

CNG: A SAFE FUEL FOR ADR TRUCKS

presented to
WP15 -Transport of Dangerous Goods
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by Dr. Jeffrey M. Seisler
on behalf of



Building blocks for NGV safety

EQUIPMENT STANDARDS:

- Materials Selection
- Factors of Safety
- Verification Testing

INSTALLATION CODES:

- Station Siting
- Pressure
- Management
- Cylinder Safety

QUALIFIED PERSONNEL:

- Training
- Operating and maintenance procedures

EDUCATION OF END USERS:

Drivers, Fleet Managers, Fueling Station Operators, First Responders, General Public



COMMON PERCEPTIONS OF NATURAL GAS AS A VEHICLE FUEL

Past & Present



Perception is Reality



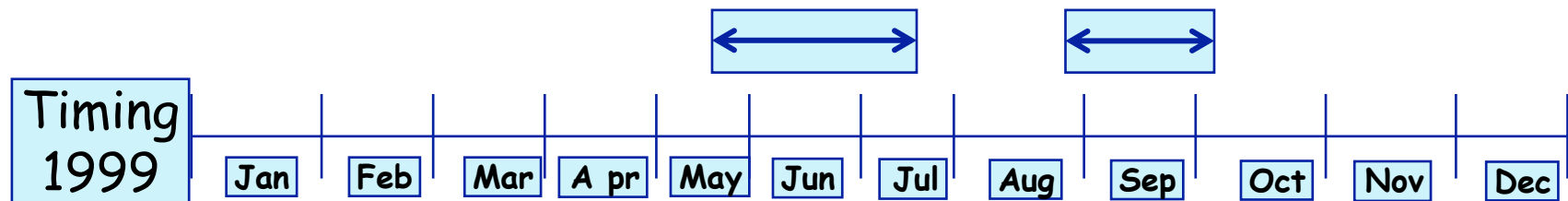


1999 Italian NGV Campaign

surveyed 800 people,
representative of the Italian drivers
population

(Eurisko marketing survey)

Media Campaign: 3 main newspapers; 8 weekly magazines; 25 monthly magazines (car, science, environment, life style)

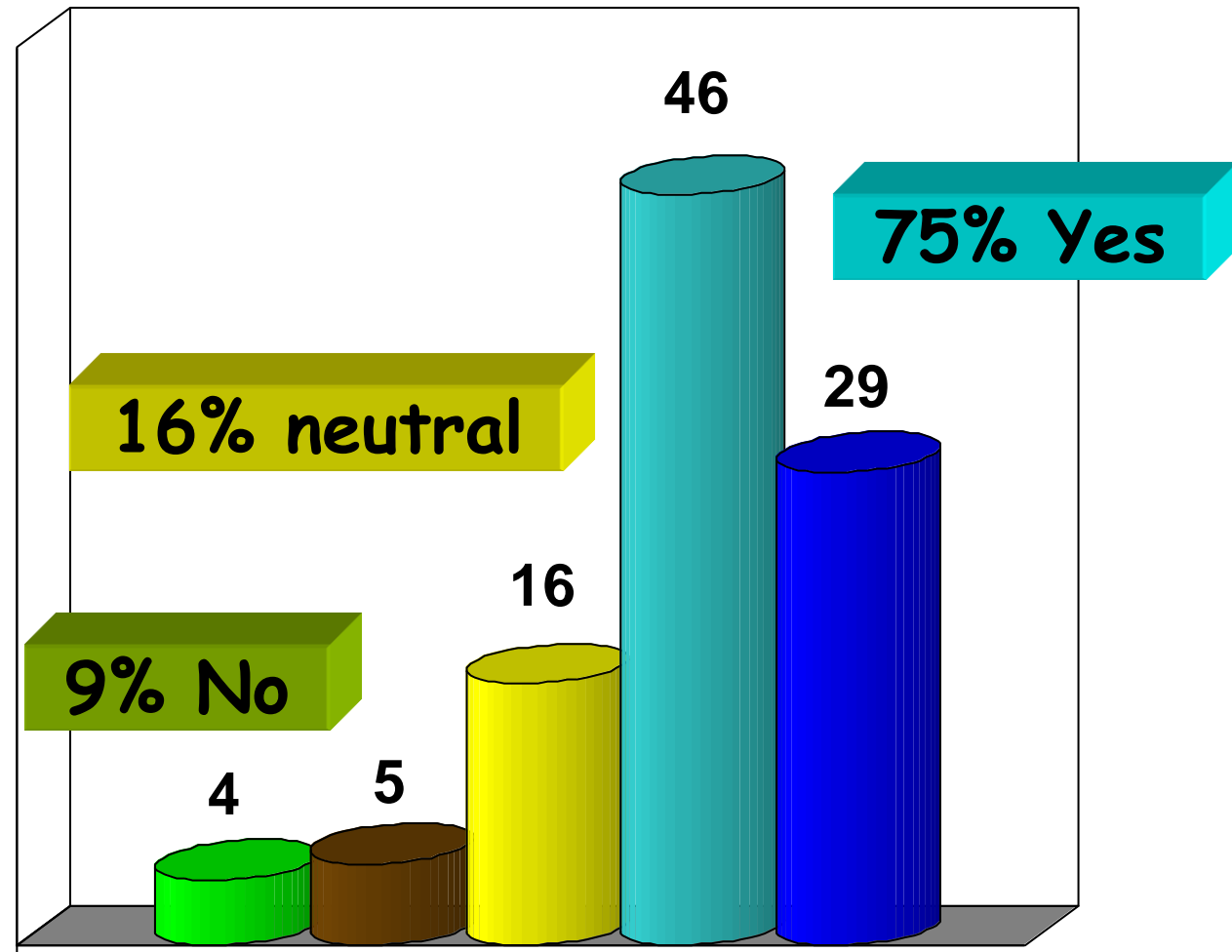
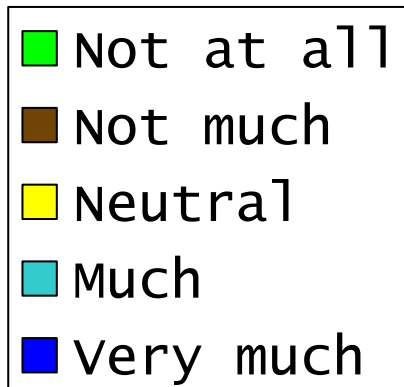


Source: The NGV Market in Italy, Flavio Mariani (ENI) as presented at the 2002 Bayerngas Symposium



Do you think CNG is an attractive motor fuel?

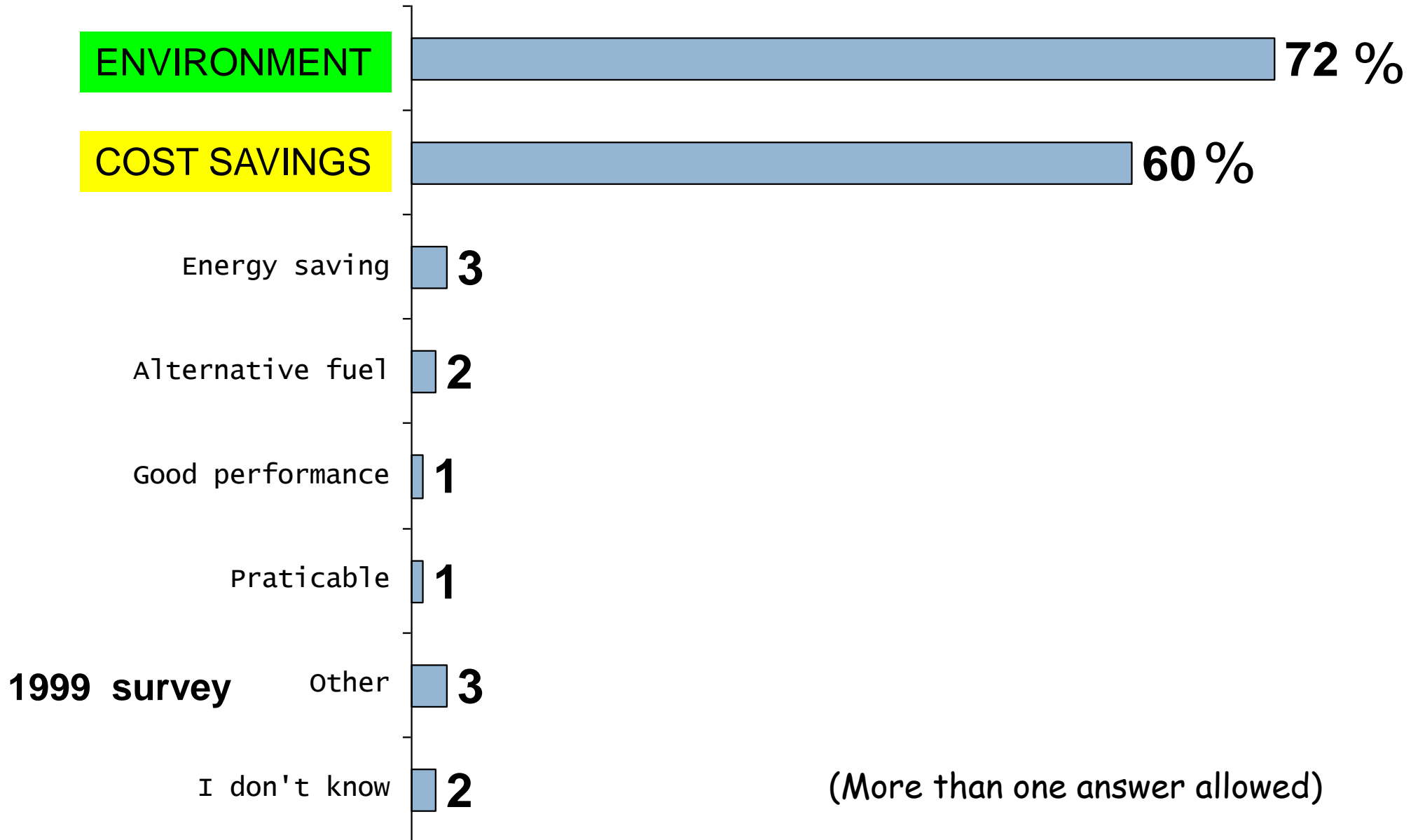
1999 survey



Source: The NGV Market in Italy, Flavio Mariani (ENI) as presented at the 2002 Bayerngas Symposium



Why do you think CNG is attractive?



1999 survey

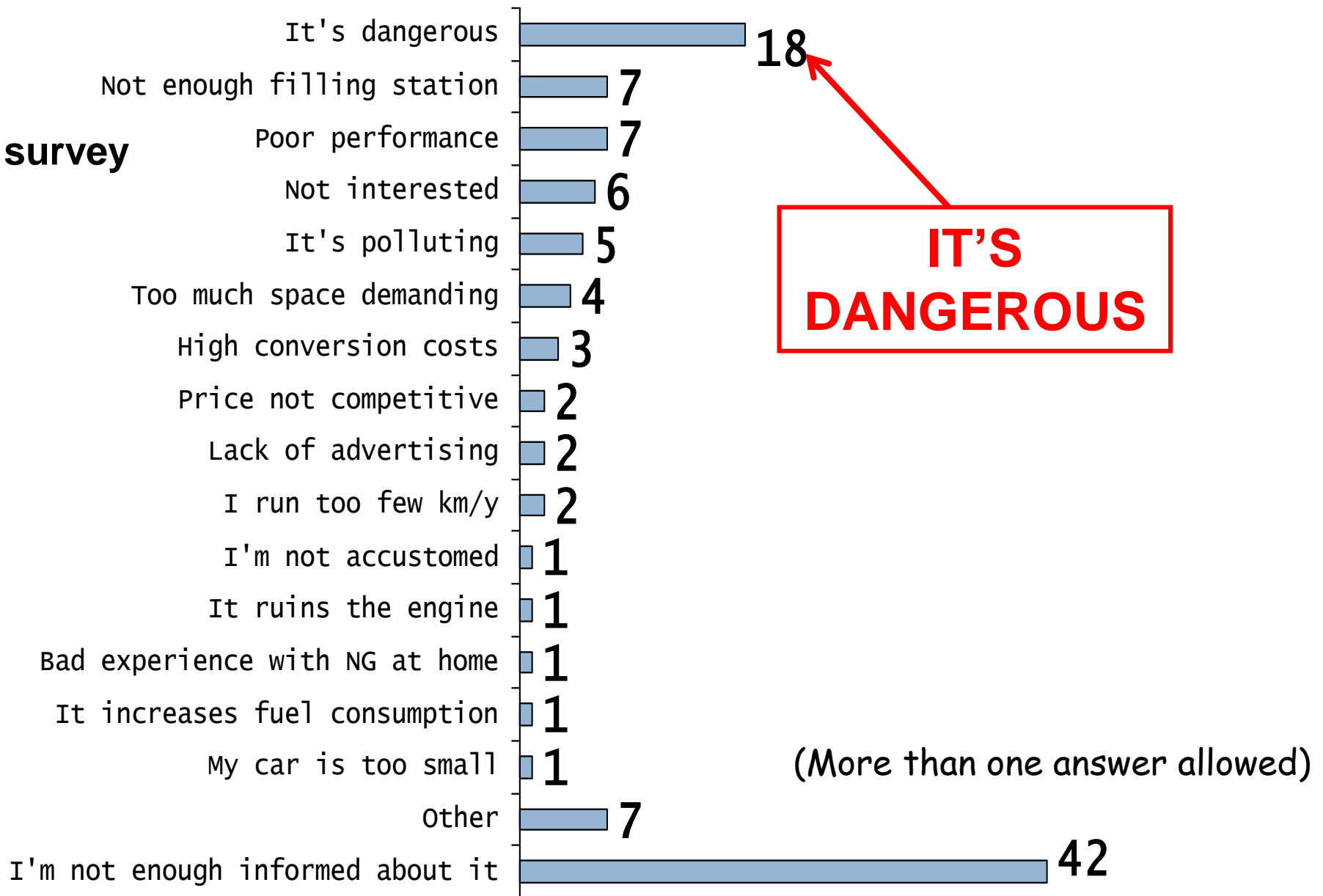


Source: The NGV Market in Italy, Flavio Mariani (ENI) as presented at the 2002 Bayerngas Symposium

Why do you think CNG is *NOT* attractive?



1999 survey

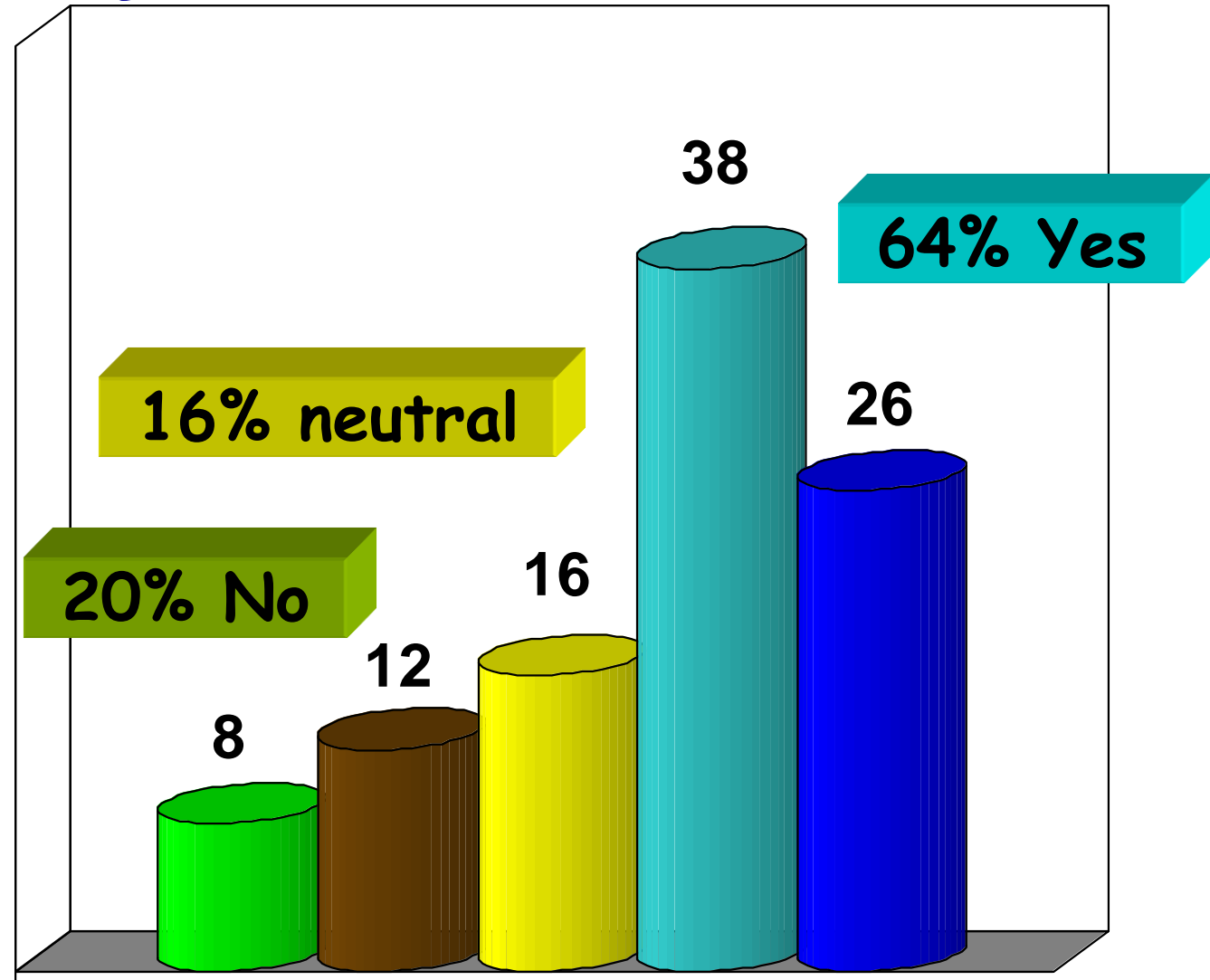
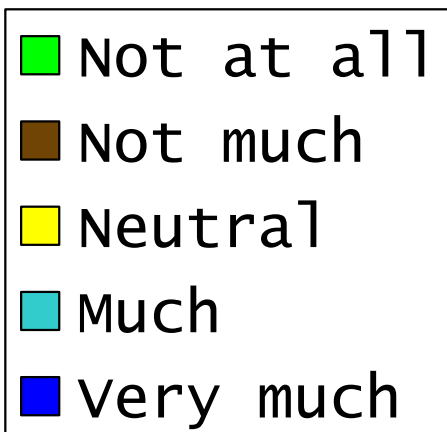


Source: The NGV Market in Italy, Flavio Mariani (ENI) as presented at the 2002 Bayerngas Symposium



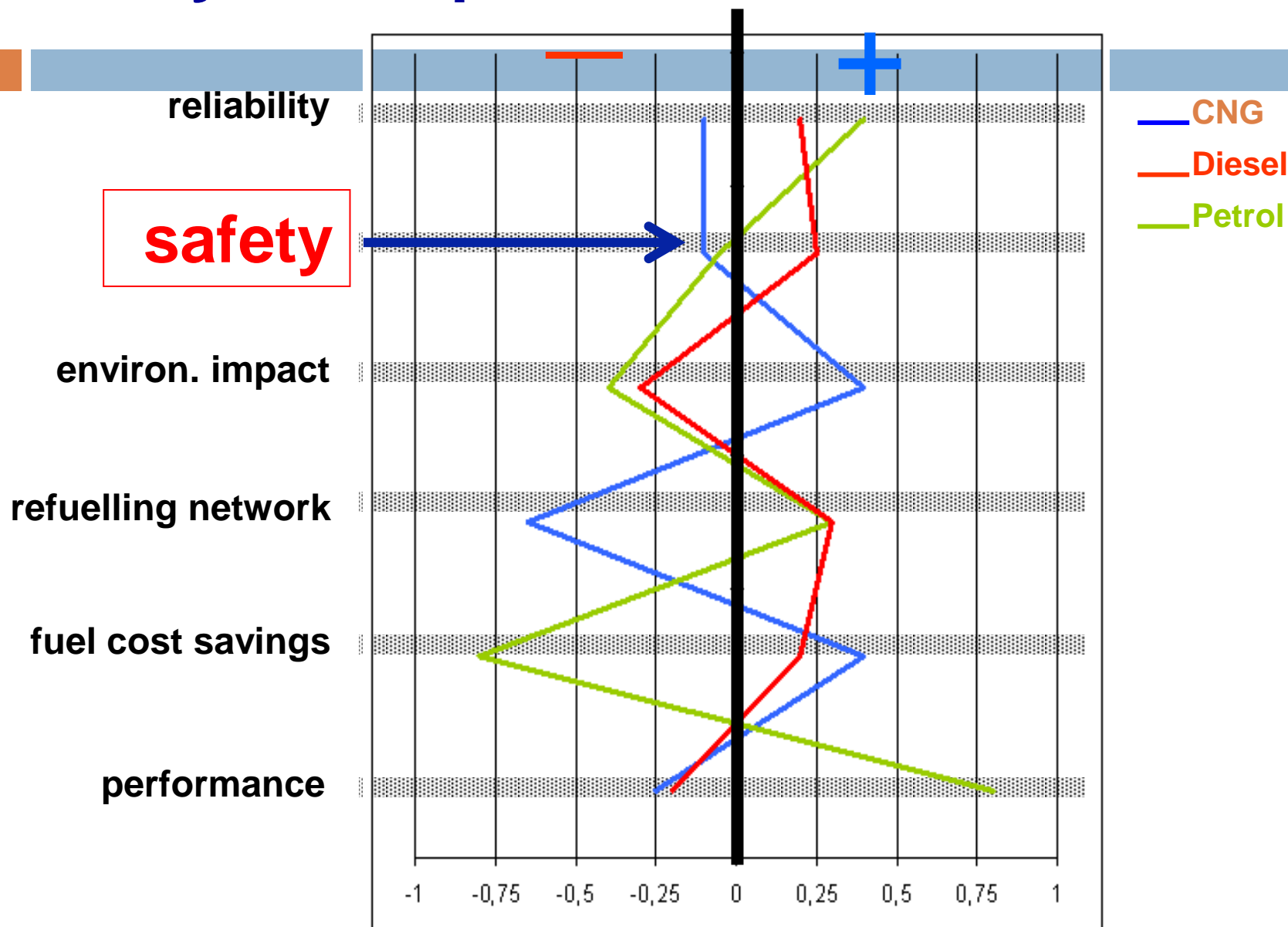
Would you be interested in CNG for your own car?

1999 survey



Source: The NGV Market in Italy, Flavio Mariani (ENI) as presented at the 2002 Bayerngas Symposium

Italian customers' appreciation of NGVs: Safety was a preceived issue in 2005



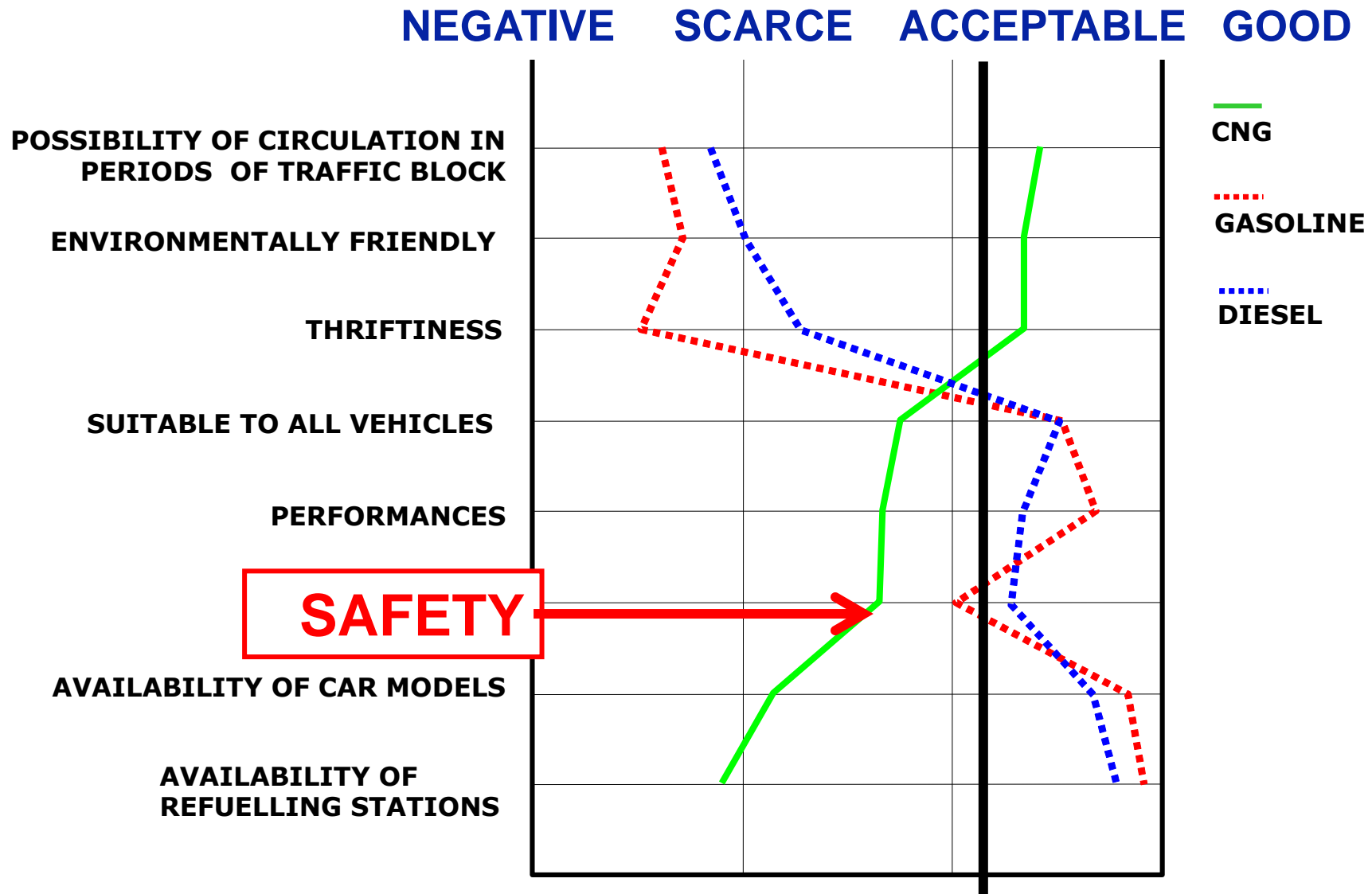
Source: Italian NGV Scenario 2005, Flavio Mariani, Metauto-ENI Divisione Gas & Power, Cattolica, September 20-21, 2005





Fleet operators opinion survey

Perception of CNG features vs gasoline and diesel



Source: Italian NGV Scenario 2005, Flavio Mariani, Metauto-ENI Divisione Gas & Power, Cattolica, September 20-21, 2005



NATURAL GAS SAFETY



Physical characteristics of natural gas shows that the fuel is as safe or safer than gasoline or diesel

Properties	Petrol	Diesel	LPG	CNG	LNG
Lower Explosive Limit (LEL)	1.2%	0.6%	1.8%	5%	
Upper Explosive Limit (UEL)	7.1%	7.5%	8.5%	15%	
Auto ignition Temperature	246 °C	210 °C	450 °C	540 °C	
Flash point	-43 °C	55 °C	-104 °C	-188 °C	
<i>Dispersion quality</i>	None	none	medium	High	Medium



CNG CYLINDER SEVERE ABUSE TEST

Only an armour-piercing bullet shot from a NATO-style assault rifle can penetrate a metal cylinder.



NGV SAFETY: SEVERE ABUSE

TESTING OF CNG CYLINDERS



Dropped Cars



**10 ...17....23...30m drops
...no leakage!!**



Dynamite Test



Gunshot Test



**Structural composites
industry, fire proof cylinders**

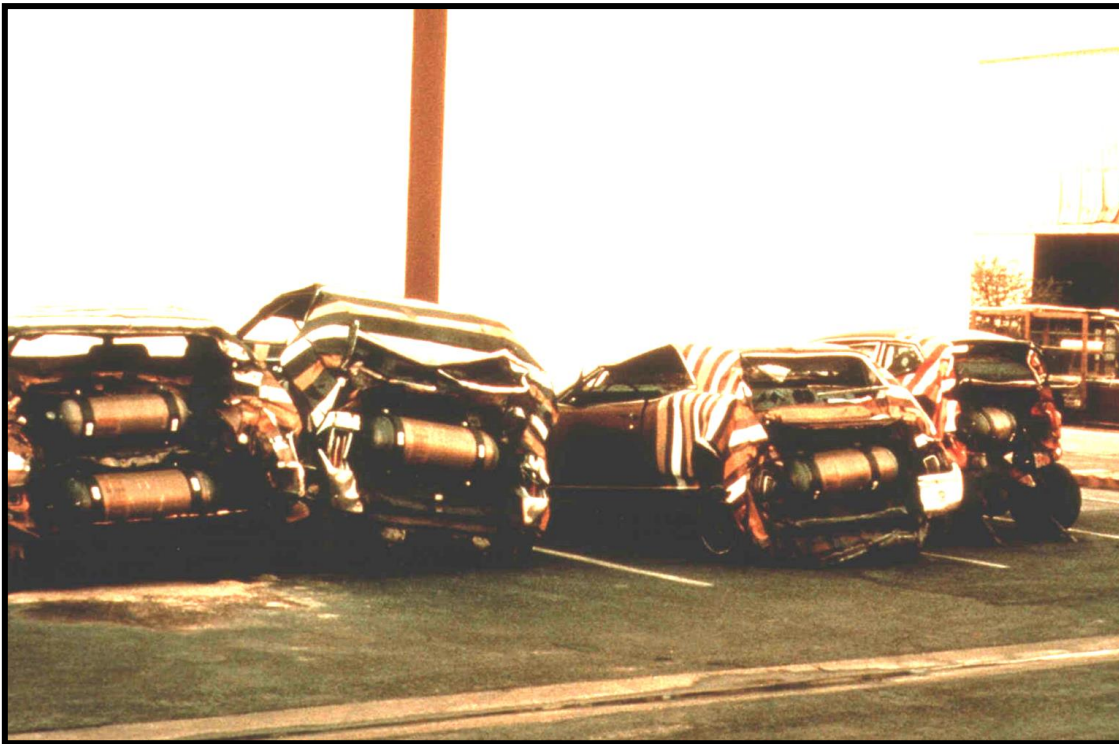
CNG cylinders remain intact under the most rigorous conditions



SEVERE ABUSE TESTING

Car drops from...

10 ...17....23...30 metres and no leakage





TESTING OF CYLINDERS



DROP TEST AT 45°



DROP TEST VERTICALLY



DROP TEST HORIZONTALLY



**FRONTAL CRASH TEST 30 G
FOR BUS**



**FRONTAL CRASH-TEST
30G FOR TRUCKS**



**CATAPULT LAUNCHING AT 50 KM/H
against a metallic sharp edge**



BONFIRE TESTING



**GUN FIRE TESTING BULLET
7.62 MM**



GRENADE TEST

Source: Ullit



HYDRAULIC BURST TEST



**EXTREME TEMPERATURE
PRESSURE CYCLING**



**HYDRAULIC TEST PRESSURE
300 BAR**



U.S. DOT study systematically characterized NGV/CNG accidents, equipment failures & fires from 1976-2010



- **138 incidents:** 56% U.S.; 44% Europe, Asia, S.America
- **All vehicles included:** 51% LDV/Trucks; 38% buses; 11% other commercial vehicles
- Most problems were with individual NGVs
- Some systemic problems identified, especially with Pressure Relief Devices (PRDs)
- 12% involved fire but most not attributed to CNG systems or NGVs (leaking petroleum liquids)



135 CNG incidents characterized (1976-2010)



Type of Incident	Number of Incidents	Percentage of Total (135)
Cylinder ruptures	50	37%
PRD release (no fire)	14	10%
Vehicle fire (no cylinder rupture)	17	13%
Accident w/another vehicle	12	9%
Single vehicle accident	6*	4%
Cylinder or fuel tank leak	14	10%
Other	7**	5%
Unknown cause	15+	11%

*5 of these were at low underpasses

** 5 related to operational/maintenance

+12 outside the U.S.



Details of Incidents (135 total listed)

Cylinder Ruptures (50 incidents)

- 18 (36 %) were due to damage to exterior of cylinder (including, for example, acid leaked from batteries carried in transit) (inspection issue)
- 8 (16%) were due to manufacturer defect

Accidents with other vehicles (12 incidents)

- 8 (47%) had no gas release
- 8 (47%) had controlled release of gas through PRD (1 ignited)

Vehicle Fires (17 incidents or 13% of total incidents [135 of total listed])

- Only 1 attributed to the natural gas system



Fire incidents generally were not related to the CNG system

- “The majority of the vehicle fires included in the list of incidents were not caused by a leaking CNG fuel system and were in light-duty vehicles;
- Most fires were started by an electrical short, stuck brakes (which ignited a tire), or leaking gasoline, diesel fuel, or hydraulic fluid impinging on a hot engine or exhaust components.



NGV Safety in Maintenance Workshops (HAZOP Study)

- 1) LNG boil off scenario
- 2) Venting/bleed CNG/LNG in maintenance scenario
- 3) Full venting of 700 L CNG tank (high volume)

FINDINGS

- 1 & 2: “Flammable regions disappeared shortly after leaks; no significant hazard expected”
- 3: “High volume release had two peaks when gas was flammable with roughly 0.5 kg of natural gas in flammable regions... could produce an overpressure of around 2.2 kPa—enough to break glass, but not much else.”

Source: “*Analyses in Support of Risk-Informed Natural Gas Vehicle Maintenance Facility Codes and Standards: Phase I*”, SANDIA REPORT, SAND2014-2342, March 2014.



Reality: CNG vehicles are safer than gasoline vehicles in tunnels.

- in 1989, several natural gas utilities and the New York State Energy Research and Development Authority jointly funded an comprehensive, \$1.2 million safety analysis of fuel-related accidents in tunnels.
- Conclusion: ***modern tunnel environments, fanned by high-powered ventilation systems, would quickly remove and disperse gaseous fuels safely above ground in the event of an accident.***

Dispersion of CNG Fuel Releases in Naturally Ventilated Tunnels, Center for Fire Safety Studies, Worcester Polytechnic Institute, Mass., November 1994



Reality: CNG vehicles are safer than gasoline vehicles in tunnels.

- Report done to address prohibitions of NGVs in tunnels in Boston, Massachusetts (1994)
- The comparison of the gasoline and CNG dispersion calculations demonstrates that ***the size of the flammable region from an incident involving a CNG fueled van is significantly smaller than the flammable region from a comparable incident involving a gasoline fueled van*** as long as the effective ventilation velocity is on the order of 0.10 m/s or higher.

Dispersion of CNG Fuel Releases in Naturally Ventilated Tunnels, Center for Fire Safety Studies, Worcester Polytechnic Institute, Mass., November 1994



CNG vs Diesel (Buses) in Tunnels

GDF SUEZ

PURPOSE

comparing inherent risks of operating CNG buses in tunnels to the inherent risks of operating diesel buses under the same conditions.

OBJECTIVES

- To identify scenarios of accidents implicating CNG buses being operated in tunnels
- To evaluate the risks of these CNG buses and to compare them to the risks associated to the operation of diesel buses under the same conditions

Source: *Comparative Study of the Inherent Risks of CNG & Diesel Buses*, Dr. Olivier Bordelanne, GdF Suez in Tunnels, NGV Global June 2010. Rome.



Two tunnel scenarios evaluated

The tunnel environment

→ Two considered scenarios for the traffic conditions :

▪ Dense traffic :

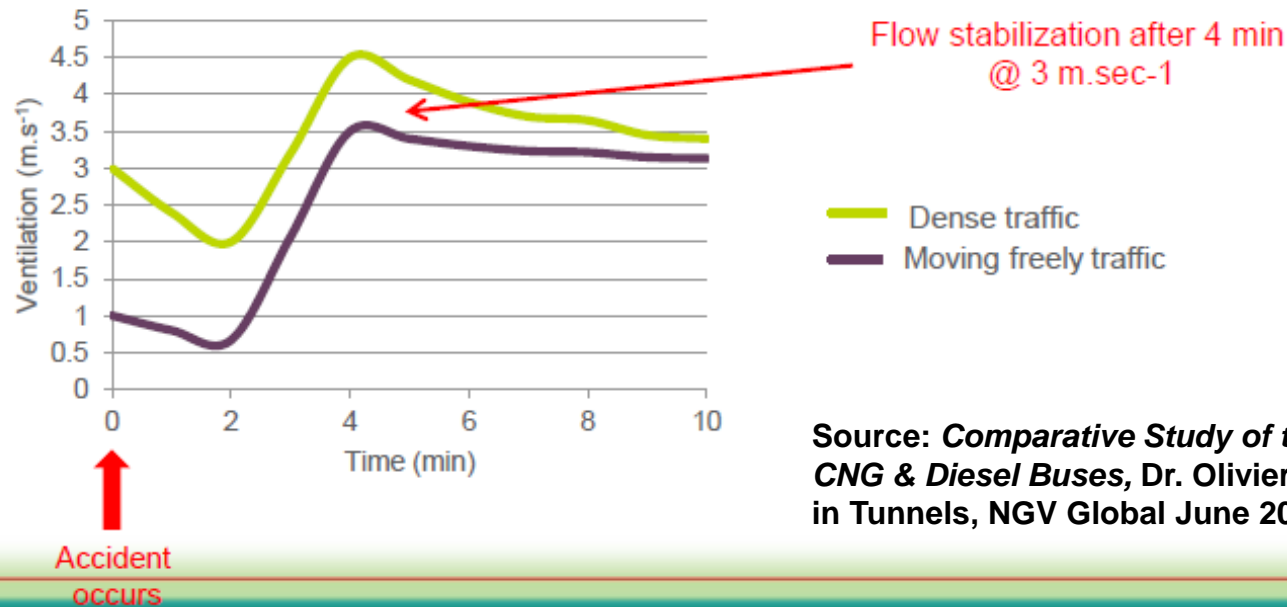
- 3000 vehicles/hour (average speed: 10 km/h)
- 100 passengers into the bus

▪ Moving freely traffic :

- 1000 vehicles/hour (average speed: 60km/h)
- 40 passengers into the bus

→ The ventilation evolution in the tunnel following the accident:

Ventilation evolution in the tunnel



Source: *Comparative Study of the Inherent Risks of CNG & Diesel Buses*, Dr. Olivier Bordelanne, GdF Suez in Tunnels, NGV Global June 2010. Rome.



Conclusions CNG vs Diesel in Tunnels

GDF SUEZ

During the first 10 minutes following the accident, the global risk level of a CNG bus is about 3 times inferior to the global risk level of a diesel bus

During the first hour following the accident, the global risk level of a CNG bus is 1.4 times inferior to the global risk level of a diesel bus

**CNG buses are not more dangerous
than diesel buses in tunnels**

Source: *Comparative Study of the Inherent Risks of CNG & Diesel Buses*, Dr. Olivier Bordelanne, GdF Suez in Tunnels, NGV Global June 2010. Rome.



Reality: NGVs pose no risk in underground parking garages

- ***“A CNG vehicle poses no extraordinary risk in a typical parking garage; that is, the risk of the CNG vehicle is equal to or less than the risk posed by a gasoline fuelled vehicle.*** The conclusion is valid for both forced and natural circulation type garage designs and should cover every type of public parking garage normally encountered. ***Overall, parking in public garages is not a major CNG safety concern.***
(Caveat: Special cases, where the analysis cannot be extended, include a garage with no ventilation, or a garage with no ceiling registers [ventilation outlets]).

Hazard Assessment of Natural Gas Vehicles in Public Parking Garages Thomas Grant, et. al, Ebasco Services Incorporated, July 1991.



Reality: Home fuelling appliances pose minimal risks in garages*

The potential for a hazardous fire due to accidents (non-misuse failures) and even misuse of the fuelling appliance are **1 in 10.7 million over one year.**



Source: *Safety Evaluation of the FuelMaker Home Refueling Concept*, Final Report, Waterland, Powars, and Stickles, National Renewable Energy Laboratory, NREL//SR540/36780, Golden, Colorado, February 2005.*Pertains only to Fuelmaker or devices with similar profiles.



CNG cylinder inspections are required every 48 months (UN/ECE R.110)

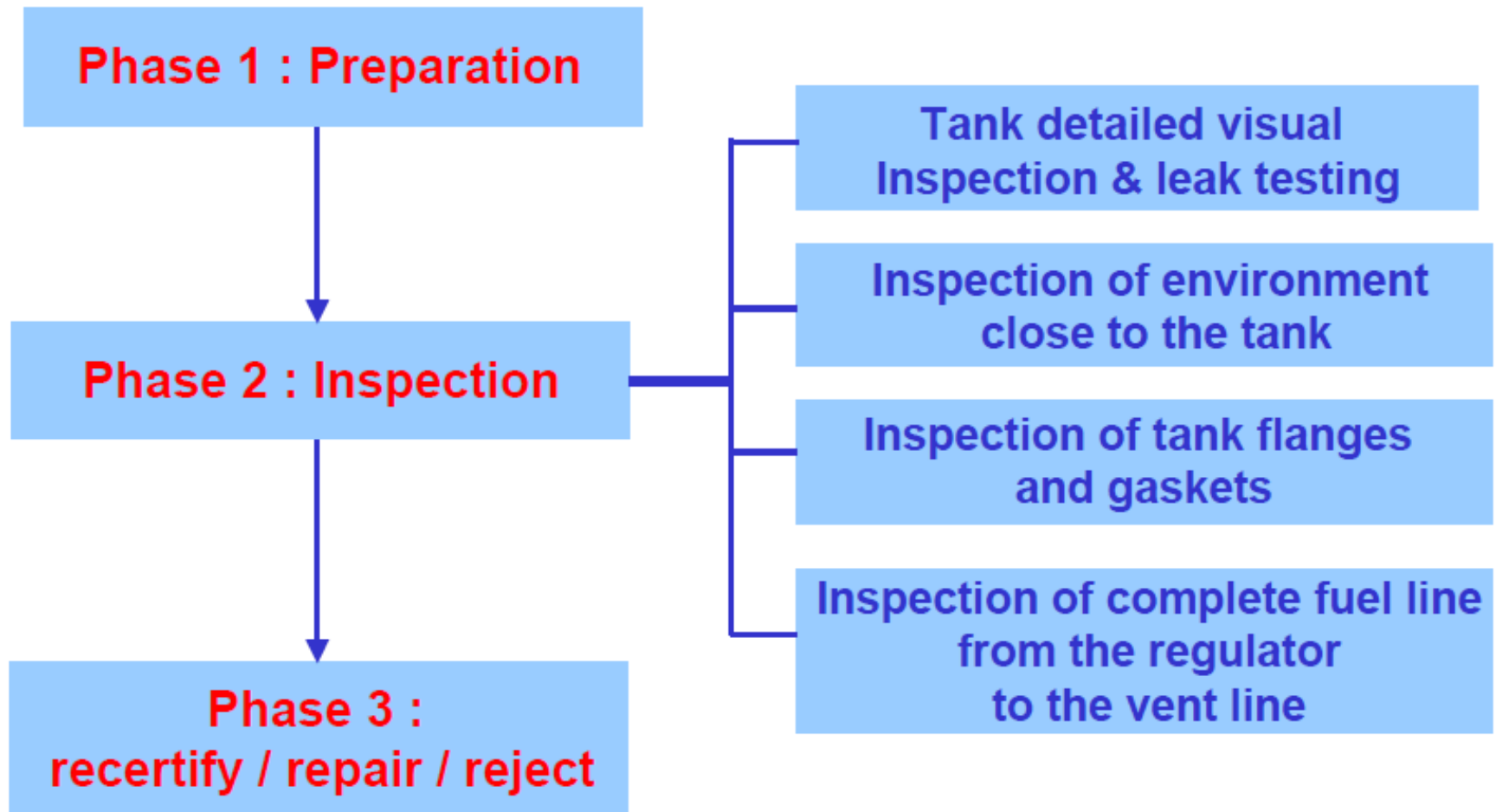
- ❑ Or...after one of the following events occurs:
- ❑ Accident affecting the high pressure system
- ❑ Over pressurization
- ❑ Exposure to corrosive products
- ❑ Other: abnormal gas smell; rapid pressure loss; whistling sound, etc.
- ❑ Installation or replacement of a cylinder



Photo source: CETIM



The inspection process



What damages are looked for on cylinders?

- labeling inspection
- heat damages
- chemical damages
- UV damages
- Delamination
- leak from the cylinder
- cracks, scratches, dent
- impact
- stress corrosion cracking
- abrasion damages
- generalized corrosion
- galvanic corrosion

Deep scratches damages



Mixed UV and chemical damages



Corrosion initiation (Type 1)



What damages are looked for on the high pressure system?

- the fuel line
- bracket
- PRD
- the valves
- the vent line
- the filling connector
- the regulator



CONCLUSIONS

- ▣ Characteristics of natural gas make it a safe fuel
- ▣ The on-board vehicle fuel system integrity is amongst the most robust of any vehicles
- ▣ CNG fuel storage system safety is outstanding...in theory and practice
- ▣ Natural gas is amongst the safest **fuels** on the road
- ▣ NGVs are amongst the safest **vehicles** on the road.....and are suitable to be certified as ADR.



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