Allowable Hydrogen Permeation Rate In Garages From Road Vehicle Compressed Gaseous Storage Systems:

Part 1
Introduction, Scenarios, And Estimation Of An Allowable Permeation Rate

By: P. Adams, Volvo Technology
A. Bengaouer & B. Cariteau, CEA
V. Molkov, University of Ulster,
A. Venetsanos, NCSRD

Hydrogen Permeation Rates For Road Vehicles

150Ncc/min per vehicle @ 55^{0}C+

1.0Nml/hr/L water capacity @ ambient

5.0Nml/hr/L water capacity

2.7Nml/hr/L water capacity @ 10^{0}C
4.6Nml/hr/L water capacity @ 15^{0}C
6.0Nml/hr/L water capacity @ 20^{0}C

???

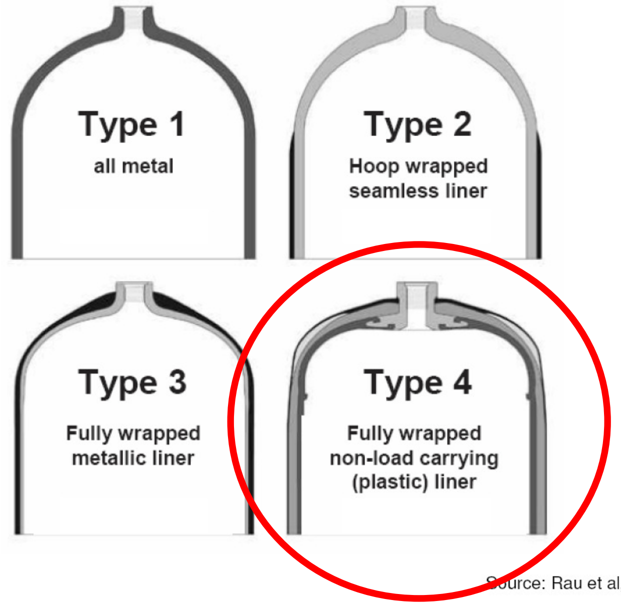
10.0Nml/hr/L water capacity @ 20^{0}C

2.0Nml/hr/L water capacity @ 35MPa/ ambient

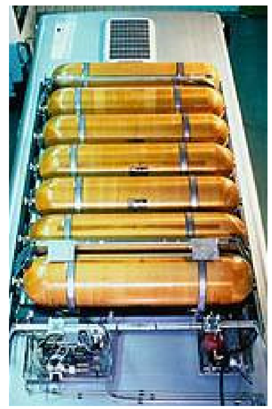
2.8Nml/hr/L water capacity @ 70MPa

75NmL/min per container @ 20^{0}C

Typical CGH_2 Containers & Permeation

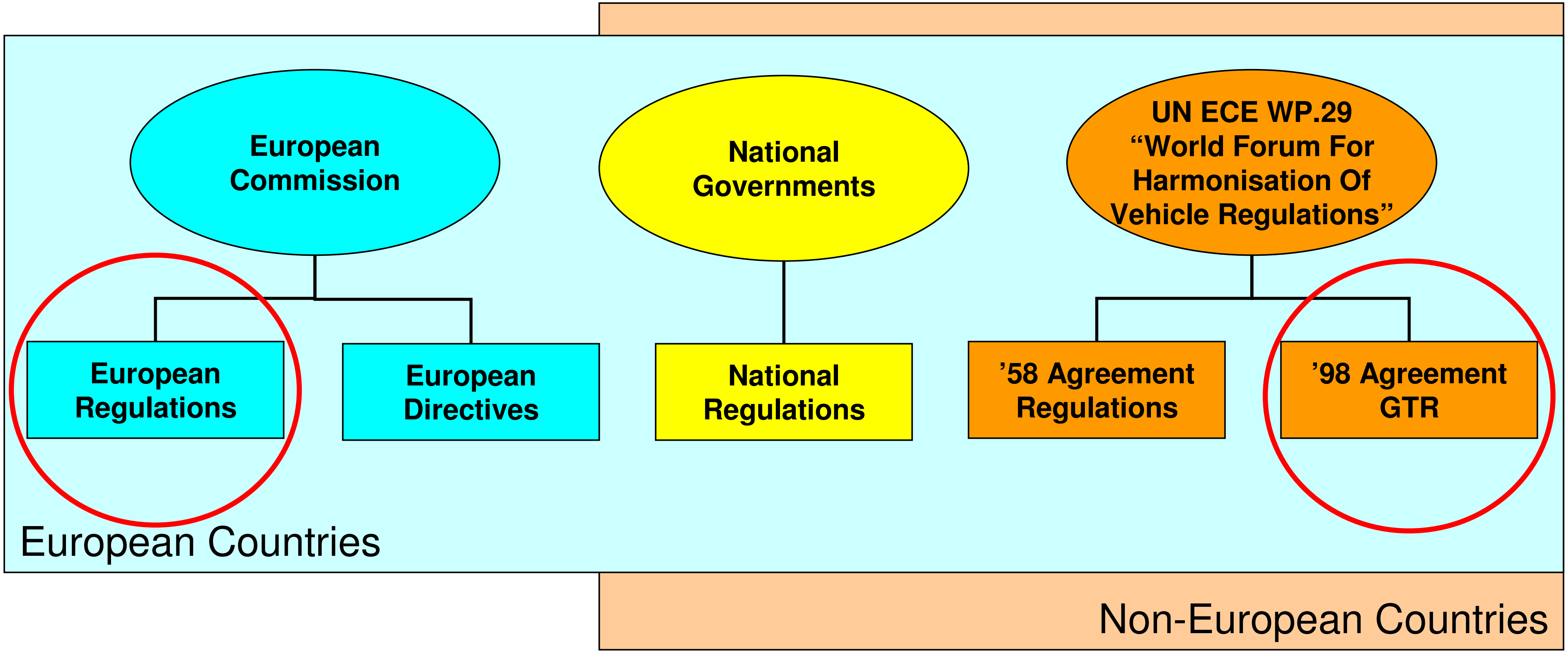


Source: Rau et al, 2006



- In automotive CGH_2 systems, hydrogen is typically stored at 35MPa or 70MPa
- Typically a liner wrapped with carbon fibre
- Due to its small molecular size, hydrogen permeates through the containment materials found in CGH_2 storage systems
- Hydrogen permeation is an issue for containers with non-metallic liners (Type 4), i.e. with plastic liners

Vehicle Regulations For Hydrogen



- Vehicle/system and component requirements
- Vehicle regulations (legal requirements) are mandatory
- Standards, e.g. ISO, SAE, are voluntary unless referenced in a regulation

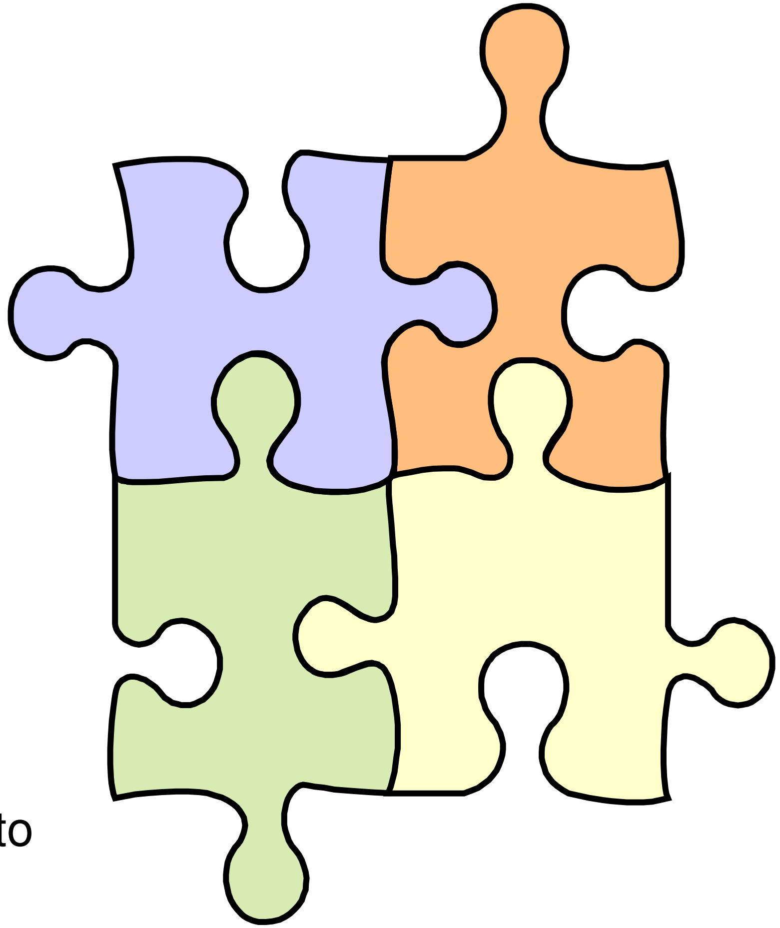
Vehicle And Building Regulations

The automotive industry increasingly has regulations harmonised at a global or regional level.

Automotive regulations do not regulate the design of structures.

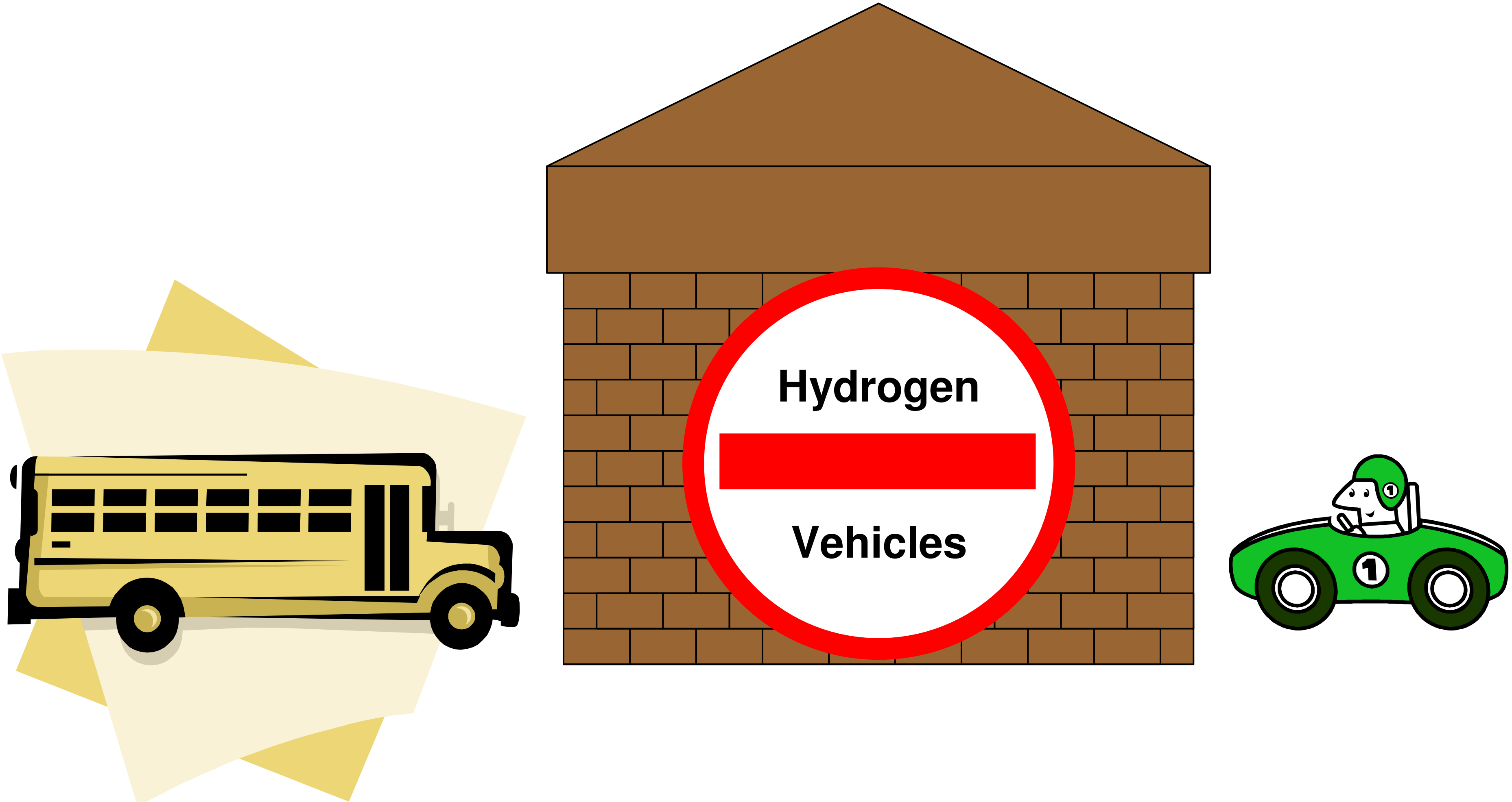
Buildings and infrastructure are regulated at a national or local level.

To achieve the safe introduction of hydrogen vehicles without unnecessary restrictions on their use we need to ensure that automotive regulations are compatible with building and infrastructure regulations and vice versa.

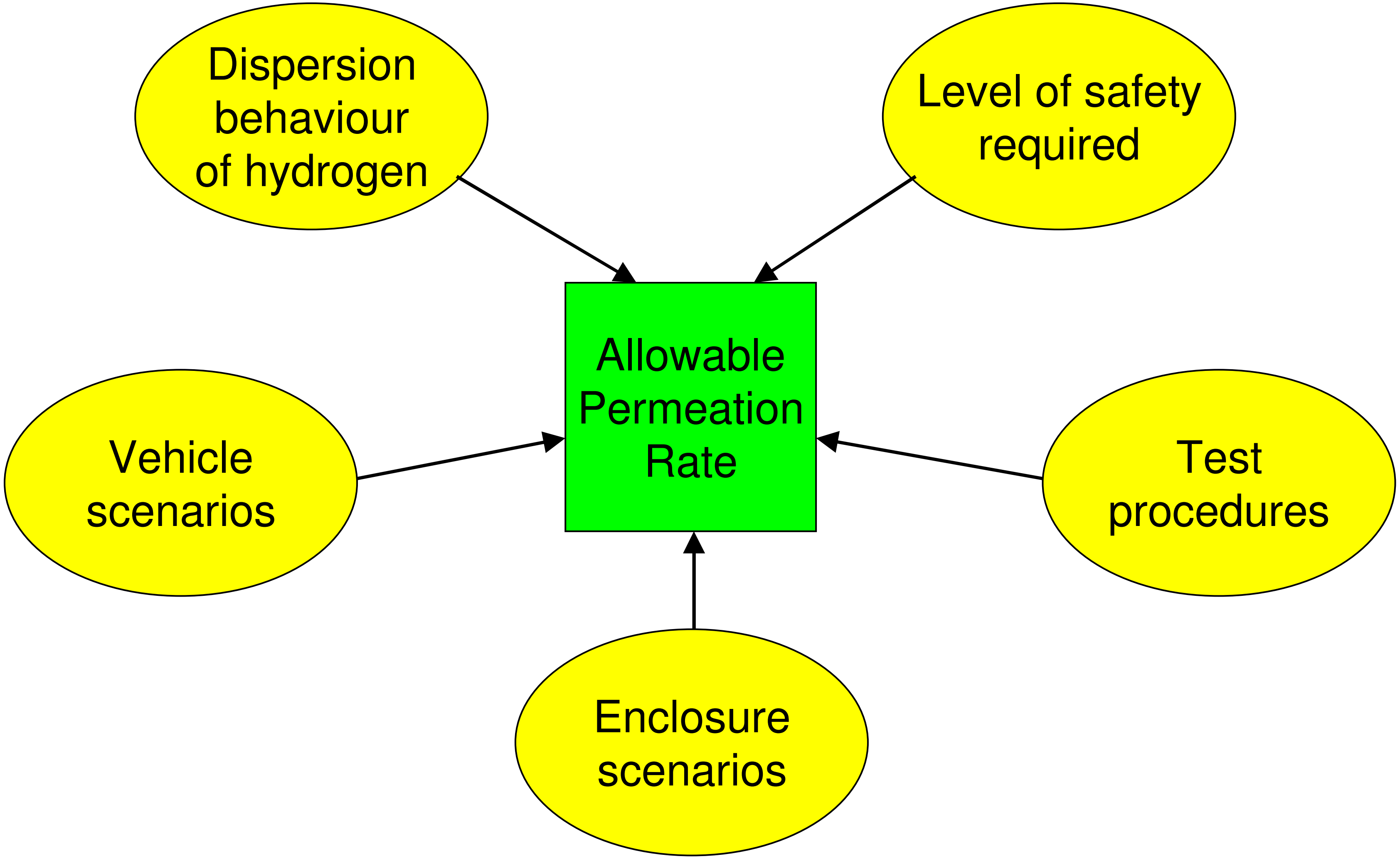


Goals

Allow hydrogen vehicles to be used safely with the minimum of restrictions for customers and manufacturers, and to avoid...



Estimation Of An Allowable Permeation Rate



Typical Enclosed Structures For Vehicles

Source: Various

Source: Various

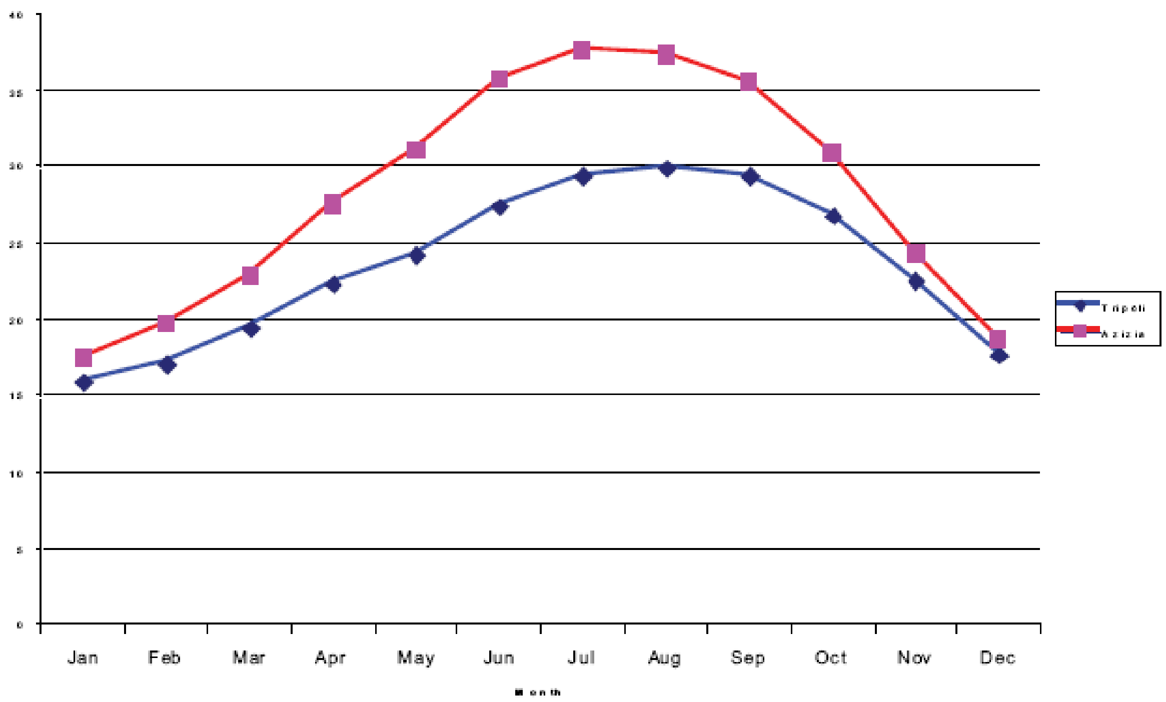
Scenarios

Scenario Details	Car Scenarios			Bus Scenarios		
	1	2	3	4	5	6
	Large Car	Small Car	Min. Garage/ Micro Car	35MPa Bus Maint. Garage	70MPa Bus Maint. Garage	Min. Bus Garage
Enclosure Length (m)	6.5	5.0	3.7	16.00	16.00	12.60
Enclosure Width (m)	3.5	3.0	2.4	6.55	6.55	3.55
Enclosure Height (m)	2.2	2.2	2.1	6.50	6.50	5.50
Free Vol. in Enclosure (m^3)	46	31	18	676	676	241
Storage pressure (MPa)	70	70	70	35	70	35
Hydrogen Stored (kg)	10	6	3	50	50	50

Maximum Prolonged Material Temperature

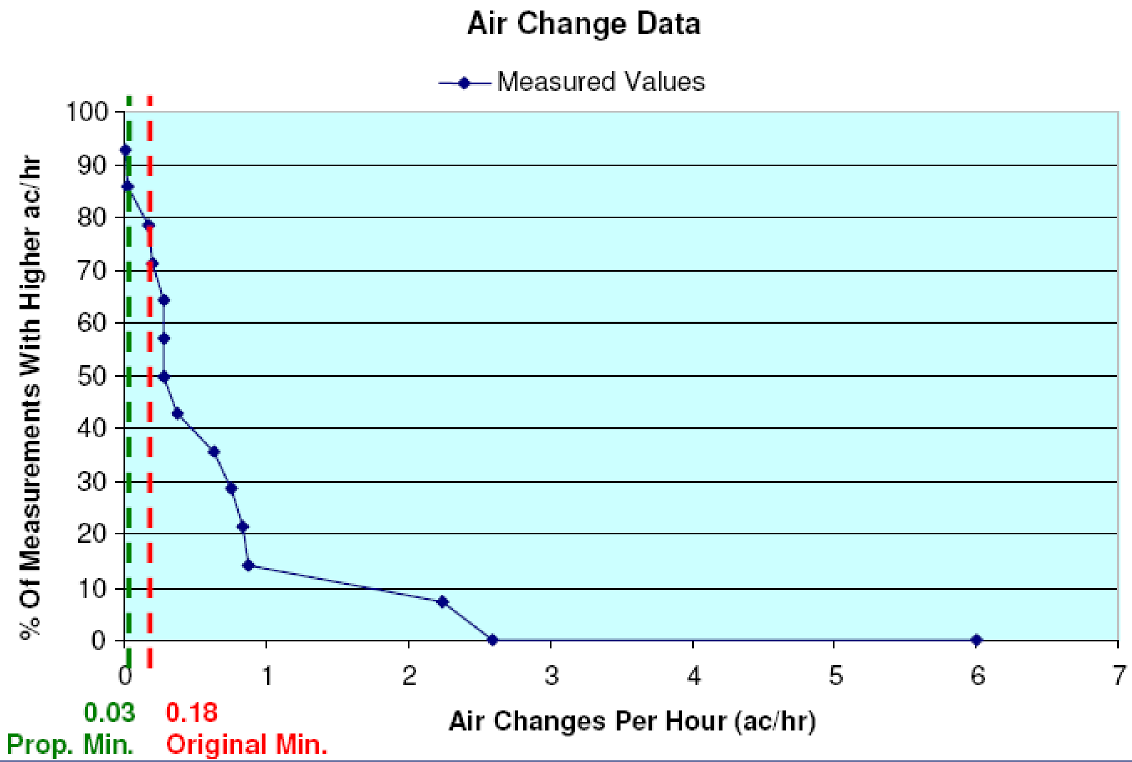
- Transient refilling temperatures (85^0C)
- Highest peak ambient temperature = 57.8^0C recorded in El Azizia in Libya in 1922
- Maximum peak temperatures last for 1-2hrs (recent Japanese study)
- Maximum prolonged ambient temperatures are in the order of $35\text{-}40^0$C
- Maximum prolonged temperature assumed = **<u>55^0C</u>** (agreed with SAE)

Tripoli and Azizia Average Max Temperature



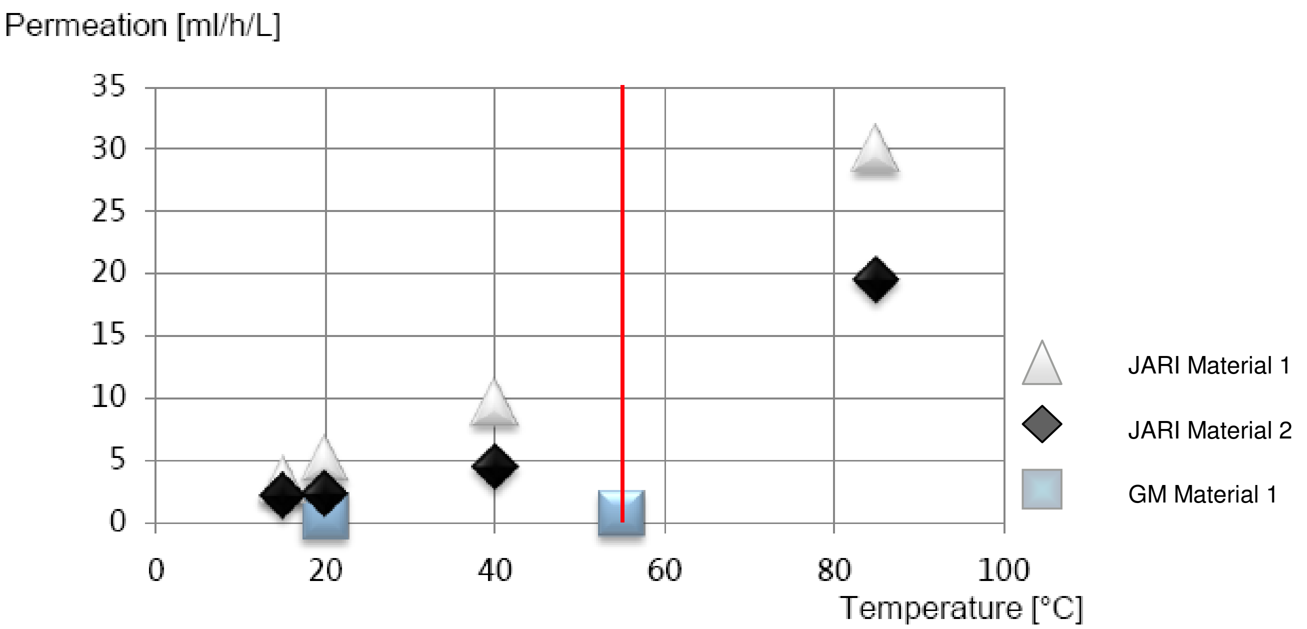
Minimum Natural Garage Ventilation Rate

- Limited real world data, but measurements below original minimum
- Weather conditions have significant influence on rates
- Significantly lower than the previously assumed figure of 0.18ac/hr
- Confirmed by experimental tests
- Minimum natural garage ventilation rate (agreed with SAE) = **<u>0.03ac/hr</u>**



Test Conditions

- Permeation increases with material temperature and towards end of life
- Allowable rate depends on test temperature and the “age” of the container
- If test is on a “new” container at ambient temperature, allowable rate must be safe at end of life and max. prolonged material temperature



Source: GM Powertrain Germany

Allowable Permeation Rate - Assumptions

The following assumptions have been made:

- The permitted permeation rate will be specified in the same manner as the rate in the draft EC proposal, i.e. NmL/hr/L water capacity
- Releases similar in size to permeation can be considered to disperse homogeneously
- Minimum natural ventilation rate for a domestic garage = 0.03ac/hr *
- Maximum permitted hydrogen concentration = 1% by volume, i.e. 25% LFL
- Maximum long term material temperature = 55^{0}C *

Note: * In agreement with SAE Fuel cell Safety Work group

Methodology

The perfect mixing equation can be used to calculate the hydrogen release rate required to give a steady state hydrogen concentration:

$$C_{\%} = \frac{100 \cdot Q_g}{Q_a + Q_g}$$

where:

$C_{\%}$ = Steady state gas concentration (%)
Q_a = Air flow rate (m^3/min)
Q_g = Gas leakage rate (m^3/min)

Based on the above, the maximum allowable hydrogen permeation rate is given as follows:

$$Qp_x = \frac{Q_a \cdot C_{\%}}{100 - C_{\%}} \cdot \frac{60 \cdot 10^6}{V \cdot f_a \cdot f_t}$$

where:

Qp_x = Allowable permeation rate (NmL/hr/L water capacity) at a test temperature of x^{0}C,
V = Water capacity of hydrogen storage (L),
f_a = Aging factor, taken to be 2, also allows for unknown aging effects, use of new materials & statistical variation around limited existing data
f_t = Test temperature factor = 3.5 at a test temperature of 20^{0}C, or 4.7 at 15^{0}C.

Allowable Permeation Rate

Based on the EC test conditions (new container):

Minimum Testing Temperature (^0C)	Max. Allowable Permeation Rate (NmL/hr/L water cap.)
15	**6.0**
20	**8.0**

The equivalent figure at the maximum prolonged temperature (55^0C+)/simulated end of life (SAE test conditions) would be: **90NmL/min/car**.

- *The HySafe proposals are intended for permeation from vehicles into enclosed structures, e.g. domestic garages.*
- *For hydrogen permeation into vehicle compartments the adoption of appropriate performance based requirements are necessary to avoid the potential development of flammable hydrogen/air mixtures.*

Thank you!

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