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The Importance of Fuel Quality

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Status ISO 14687-2 Standard

- The current Standards (ISO 14687-2 and SAE J2719) are based on investigations, conducted in Japan, France and US around 2004.

- Modern MEA configurations are not properly considered within ISO 14687-2.

- The ISO standard 14687-2 is based on the evaluation of single contaminants. The effect of an “ISO-cocktail (*” has not been evaluated.

- The current standard only considers contaminants, which are originated from the hydrogen production process. Contaminants from transportation or hydrogen refueling station technology are not sufficiently considered

* ISO Cocktail: *Mixture of 99,97% Hydrogen and contaminates, according to the ISO 14687-2*

Status H_2 Specification (ISO 14687-2)

Characteristics (assay)	Type I, Type II
	Grade D
Hydrogen fuel index (minimum mole fraction)[a]	99,97 %
Total non-hydrogen gases	300 µmol/mol
Maximum concentration of individual contaminants	
Water (H_2O)	5 µmol/mol
Total hydrocarbons[b] (Methane basis)	2 µmol/mol
Oxygen (O_2)	5 µmol/mol
Helium (He)	300 µmol/mol
Total Nitrogen (N_2) and Argon (Ar)[b]	100 µmol/mol
Carbon dioxide (CO_2)	2 µmol/mol
Carbon monoxide (CO)	0,2 µmol/mol
Total sulfur compounds[c] (H_2S basis)	0,004 µmol/mol
Formaldehyde (HCHO)	0,01 µmol/mol
Formic acid (HCOOH)	0,2 µmol/mol
Ammonia (NH_3)	0,1 µmol/mol
Total halogenated compounds[d] (Halogenate ion basis)	0,05 µmol/mol
Maximum particulates concentration	1 mg/kg

For the constituents that are additive, such as total hydrocarbons and total sulfur compounds, the sum of the constituents are to be less than or equal to the acceptable limit.

a The hydrogen fuel index is determined by subtracting the "total non-hydrogen gases" in this table, expressed in mole percent, from 100 mole percent.

b Total hydrocarbons include oxygenated organic species. Total hydrocarbons shall be measured on a carbon basis (µmolC/mol). Total hydrocarbons may exceed 2 µmol/mol due only to the presence of methane, in which case the summation of methane, nitrogen and argon shall not exceed 100 µmol/mol.

c As a minimum, total sulphur compounds include H_2S, COS, CS_2 and mercaptans, which are typically found in natural gas.

d Total halogenated compounds include, for example, hydrogen bromide (HBr), hydrogen chloride (HCl), chlorine (Cl2), and organic halides (R-X).

- Standard and quality control at HRS are focused on gaseous contaminants, according to ISO 14687-2.
- Particles are not defined in detail. Liquids are only mentioned in conjunction with particles.
- Current H_2-specification does not comply with the requirements from Gas Industry and Automotive Industry
- Current revision of ISO 14687-2 ongoing within ISO/TC 197/WG27.

Examples for Standard Revision Needs

Impact of the CO concentration on the irreversible degradation rate.

- A state of the art life time target is 5000 to 7000 h [1-2]. Today this still a challenge for automotive Fuel Cell Applications.
- End of life, a typical Performance loss of about 10% of the full power point is accepted, which presents a value of about 60 mV.

Irreversible Stack Perfromance Loss

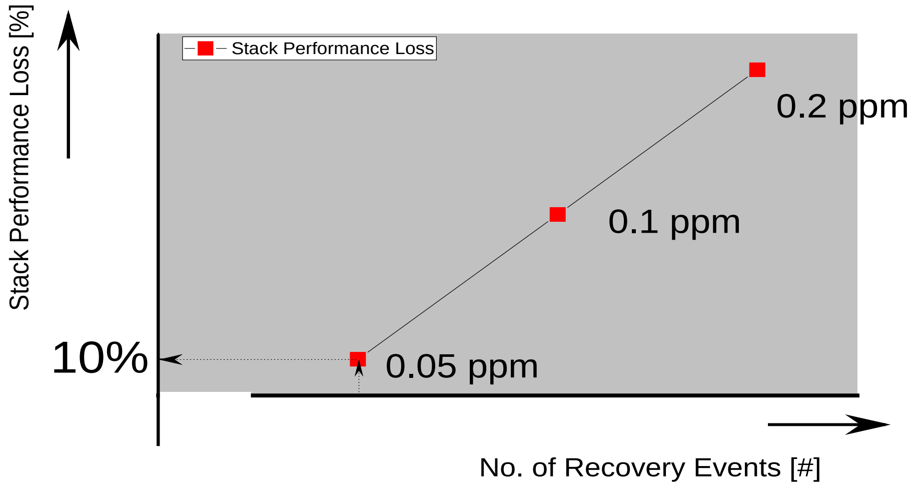


Fig.: Irreversible Stack Performance Degradation due to Recovery Events

- CO contamination on the anode can be fully recovered.
- But typical Recovery Events, e.g. applying high potentials to the anode cause additional irreversible Degradation on the Stack Performance.

➢ **Required number of recovery events for 0,05 ppm CO in hydrogen feed will enable to reach lifetime target!**

[1] M. Marrony, Encyclopedia of Electrochemical Power Sources (2009), Pages 297–308
[2] P. Mock, S.A. Schmid / Journal of Power Sources 190 (2009) 133–140

Examples for Standard Revision Needs

Impact of the H_2S concentration on the degradation rate.

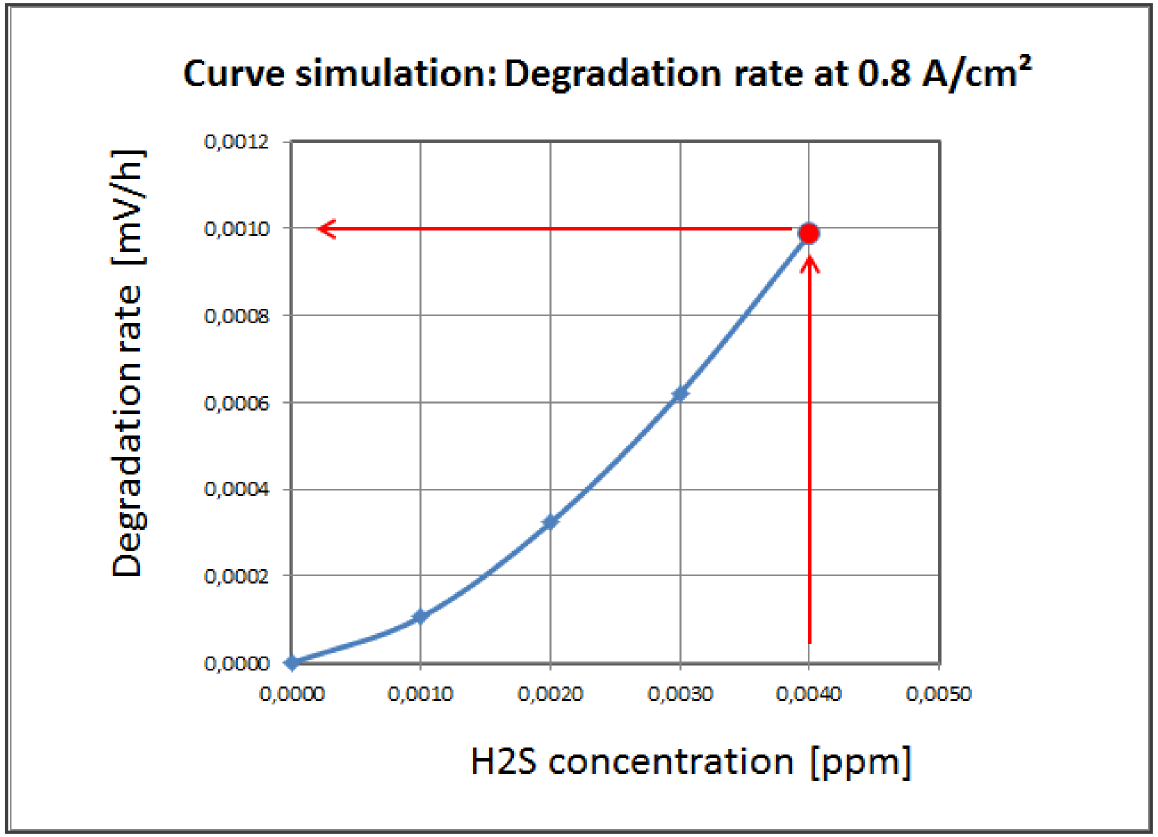


Fig.: Assessment of the Degradation rate at 4 ppb H_2S concentration.

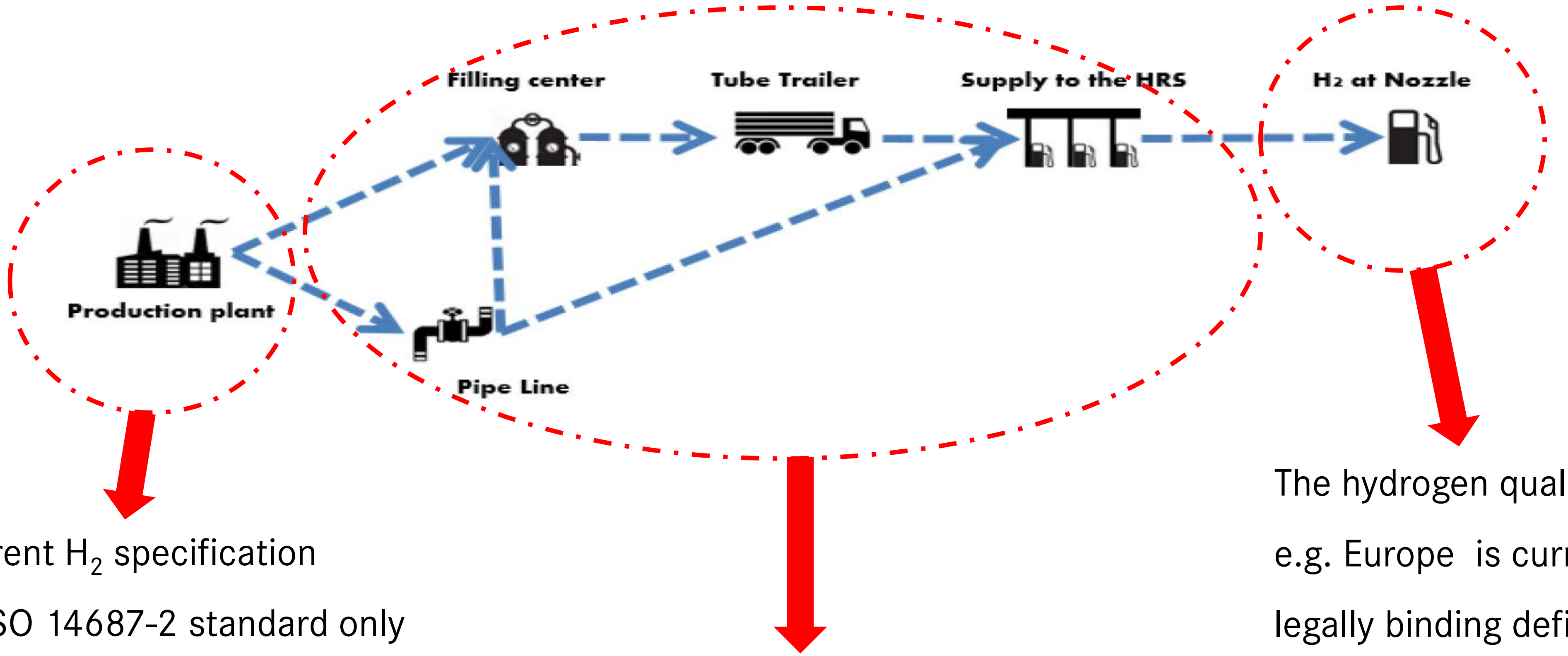
- The data, and the subsequent non linear fit, allow the extraction of a degradation rate as a function of the H2S concentration.
- The degradation rate at 0.8 A/cm^2 and a H2S concentration of 4 ppb is about 0.001 mV/h. After 6000 h of operation, this cold cause a total degradation of 6 mV.

➢ 6 mV presents already 10% of the total degradation budget for the entire Stack!

[1] W. Shi et al. / Journal of Power Sources 164 (2007) 272–277

H_2 from manufacturing to vehicle

Potential sources of contamination



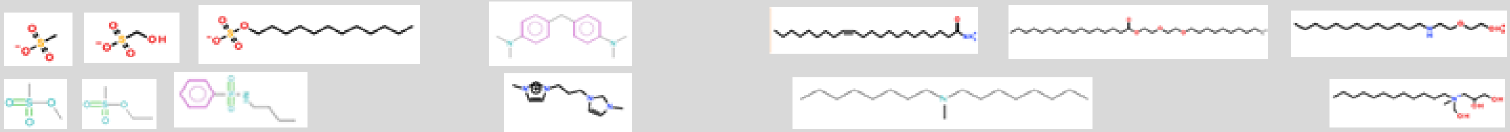
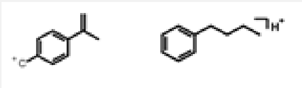
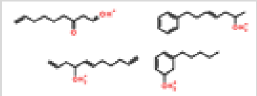
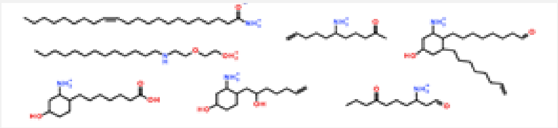
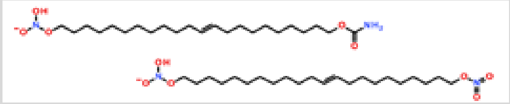
The current H_2 specification within ISO 14687-2 standard only considers contaminants, which are originated from the hydrogen production process.

Contaminants from transportation or hydrogen refueling station technology are not sufficiently considered.

The hydrogen quality at HRS in e.g. Europe is currently not yet legally binding defined. Only California has defined the SAE hydrogen standard SAEJ2719 for their HRS.

New Contaminants

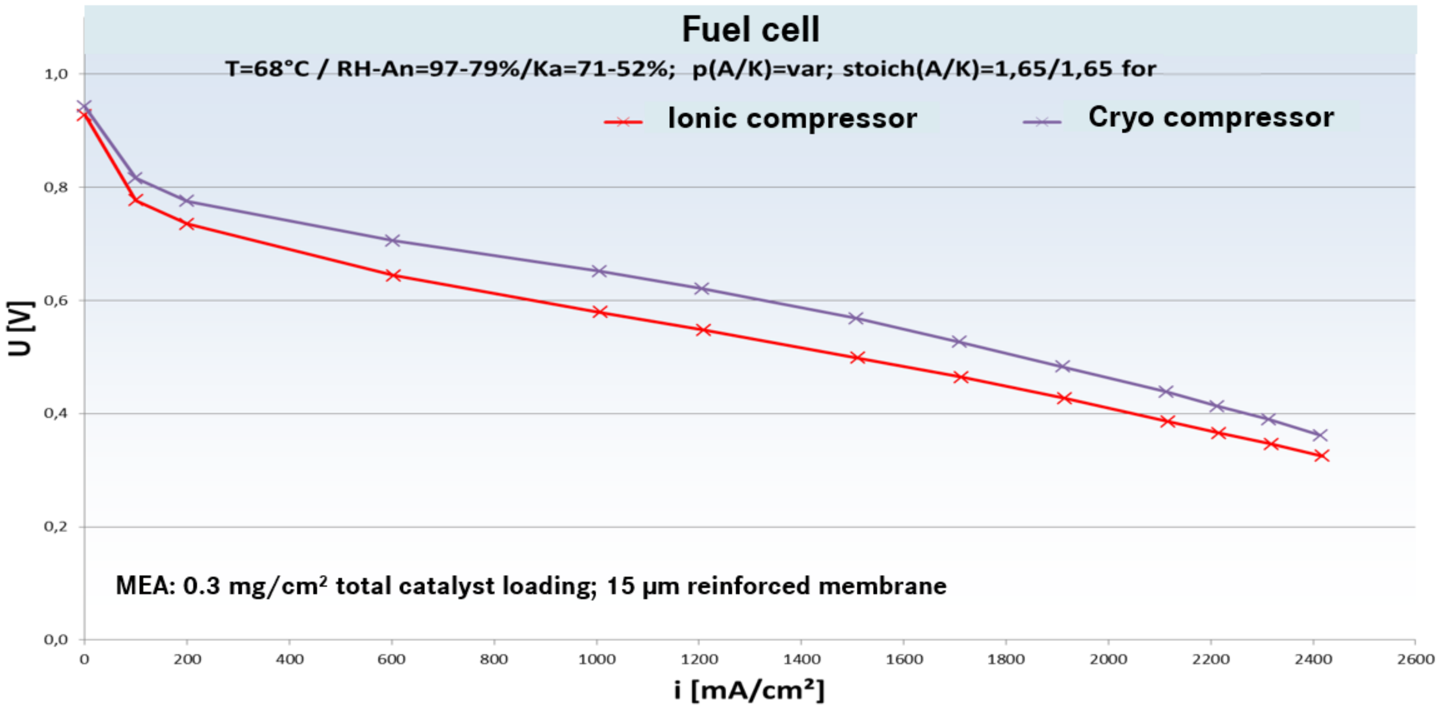
What we already have found at Hydrogen Refuelling stations

	collected contaminates
Particulates	Steel, Aluminium Alloy, Copper Alloy, Plastic, Abrasives (SiC, SiO, Al2O3,...)
Metal Ions	Aluminium, Lead, Boron, Calcium, Iron, Potassium, Cadmium, Copper, Magnesium, Manganese, Molybdenium, Nickel, Silver, Silicium, Titan, Zinc, ...
Ionic Liquid (incl. Additives and Decomposition Products)	
Lubricants	Aromates und Alkenes with one to three double bonds oxidised Alkenes 
Cleanser	
Solvents (possibly from the manufacturing of the ionic liquid)	
Others (e.g. Acids, Nitrate, Siloxane, ...?)	HNO3, H2SO3, .. 

Cryo Compressor vs. Ionic Compressor

Performance loss in a single cell (50 cm²)

- Single Cell, H2/Air Polarization Test was conducted with Normal Operating Conditions.

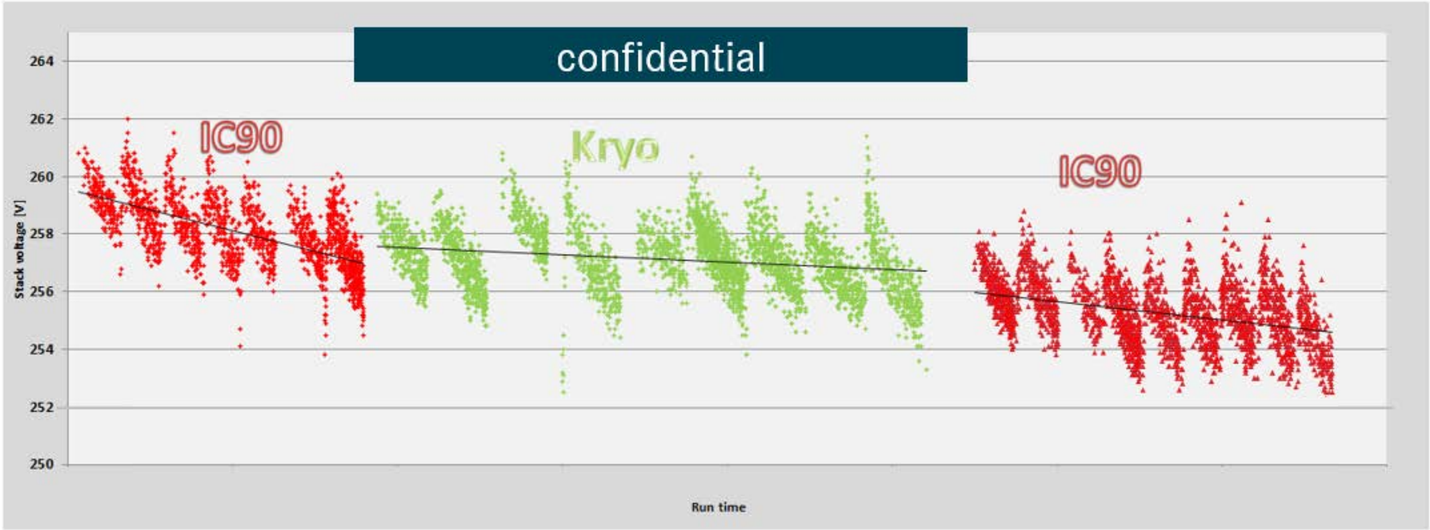


- Fuel cell, operated with hydrogen from an ionic compressor, shows a reduced performance.

Cryo Compressor vs. Ionic Compressor

Performance degradation in a fuel cell drive train

- Test with a fuel cell drive train has been conducted with hydrogen from different HRS.
- The test was conducted with a typical load cycle.
- The test was interrupted regularly with a typical recovery procedure.



- The performance degradation with Hydrogen from HRS with Ionic compressors is significantly higher. Reasons are not identified yet.

Conclusion

- The current H2 Quality Standards on hydrogen quality needs to be adapted to modern fuel cell configurations.

- Next revisions H2 Quality Standards have to consider the contaminants from hydrogen infrastructure.

Fuel Cell technology can only become a competitive alternative to conventional internal combustion engines by achieving the lifetime targets. The lifetime is strongly dependent on appropriate H2 Quality!

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Thank You!