Fahrt der Hindenburg'' by *Von Annika Zeitler*

Causes of leak

To prevent leakage, it's important to identify where in the system leakage occurs. The most common leakage is due to mechanical force, Poor installation (due to stress), Joint leakage and hydrogen embrittlement. Mechanical force leakage is an indirect leakage due to some external force on the system such as a crash or something that is dropped onto the system causing damage. Joint leakage is the same that happened in Mariestad in March 2022 where the pressure vessel was unattached caused by vibrations. Hydrogen embrittlement on the other hand is more complex. Due to hydrogens' good ability to travel anywhere it's possible for the hydrogen to travel through some material. This is hard to detect and this is dangerous due to the change in material properties when the hydrogen is getting stuck in the structure of the material. The material loses its elongation properties and becomes brittle, making it prone to huge leaks.



Risk of explosion compared to other common fuels

A regular assumption about hydrogen is that it is very dangerous and explosive compared to more common fuels. This assumption depends on how the fuel is handled and what safety measurements are taken. In the table (11.3) the comparison between hydrogen, methanol and propane are listed. The risk for a fire and explosion in the three different fuels are dependent on many factors - flammability range, minimum ignition energy and also the percentage of fuel mixed with the air. For hydrogen, the ignition range is between 4% to 77%, while methane has a range between 4.4-16.5% and propane between 1.7-10.9%. The minimum ignition energy is much lower for hydrogen compared to the other fuels. The important conclusion when comparing hydrogen with other fuels regarding risks of possible accidents and explosions is that they can all be safely used if proper safety measures and regulations are followed.

Table 11.3 Properties relevant to safety for hydrogen and two other commonly used gaseous fuels.

	Hydrogen	Methane	Propane
Density ($kg\,m^{-3}$ at NTP[a])	0.084	0.65	2.01
Ignition limits in air (vol.% at NTP[a])	4.0–77	4.4–16.5	1.7–10.9
Ignition temperature (°C)	560	540	487
Minimum ignition energy in air (MJ)	0.02	0.3	0.26
Maximum combustion rate in air ($m\,s^{-1}$)	3.46	0.43	0.47
Detonation limits in air (vol.%)	18–59	6.3–14	1.1–1.3
Stoichiometric ratio in air	29.5	9.5	4.0

Source: Dicks, Andrew L. Rand, David A. J.. (2018). *Fuel Cell Systems Explained (3rd Edition).* John Wiley & Sons (S.326, Table 11.3)

Safety of Hydrogen - Risk mitigation

Quantifying the risks associated with hazards enables us to design hydrogen systems safer. Conclusions from these studies are incorporated as safety features in the design phase. Some of the popular and effective techniques are:

i) HAZOP - Hazards and Operatibility Study is conducted after the piping architecture is frozen in the initial design phase. System under study is divided into nodes or sub-systems whose risks are analysed separately, for example cathode loop, fuel loop and so on.
ii) HAZID - Hazard Identification also called as failure case selection aims to get a list of hazards in different sections of the system. They can be sources of ignition, flammable substances, toxins etc. Based on these facts, possible hazard scenarios are listed - leaks, explosion, unignited release or dispertion situations.
iii) FMEA - Failure Modes and Effects Analysis identifies failure modes and how the equipment fails. The severity of the effects is then rated on a likelihood and consequence scale. It is carried out on system or component level and mechanisms leading to the failure are studied.
iv) QRA - Quantitative Risk Assessment uses tools such as fault tree, event sequence diagrams in combination from data from the hydrogen system to provide an insight into the fatality risk. These facts provide important design improvements resulting in a safer system.