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Comparative study of the inherent risks of CNG and Diesel Buses/Heavy Duty Vehicles (HDVs) & Garbage Trucks (GTs) in tunnels

Dr. Olivier BORDELANNE, GDF SUEZ

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A specific context in France justifying the need for a comparative safety study in tunnels

- In 2005, two incidents involving CNG buses occurred in France, causing **fires on these CNG buses**. In both cases, **some of the composite gas cylinders exploded**.

- In 2006, following the analysis of these 2 accidents, the French Office of Road Transports Accidents (BEATT) has suggested that ***"the driving of CNG buses in tunnels usually forbidden to dangerous goods transportation should be also forbidden"***.

- In order to build counter-arguments, the **French Association for Natural Gas Vehicles (AFGNV) has settled up a Working Group** involving GDF SUEZ, Ministry representatives, CETU (French Tunnels Studies Centre), SECTOR Company, etc.

- This working group has conducted **two complete studies** aiming at :

  • Analyzing the risk of CNG buses/Heavy Duty Vehicles (HDVs) & Garbage Trucks (GTs) being operated in tunnels to identify **scenarios of accidents and related dangerous phenomena**;

  • **Evaluating the risks of these CNG buses/HDVs/GTs** and **to compare** them to the risks associated to the operation of **Diesel buses/HDVs/GTs** under the same conditions;

The adopted method for these 2 studies

- These studies are built around a **risk evaluation approach** named **Globally At Minimum Equivalent (GAME)**. With such approach, in case of incertitudes, the **adopted values are the maximum ones for the CNG case** in order not to advantage the CNG case versus the Diesel case.

- To compare the risks between CNG and Diesel vehicles, **3 major points** were evaluated:
  - The **Probability** a dangerous phenomena occurs **(P)**
  - The **Seriousness** of the phenomena **(S)**
  - The **global risk level** also called **Criticalities (C)** with

$$C = P \times S$$

- **Sensitivity studies** have been conducted also, considering:
  - Technical requirements adopted in R96M and ECE R110 regulations for CNG buses;
  - Technical characteristics of the industrial vehicles (HDVs and GTs) and their weight (Fully Loaded Total Weight (PTAC));
  - Traffic conditions (moving freely/dense).

The studied vehicles

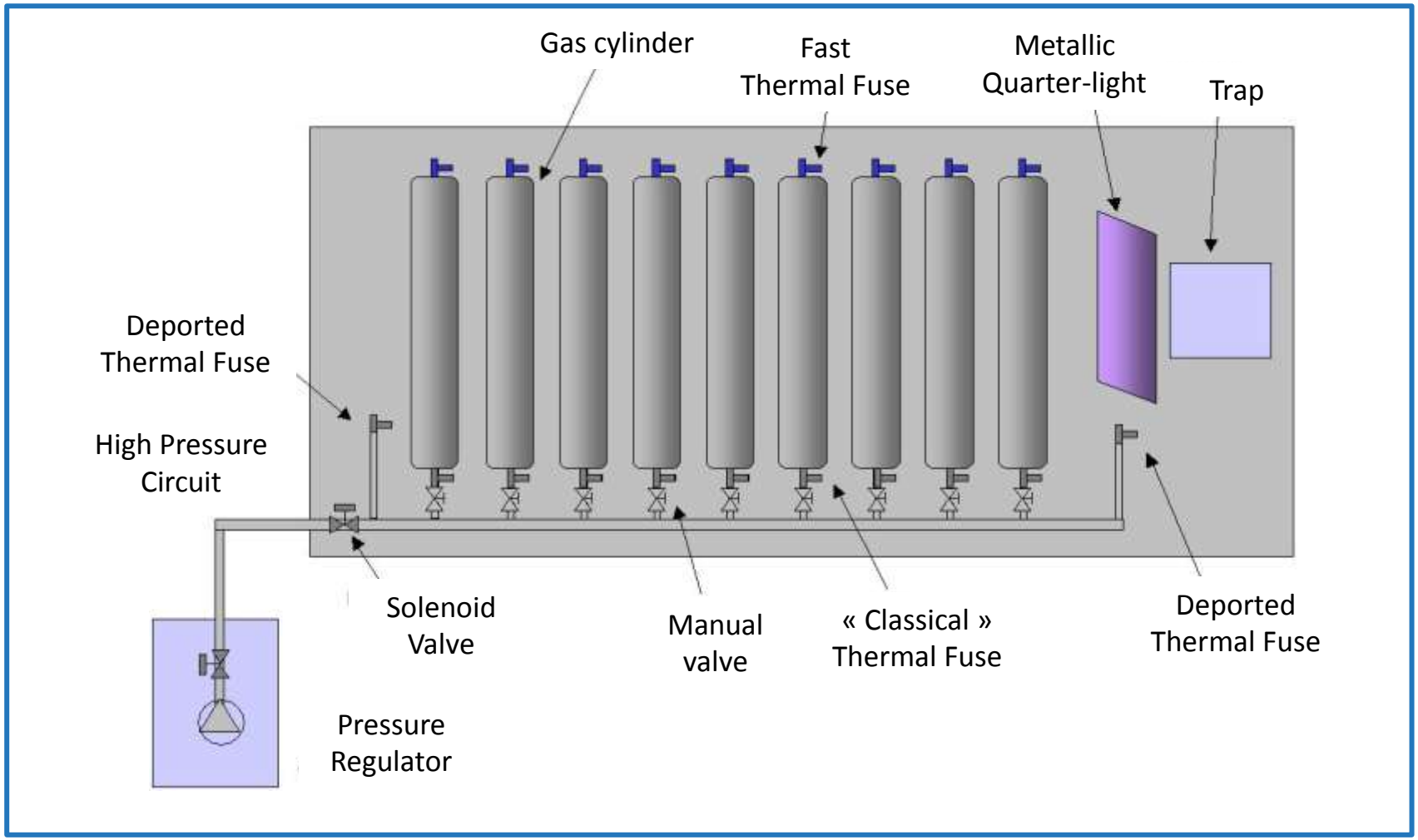
- **Diesel bus:**
  - Volume of tank: 300 litres of fuel
  - Bus dimensions: length = 12 meters, width = 2,5 meters, height = 3,3 meters.

- **GNG buses:**
  - Volume & type of tank: 9 cylinders of 126 litres each - Composite cylinders type-3 or type-4
  - 2 generations of CNG buses: based on R96M regulation or based on the ECE R110 regulation

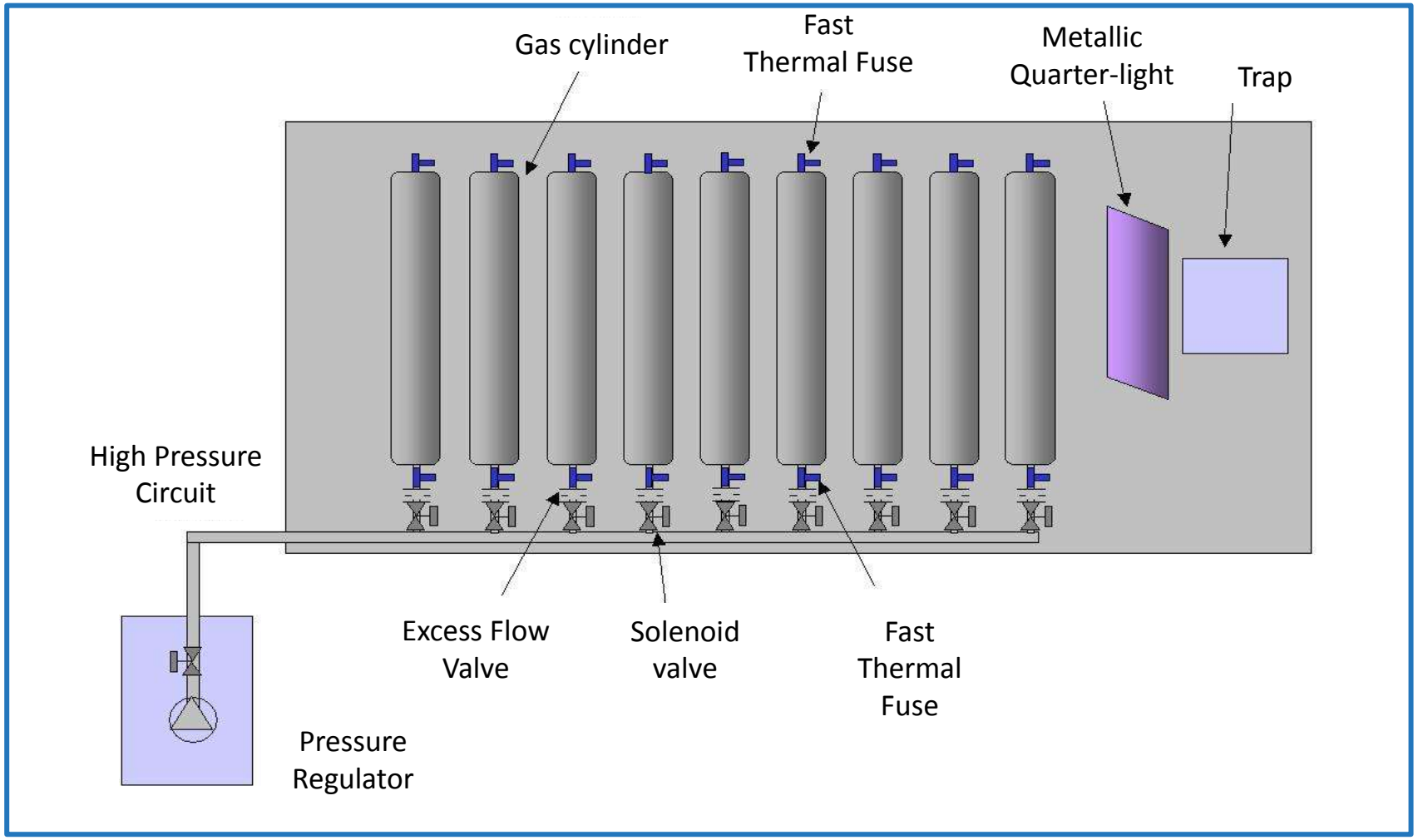
- **The industrial vehicles (HDVs & GTs):**
  - Industrial vehicles are classified following their Fully Loaded Total Weight (PTAC)

Categories (PTAC)	Diesel Vehicles		CNG Vehicles	
	HDVs	GTs	HDVs	GTs
C#1 (3,5-10 T)	70 to 100 litres		2 cylinders x 80 litres + 1 cylinder x 60 litres + 2 cylinder x 30 litres = 280 litres	2 cylinders x 80 litres + 1 cylinder x 60 litres = 220 litres
C#2 (10-19 T)	115 to 280 litres but can be 2 x 280 litres		6 cylinders x 80 litres = 480 litres	6 cylinders x 80 litres = 480 litres
C#3 (19-26 T)	300 to 800 litres but can be 1 500 litres		8 cylinders x 80 litres = 640 litres	4 cylinders x 80 litres + 4 cylinders x 70-80 litres = 600 - 640 litres

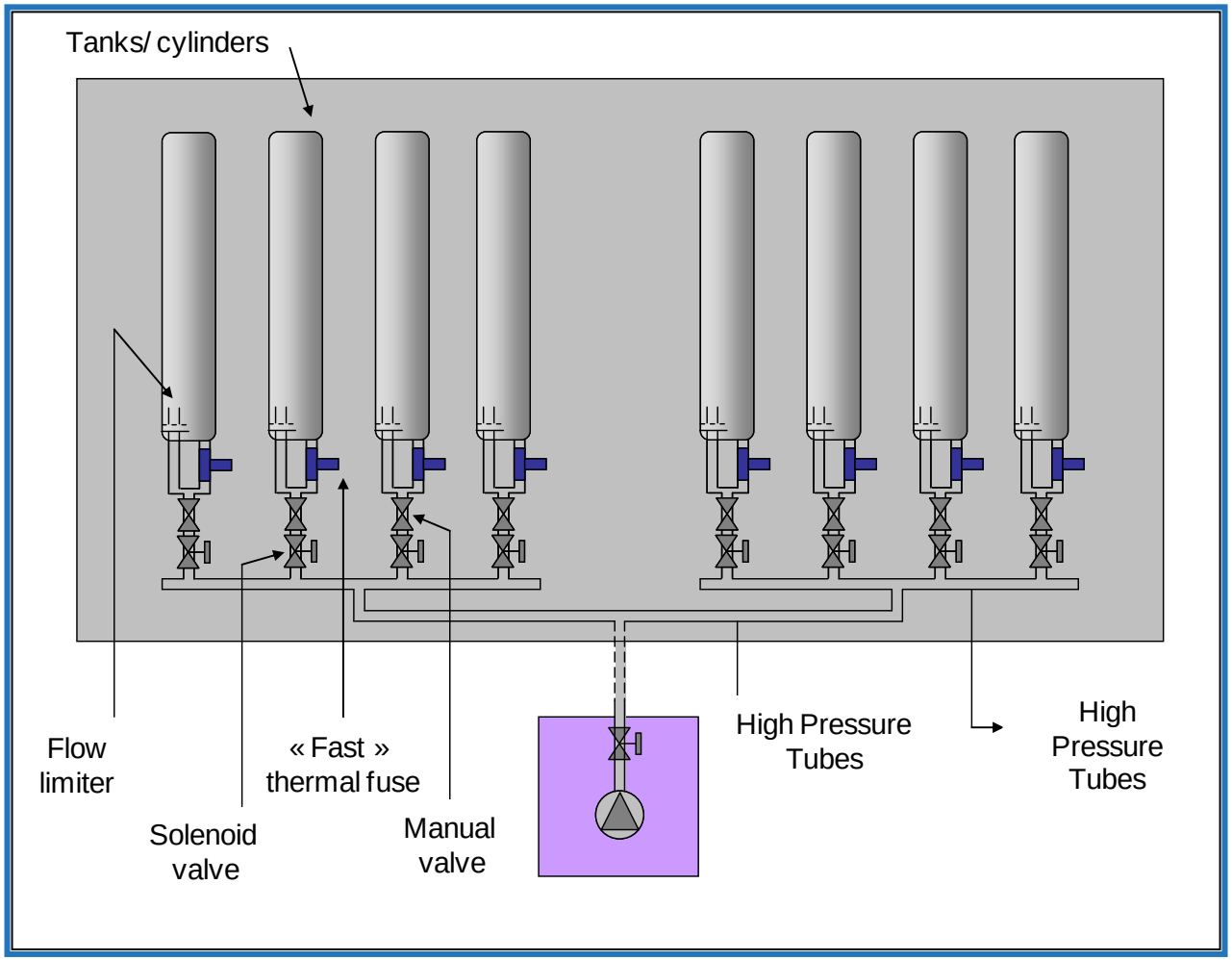
The schematic representation of a CNG bus complying with R96M regulation



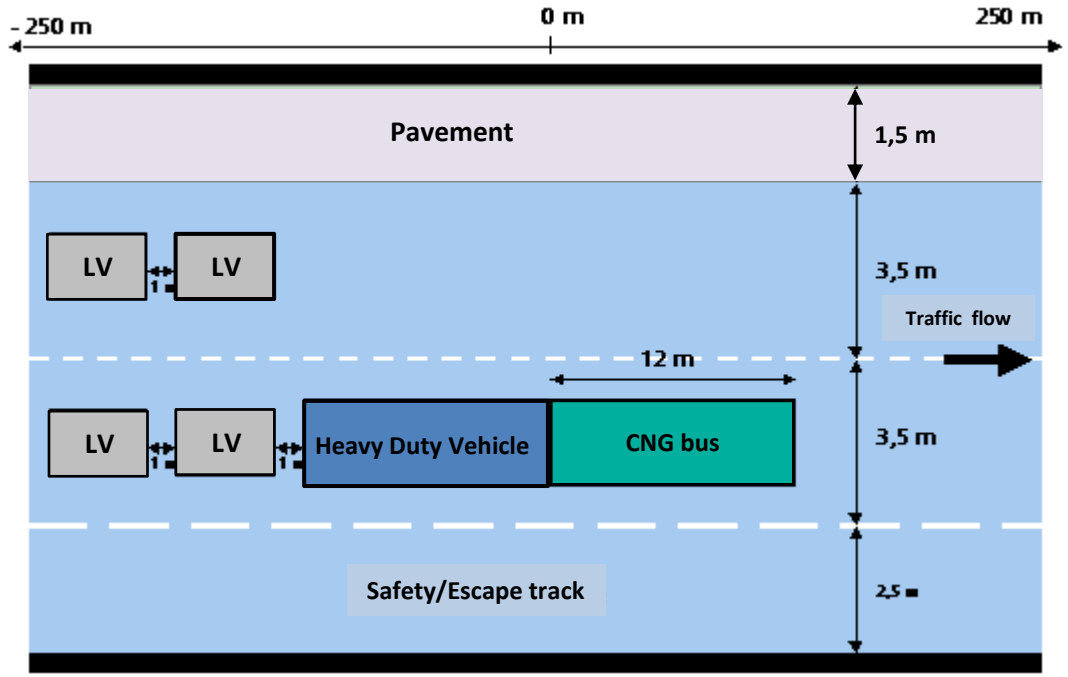
The schematic representation of a CNG bus complying with ECE R110 regulation

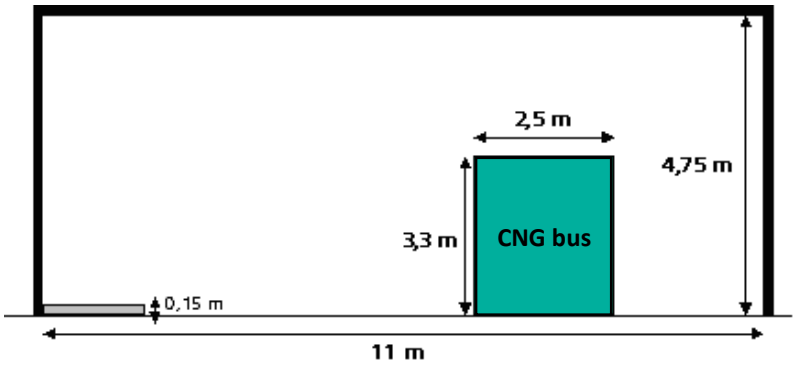


The schematic representation of CNG HDVs/GTs complying with ECE R110 regulation



The schematic representation of tunnel considered for the study

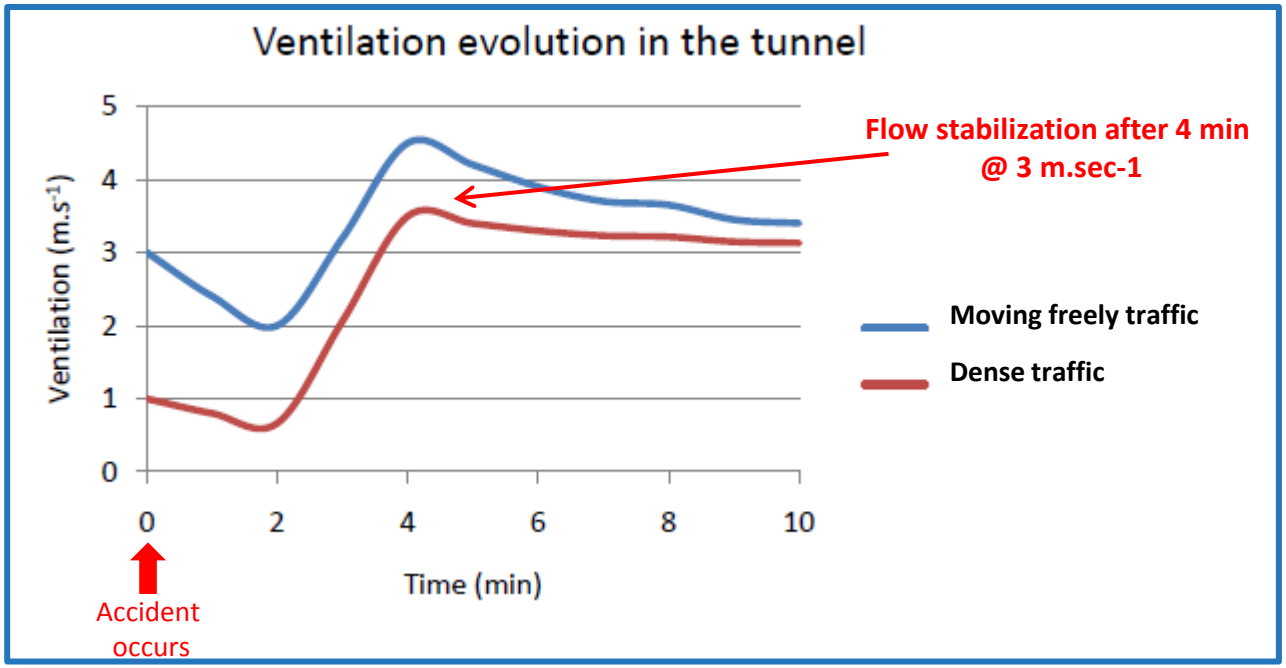




The tunnel environment

- **Two scenarios considered for the traffic conditions:**
  - **Dense traffic:**
    - **300 vehicles/hour** *(average speed: 10 km/h)*
    - **100 passengers into the bus**
  - **Moving freely traffic:**
    - **1000 vehicles/hour** *(average speed: 60 km/h)*
    - **40 passengers into the bus.**

- **The ventilation evolution in the tunnel following the accident:**



Results for buses:
Dangerous phenomena probabilities comparison

- **For each scenario, the probability of occurrence of a phenomena is evaluated.**

Cases	Central feared event / Dangerous phenomena	Probability for Dangerous phenomena (per vehicle)	
		Free traffic	Dense traffic
Diesel	Fire / Bus and gasoil fire	9,9E-10	2,1E-09
CNG R96M	Leak / Inflammation	6,2E-11	4,7E-10
	Breach / Torch	7,9E-12	0,0E+00
	Breach / Vapour Cloud Explosion (VCE)	7,9E-12	0,0E+00
	Breach / Anoxia (lack of oxygen)	3,2E-10	0,0E+00
	Fire / Torches from fuses	9,7E-10	2,4E-09
	Fire / Gas cylinder bursting	2,4E-17	6,0E-17
CNG ECE R110	Leak / Inflammation	6,2E-11	4,7E-10
	Breach / Torch with limited flow	4,7E-17	0,0E+00
	Breach / Torch	2,4E-23	0,0E+00
	Breach / VCE	9,2E-24	0,0E+00
	Breach / Anoxia (lack of oxygen)	3,7E-22	0,0E+00
	Fire / Torches from fuses	9,7E-10	2,4E-09
	Fire / Gas cylinder bursting	4,9E-14	1,2E-13

Lower probabilities due to the flow excess valve

Results for buses:
Phenomena seriousness comparison

- **Seriousness of a phenomena is evaluated in *"dead people equivalent"***
- **This evaluation is based on: (i) Return on real cases, (ii) Simulations**

Cases	Central feared event / Dangerous phenomena	Phenomena Seriousness	
		Free traffic	Dense traffic
Diesel	Fire / Bus and gasoil fire	0,34	0,86
CNG R96M	Leak / Inflammation	0	0
	Breach / Torch	0,10	/
	Breach /Vapour Cloud Explosion (VCE)	0,022	/
	Breach / Anoxia (lack of oxygen)	0,0001	/
	Fire / Torches from fuses	0,10	0,26
	Fire / Gas cylinder bursting	8,7	12,1
CNG ECE R110	Leak / Inflammation	0	0
	Breach / Torch with limited flow	0,029	/
	Breach / Torch	0,10	/
	Breach /Vapour Cloud Explosion (VCE)	0,10	/
	Breach / Anoxia (lack of oxygen)	0,0001	/
	Fire / Torches from fuses	0,10	0,26
	Fire / Gas cylinder bursting	8,7	12,1

Results for buses:
Global risk level (criticalities) comparison

Cases	Central feared event / Dangerous phenomena	Risks Levels	
		Free traffic	Dense traffic
Diesel	Fire / Bus and gasoil fire	**3,4E-10**	**1,8E-09**
CNG R96M	Leak / Inflammation	0	0
	Breach / Torch	7,9E-13	/
	Breach /Vapour Cloud Explosion (VCE)	1,7E-13	/
	Breach / Anoxia (lack of oxygen)	3,2E-14	/
	Fire / Torches from fuses	9,7E-11	6,2E-10
	Fire / Gas cylinder bursting	2,1E-16	7,2E-16
	Total	**9,8E-11**	**6,2E-10**
CNG ECE R110	Leak / Inflammation	0	0
	Breach / Torch with limited flow	1,4E-18	/
	Breach / Torch	2,4E-24	/
	Breach /Vapour Cloud Explosion (VCE)	9,5E-25	/
	Breach / Anoxia (lack of oxygen)	3,7E-26	/
	Fire / Torches from fuses	9,7E-11	6,2E-10
	Fire / Gas cylinder bursting	4,2E-13	1,4E-12
	Total	**9,7E-11**	**6,2E-10**

Critical event bringing the highest risk for CNG buses

Results for HDVs & GTs: Global risk level (criticalities) comparison

Case	Central feared event / Dangerous phenomena	Crticalities of Dangerous Phenomena					
		Free Traffic			Dense Traffic		
		3,5-10T	10-19T	19-26T	3,5-10T	10-19T	19-26T
Diesel HDVs	Fire / Gasoil fire	1,18E-10	2,27E-10	4,85E-10	4,08E-10	7,97E-10	1,70E-09
Diesel GTs	Fire / Gasoil fire	3,73E-10	5,15E-10	8,69E-10	1,31E-09	1,80E-09	3,05E-09
CNG HDVs ECE R110 regulation	Leak / Inflammation	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Breach / Torch or fire ball with limited flow	1,16E-17	7,18E-18	5,74E-17	0,00E+00	0,00E+00	0,00E+00
	Breach / Torch o fire ball with important flow	9,84E-23	5,80E-23	1,69E-22	0,00E+00	0,00E+00	0,00E+00
	Breach /Vapour Cloud Explos	9,12E-24	4,35E-24	1,16E-23	0,00E+00	0,00E+00	0,00E+00
	Breach / Anoxia	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Fire / Torches from fuses	4,54E-11	5,61E-11	6,15E-11	1,75E-10	2,17E-10	2,38E-10
	Fire / Gas cylinder bursting	2,83E-16	3,39E-16	9,04E-16	2,23E-15	2,66E-15	7,10E-15
	Total CNG HDVs	**4,54E-11**	**5,61E-11**	**6,15E-11**	**1,75E-10**	**2,17E-10**	**2,38E-10**
	gap (Diesel-CNG)/Diesel %	**61**	**75**	**87**	**57**	**73**	**86**
CNG Garbage Trucks (GTs) ECE R110 regulation	Leak / Inflammation	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Breach / Torch with limited flow	1,93E-18	9,38E-18	1,77E-17	0,00E+00	0,00E+00	0,00E+00
	Breach / Torch with Important flow	1,95E-22	4,44E-22	7,65E-22	0,00E+00	0,00E+00	0,00E+00
	Breach Vapour Cloud Explos	4,83E-24	9,66E-24	1,29E-23	0,00E+00	0,00E+00	0,00E+00
	Breach / Anoxia	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Fire / Torches from fuses	3,77E-10	4,30E-10	5,56E-10	1,47E-09	1,67E-09	2,16E-09
	Fire / Gas cylinder bursting	2,06E-16	4,11E-16	5,48E-16	1,62E-15	3,23E-15	4,31E-15
	Total CNG GTs	**3,77E-10**	**4,30E-10**	**5,56E-10**	**1,47E-09**	**1,67E-09**	**2,16E-09**
	gap (Diesel-CNG)/Diesel %	**-1**	**16**	**36**	**-12**	**8**	**29**

The only case unfavourable to CNG in comparison to Diesel

Conclusions

- For buses moving in a tunnel, when considering the 10 first minutes after the accident occurs, **quantitative analysis shows that the global risk level of a CNG bus is about 3 times inferior to the global risk level of a Diesel bus**.

- The **average production of fumes** over the 10 first minutes following the accident **is much lower – about -80% - in the CNG case than in the Diesel case**.

- Considering the period of 1 hour following the accident, **the global risk level of a CNG bus is 1,4 times inferior than the global risk level of a Diesel bus**.

- In the case of HDVs, **the global risk level of CNG HDVs is 61% less important than the global risk level of Diesel HDVs** (free traffic conditions – HDVs from 3.5 to 10 tons). For the **heavier HDVs (from 19 to 26 tons), the risk is 87% less important with CNG HDVs than with Diesel HDVs**.

For the studied scenarios, it appears that CNG vehicles (buses, HDVs, GTs) are not more dangerous than Diesel equivalent vehicles in tunnels

Acknowledges

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  - **SECTOR** Company
  - **Cmr Gexcon** Company

Thank you for your attention !

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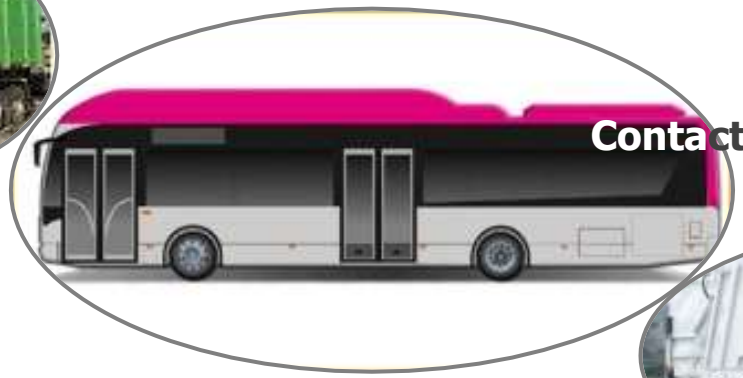

Contacts: olivier.bordelanne@gdfsuez.com