CNG & H2 CYLINDERS:
Opportunities, Challenges & Strategies

11-12 MARCH 2008

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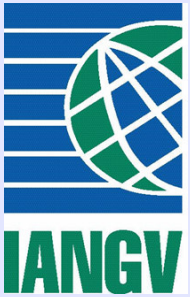

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PURPOSE OF THIS WORKSHOP

- **Bring together high-level experts & stakeholders to address very specific & challenging issues facing CNG & H2 storage systems**
- **Based upon critical issues identified, advance actions & strategies required in the near-and-longer term**

Topics to be Covered

- Issues with associated cylinders & hardware, including PRDs & valves
- Cylinder incidents and learning from them
- Cylinder inspection techniques and practices
- Standards and regulatory issues for both CNG and hydrogen storage
- Concerns about emerging markets for CNG & H2
- The strong link between CNG and hydrogen fuel storage systems should identify synergies that can be of mutual benefit to all participants
- Next stratetgic steps

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WHERE WE WERE

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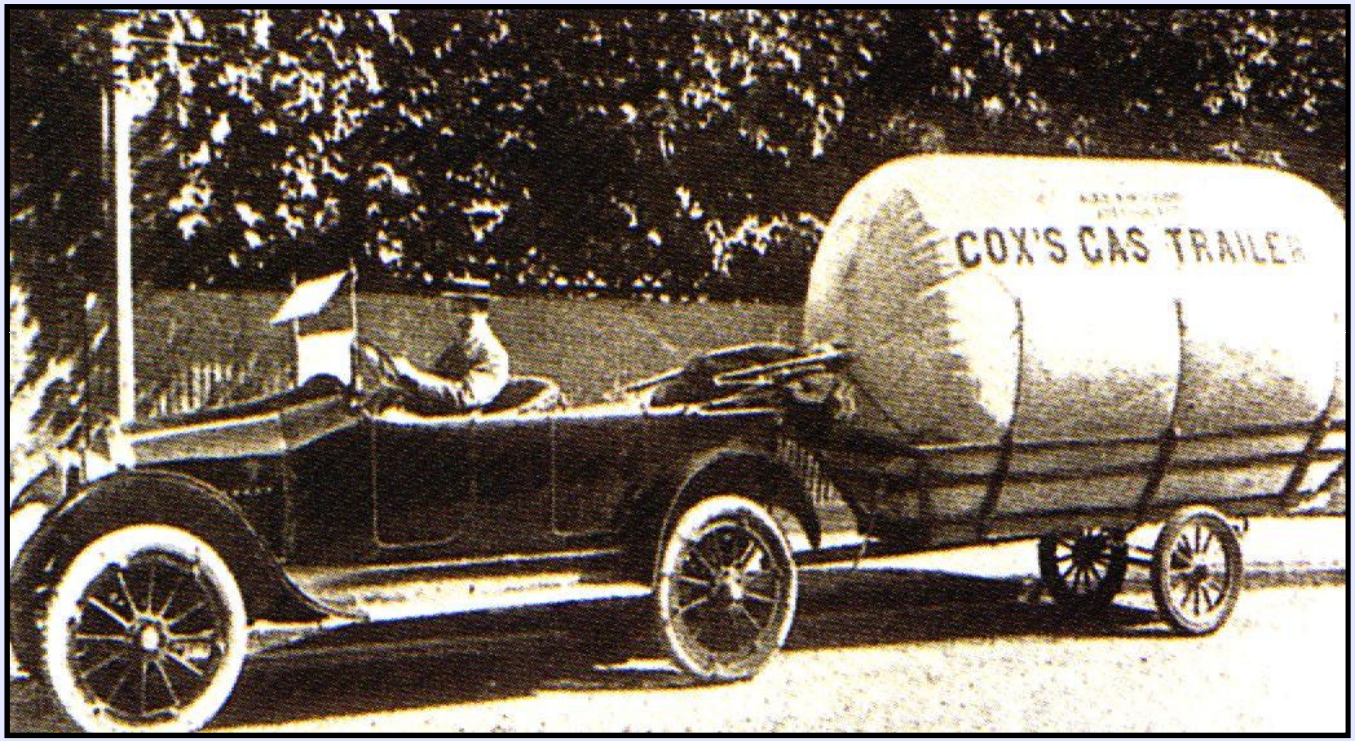
Natural Gas Vehicles History



Low-pressure bag carried on a trailer (early 20th century)

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Classics - Cars

Birmingham, UK

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VINTAGE NGVs

Bus with Coal Gasifier

Adler-Diplomat – 1939
Coal Gas Conversion

Citroën Diesel-Gas (?)

THE Classic VW
Beetle (1939)

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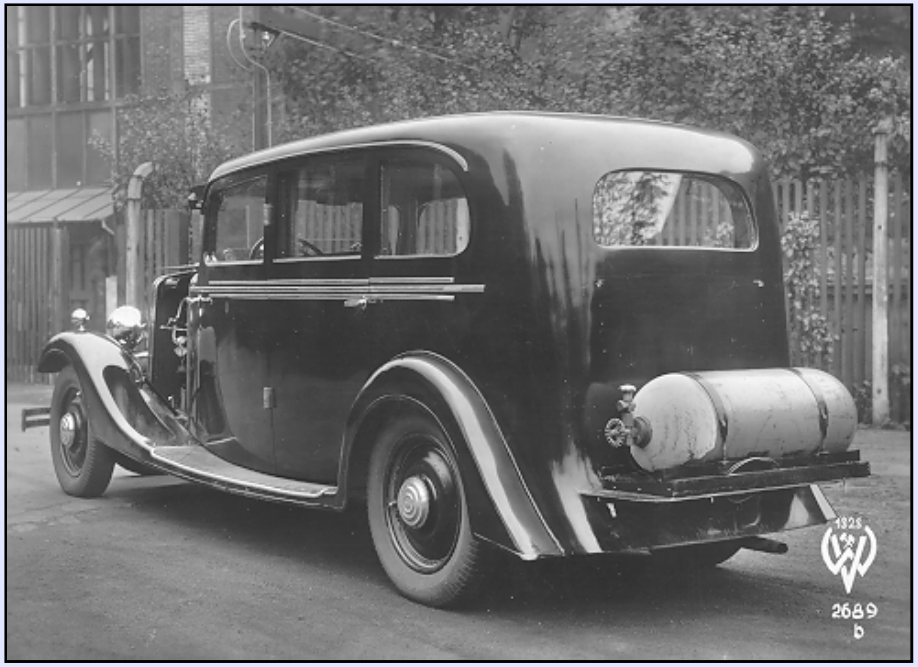
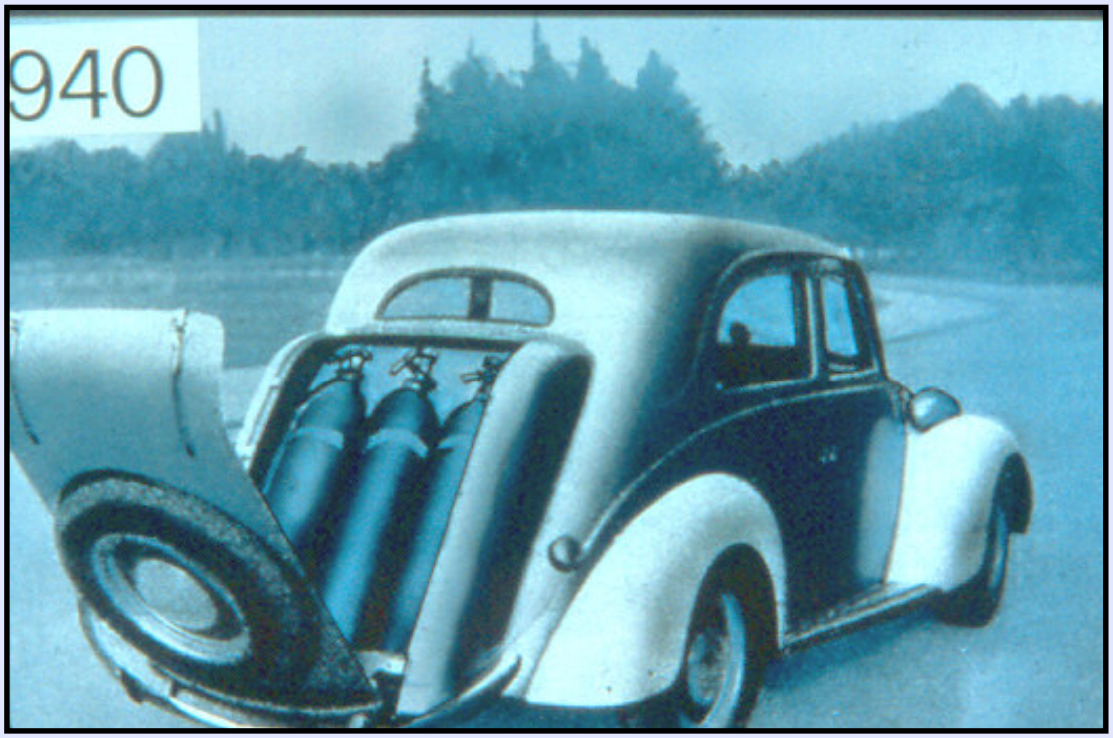
NGV Classics



Czech passenger car Wikov running on compressed town gas – around 1936

Natural Gas Vehicles History



1940's : High-pressure bottles inside the car

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Type II Hoop Fiberglass Wrapped on Extruded Aluminum Cylinder (1983)

Norm Fawly, CNG Cylinder Corporation

Dedicated Ford Ranger Prototype

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CNG CYLINDER SEVERE ABUSE TEST

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

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SEVERE ABUSE TESTING

Car drops from…
10 …17….23…30 metres and no leakage

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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

Type III & Type IV
Fully Wrapped Metal/Composite

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CURRENT SITUATION

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Cylinder Type Use by Country

Country	Type I	Type 2	Type 3	Type 4
Argentina	100%			
Australia	87%	12%		1%
Brazil	99%	1%		
Italy	80%	20%		
Japan	80%		15%	5%
Russia & C.I.S. (FSU)	95%	4%	1%	
USA	23%	50%	15%	12%

Source: About Cylinders & Manufacturers. *Gas Vehicles Report, Number 18, July 2003, p. 31*

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Cylinder Type Market Share by Country

Cylinder Type	Price (US$/litre)	Market %
I	3 to 5	90
II	5 to 7	4
III glass	9 to 14	1
III and IV carbon	11 to 18	3

Source: About Cylinders & Manufacturers. *Gas Vehicles Report, Number 18, July 2003, p. 31*

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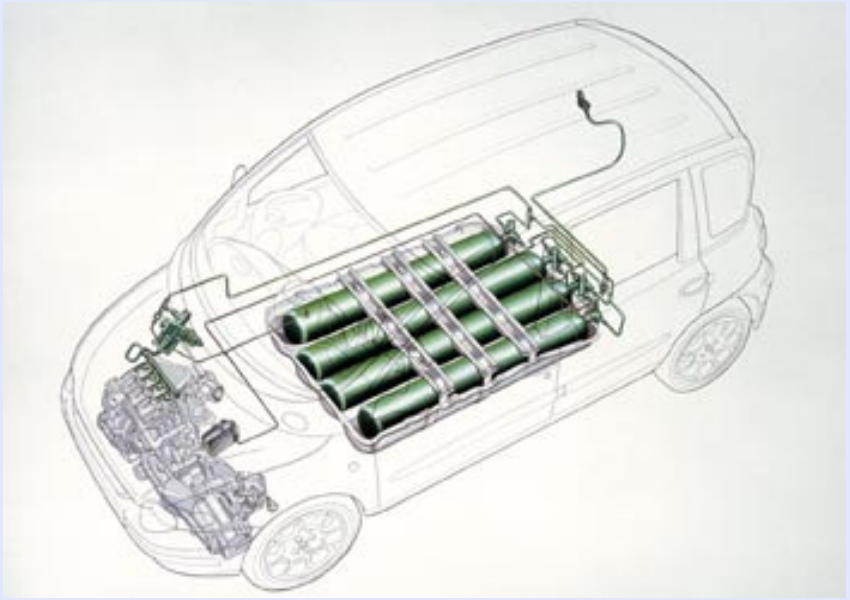
NEW GENERATION OF NGVs



Fiat Multipla Blupower
1.6 L, 4 cylinders
4 valves engine
cylinders in the chassis

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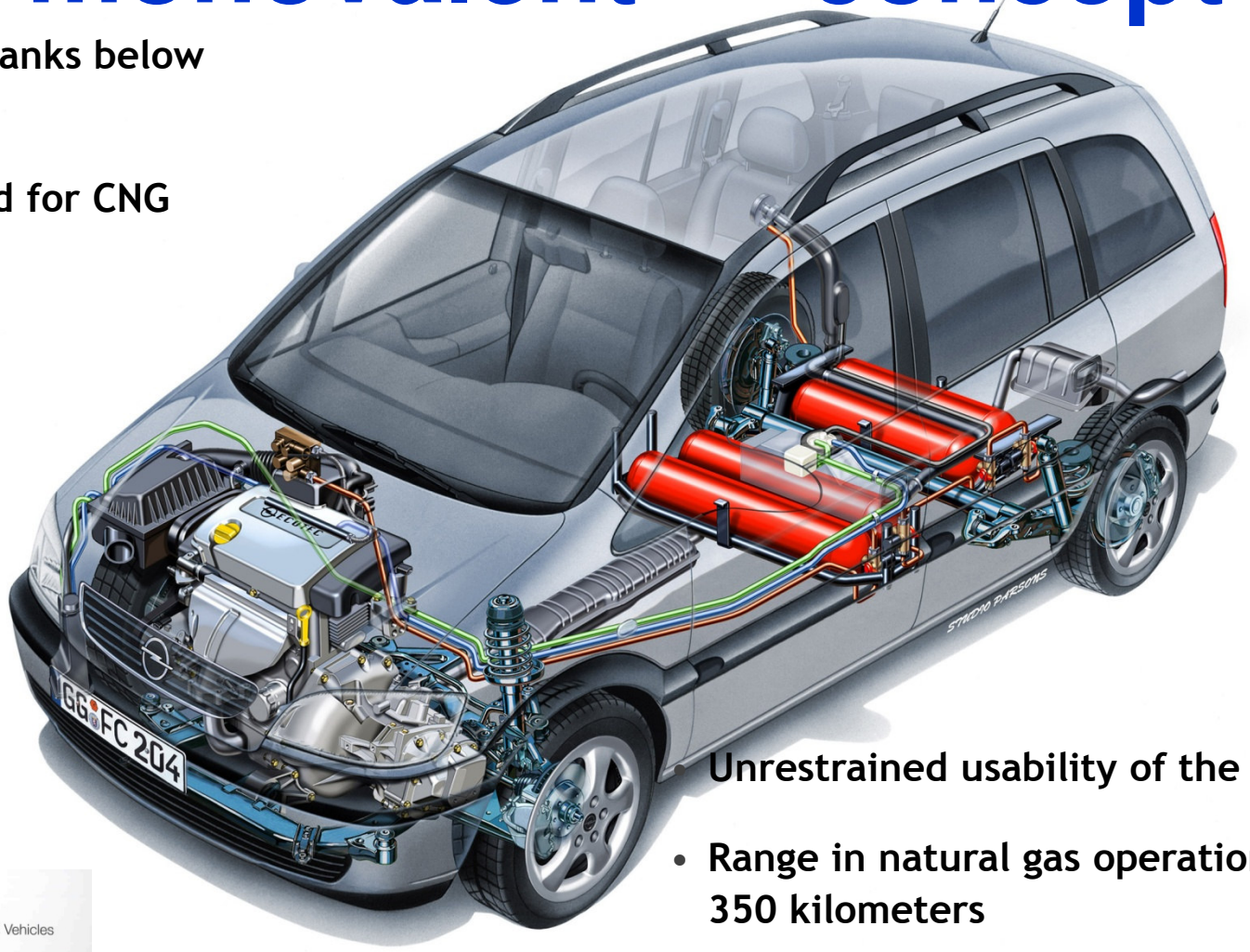
The monovalent^{plus}-concept

- Location of gas tanks below floorpan
- Engine optimized for CNG
- Petrol operation with reduced power (ca.15%)
- 14-litre petrol reserve tank



Unrestrained usability of the vehicle

- Range in natural gas operation > 350 kilometers

OSV Opel Special Vehicles

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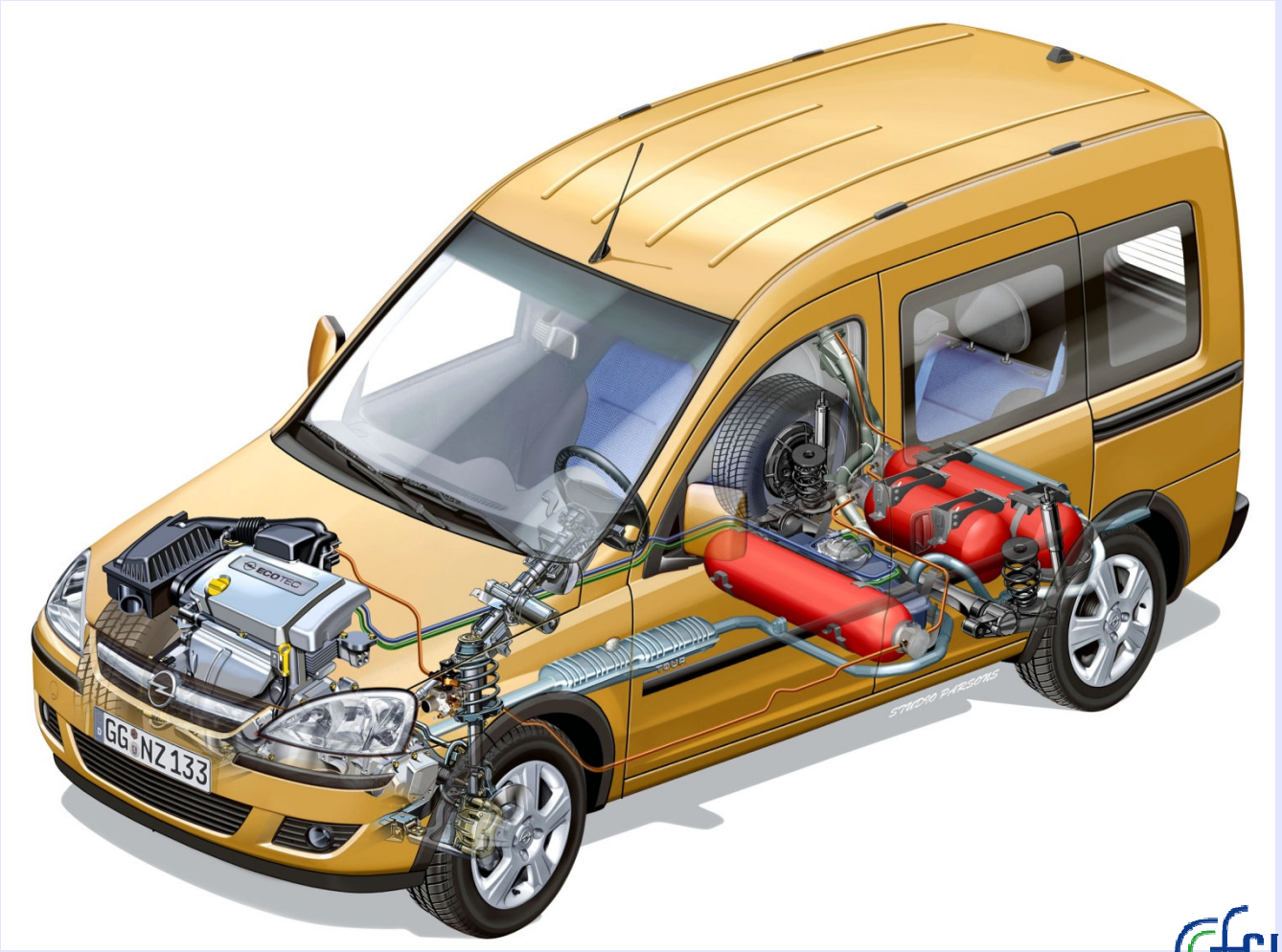
Opel Combo CNG



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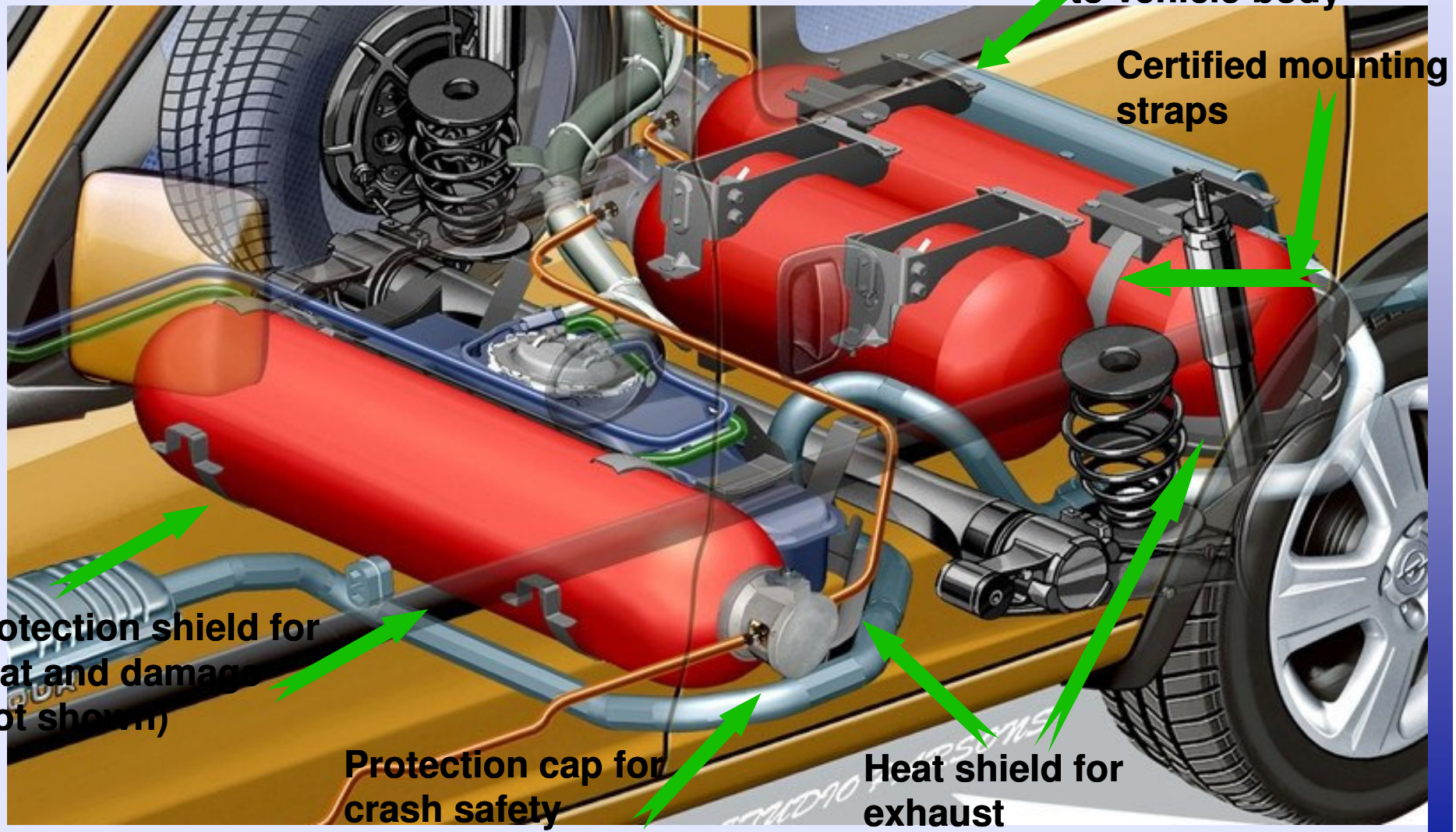
CNG tank-mounting Light-Duty attention items

Source : Opel



VOLVO CNG

Transparency with petrol vehicles

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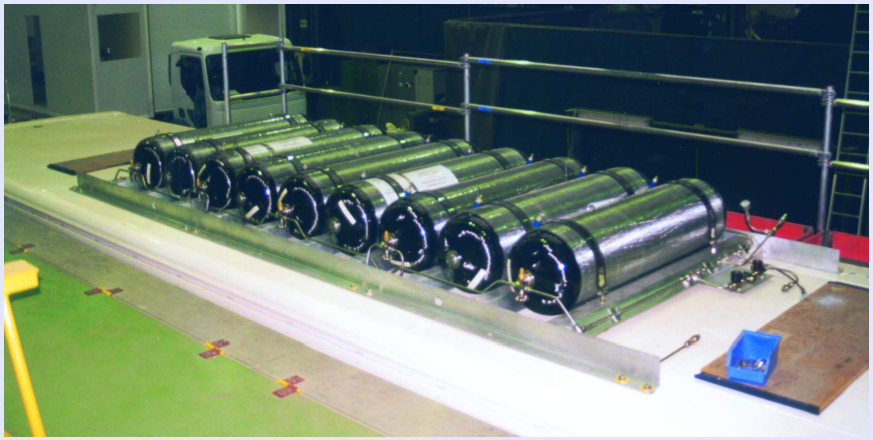
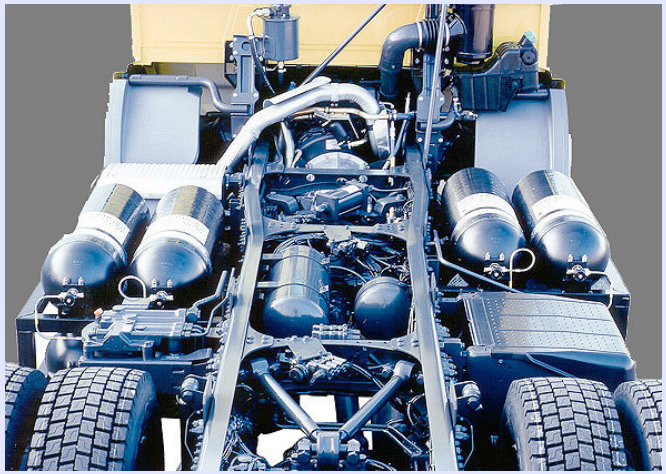
Heavy Duty Vehicle Cylinder Applications



Roof top mounting of cylinders on a bus



The Mercedes Econic

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DIFFERENT APPROACHES TO TECHNOLOGY IMPLEMENTATION

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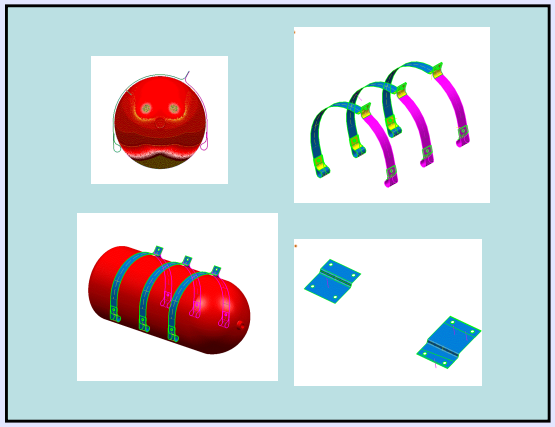
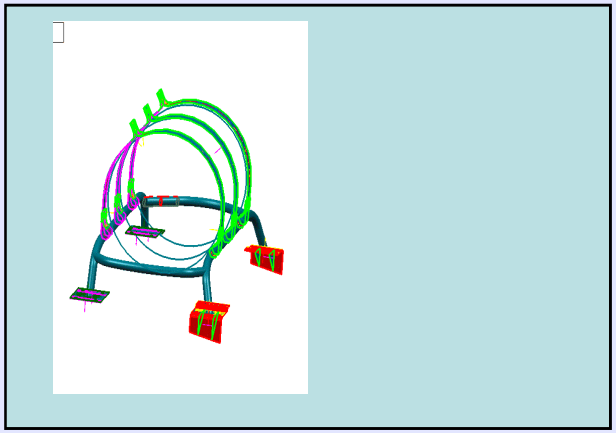
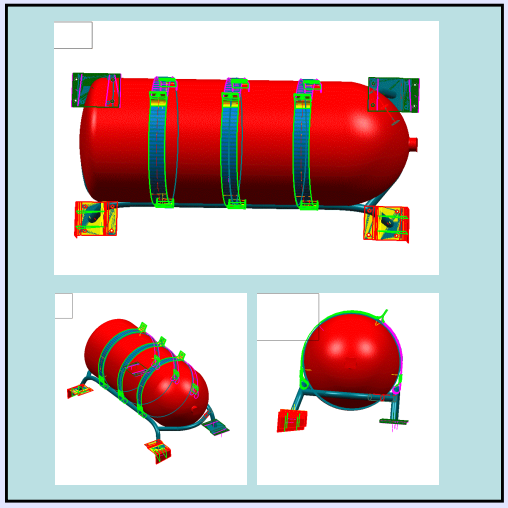
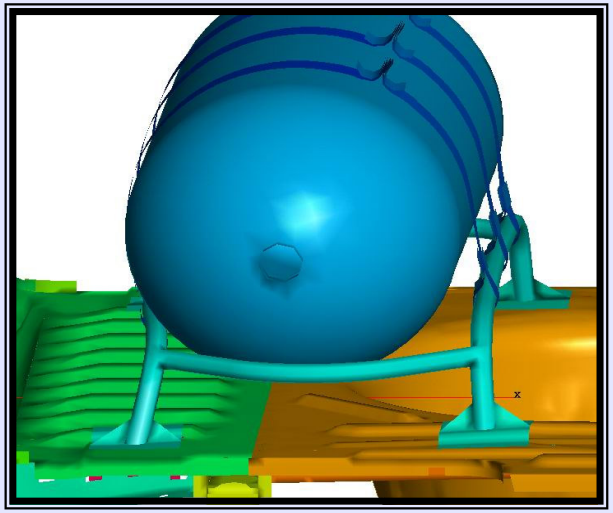
CNG CYLINDER MOUNTING IRAN









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Mother-Daughter Fuelling with Over-the-Road Transport

Mother-Daughter Refilling in China

Fuel Transportation of CNG in India

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"UNUSUAL" NGVs

"If it has an IC engine, it can be converted to gas."

Honda, Kuala Lumpur
1996

Ride-on Lawn Mower
Washington Gas Light ~1993

Two-Stroke Lawn Mower
Dallas, TX ~1990

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SCOOTER WITH REMOVABLE CYLINDERS

Concept Scooter: IANGV Bi-Annual Conference

Kuala Lumpur, Malaysia 1998

- **Designed as urban package delivery vehicle**
- **Concept: Cylinders replaced at vending machines in gas stations**
- **Cylinders to be recharged at central CNG station & returned full to vending machines**

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Alternative Fuel on *Alternative* Vehicles

World's Fair of Natural Gas & Hydrogen Vehicles,
Bolzano, Italy 2005

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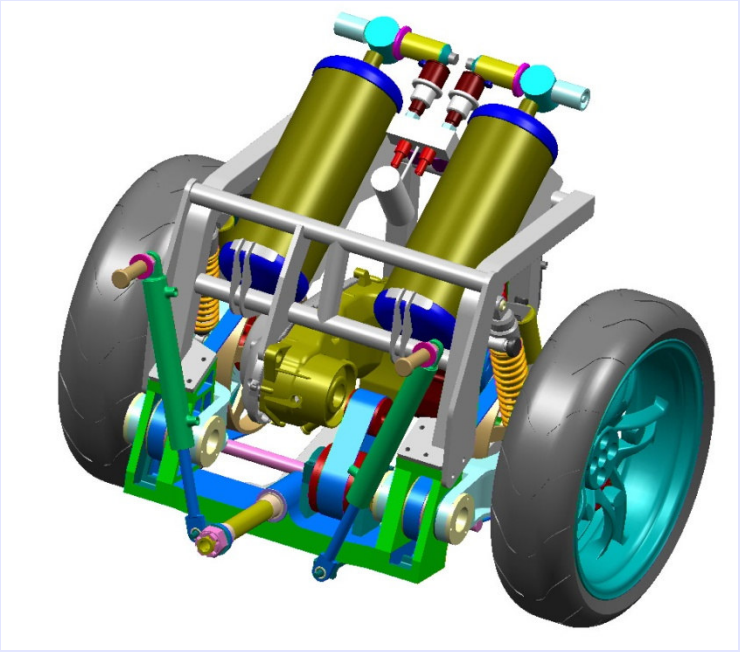
Compact Low Emission Vehicle for Urban Transport (Clever)



Removable Cylinder System

European Commission-funded Project 2004-2006…with BMW, Weh, etc.

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Compact Low Emission Vehicle for Urban Transport (Clever)

1 CNG cylinders

2 cylinder valve

3 Quick Connector Fitting

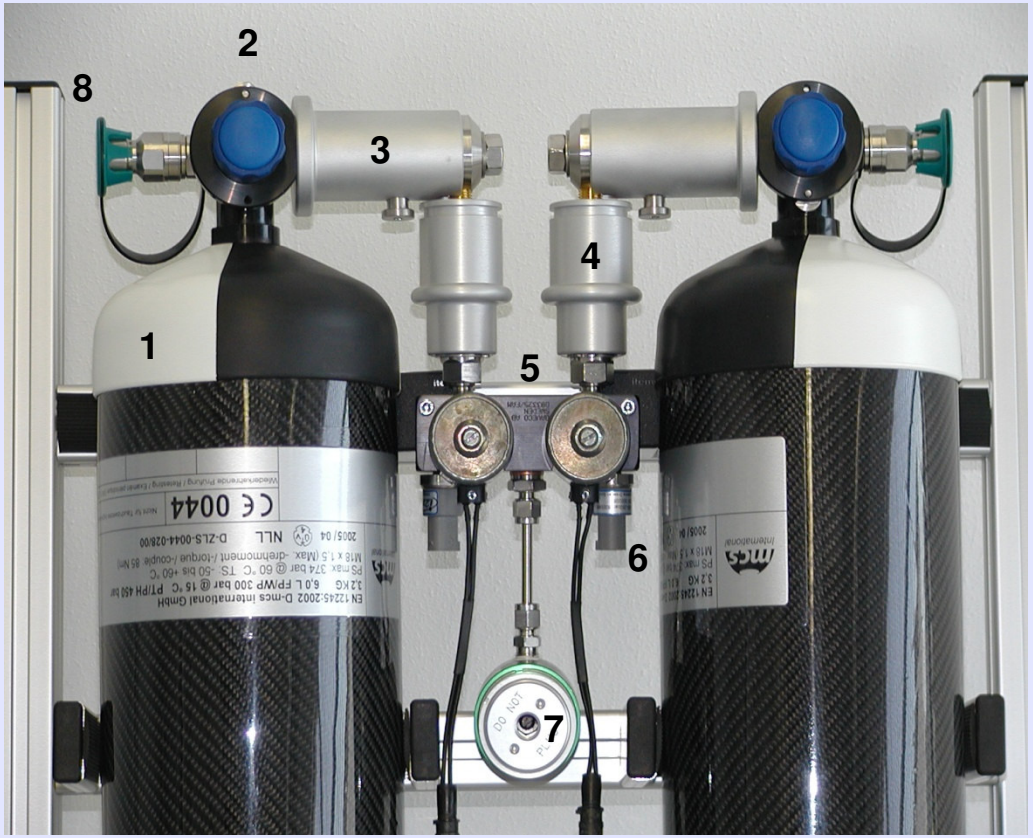
4 Quick Connector

5 Solenoid Valve (parallel)

6 Fuel level indicator

7 Pressure regulator

8 Filling receptacle



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Another Approach
CNG Storage Spheres

- Made by Allied Equipment Inc, Texas (USA)
- 122 CM Inside Diameter
- 333 to 366 Bars Design Pressure

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LOOKING TO THE FUTURE

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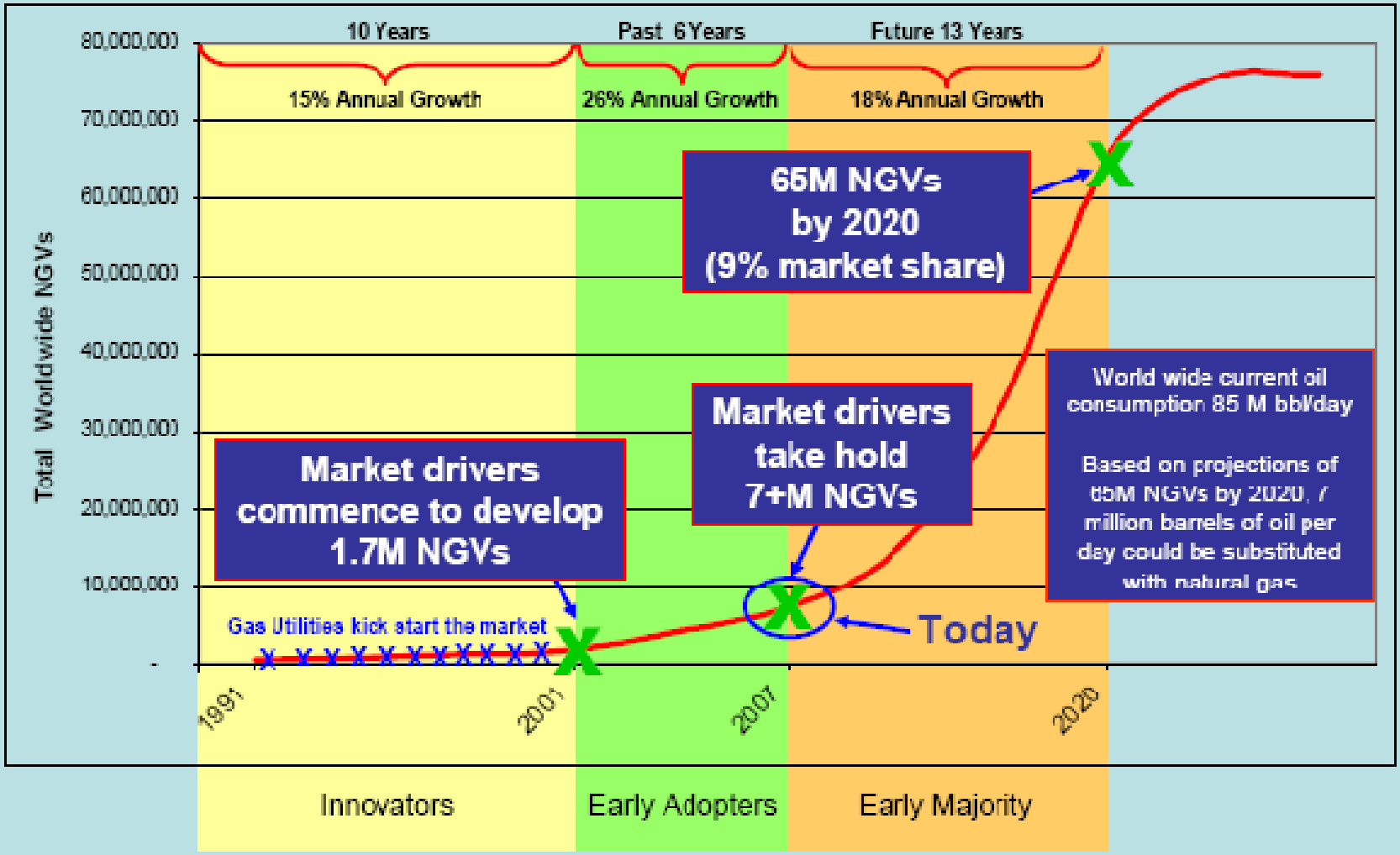
NGV World Market "S Curve" 1991 to 2020



John Lyon, IANVG 2007

GROWTH RATES 2006-2007

January 2008

	2006	2007	%
WORLD	4.6 Million	7.55 Million	64%
CHINA	97,200	200,873	107%
BRAZIL	1 Million	1.48 Million	48%
EUROPE	556,000	748,749	35%
UKRAINE	67,000	100,000	49%
ITALY	382,000	432,900	13%

Source: GVR Dec. 2007

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GROWTH RATES 2006-2007

January 2008

	2006	2007	%
ARGENTINA	1.42 Million	1.67 Million	17%
PAKISTAN	1 Million	1.65 Million	65%
INDIA	248,000	334,820	35%
BANGLADESH	50,534	80,000	58%

Source: GVR Dec. 2007

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Hydrogen Vehicles

Technologies

- –ICEs
- –Hybrids
- –Fuel Cells

When Will The Transition Be?

TODAY

- RD&D
- Portable and Stationary Power
- Battery Replacement

Next few years

- Hydrogen ICE and Hybrid Vehicles

2010

- Early Fleets
- FCVs

2015

- Commercialized Fleets

2020

- Personal Vehicles Marketed

ISSUES FOR CONSIDERATION

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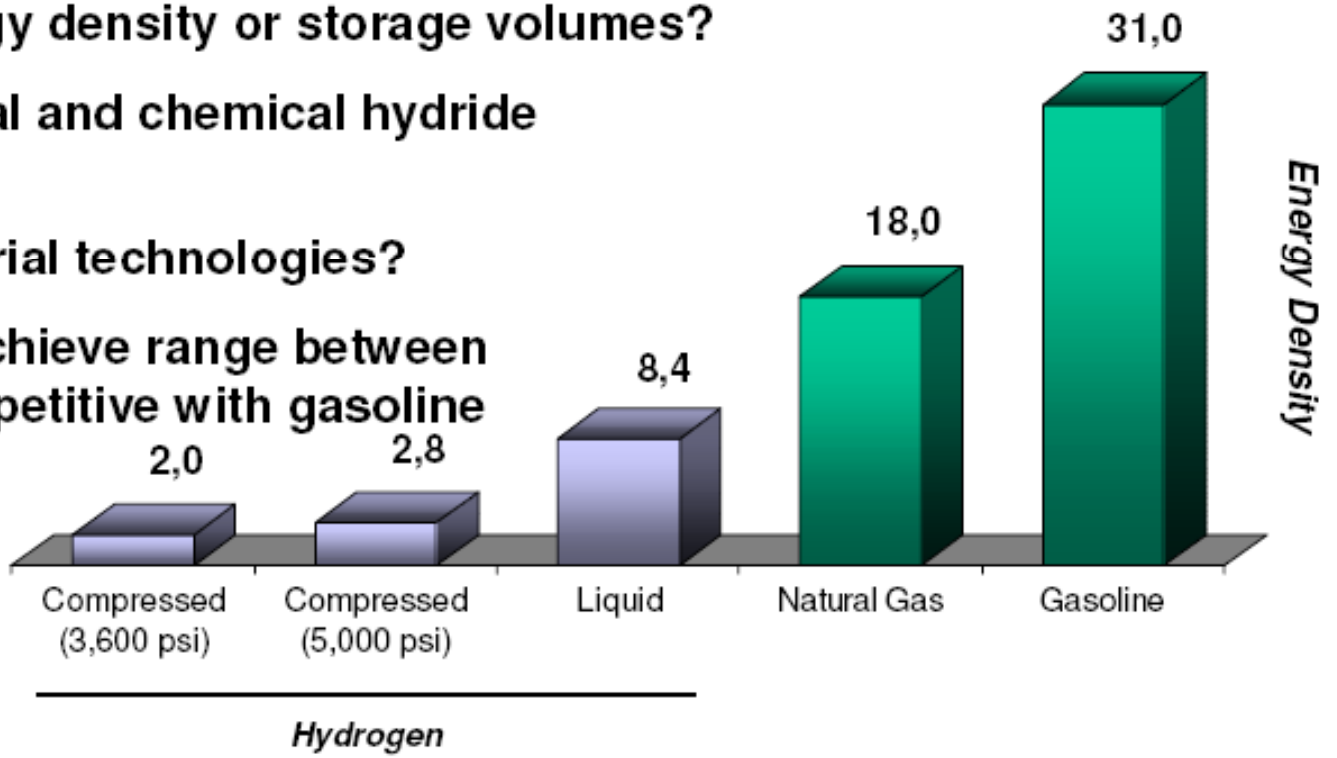
WHERE ARE WE WITH CNG & H2 STORAGE?

The Great Storage Challenge

(Units = MJ/Liter)

- Improve energy density or storage volumes?
- Continue metal and chemical hydride development?
- Improve material technologies?
- Autos must achieve range between refueling competitive with gasoline

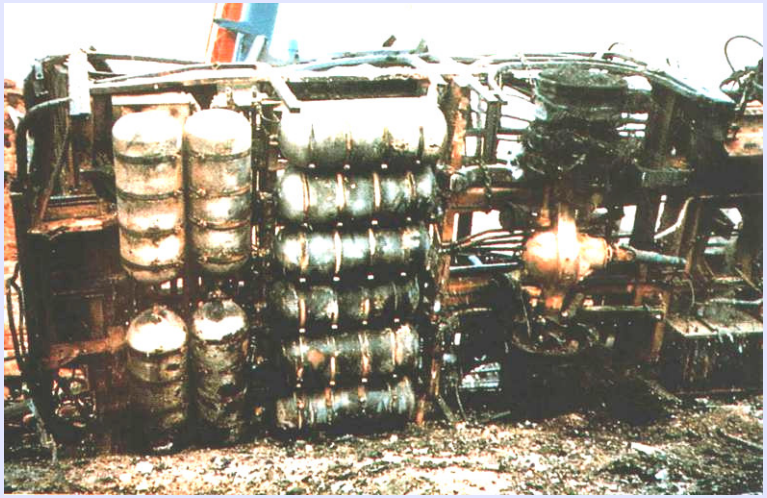


Karen Hall 2006

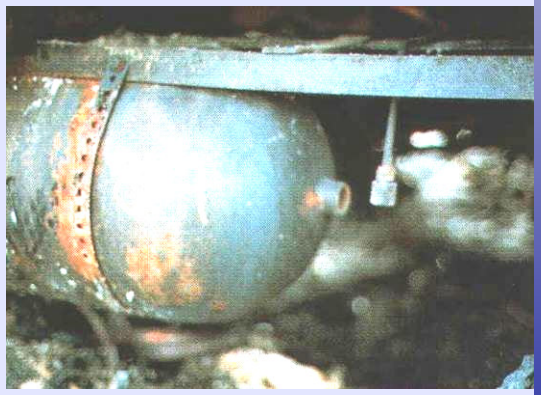
NGV SAFETY

Fire in a bus garage in Utrecht, Netherlands, 6th July 1990

The meltable fuse performs as designed



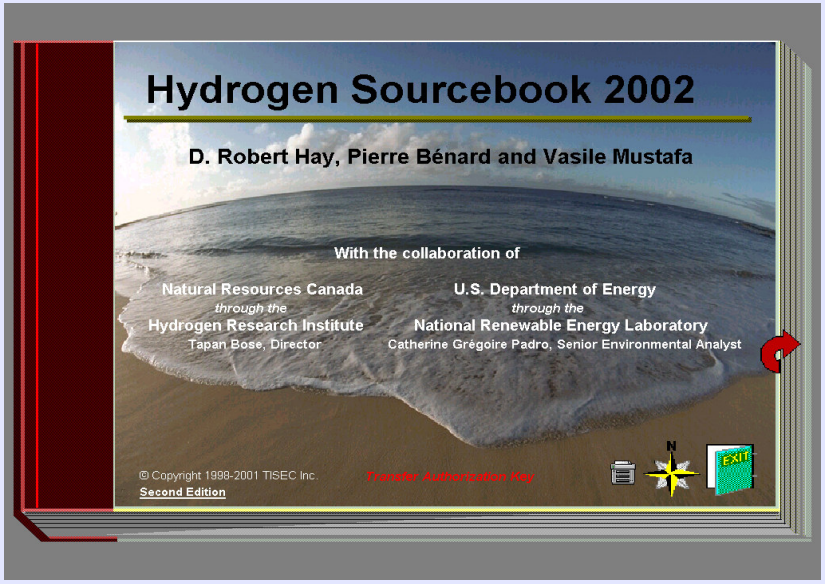
Remains of the natural gas bus. All cylinders are intact; no explosions occurred

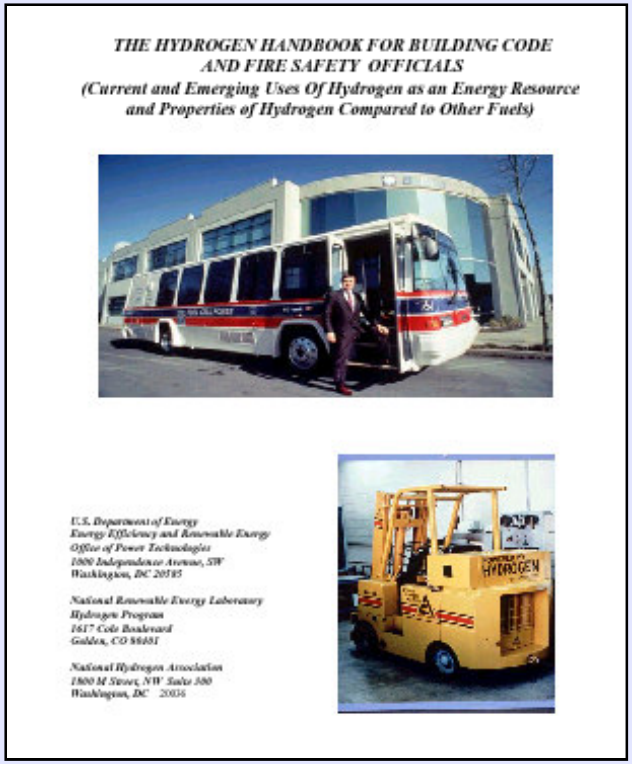


The valve melted away

Guidelines for Hydrogen Systems

- **The Hydrogen Handbook for Building Code and Fire Safety Officials**
- **The Hydrogen Sourcebook**





ISSUES FOR CONSIDERATION

Manufacturing & testing

- **Materials integrity**
- **Impact of accidents including tool drops and personnel stepping on PRDs (for example)**
- **Compliance with testing requirements**
- **Cylinder ‘assemblies’ (prefabricated ‘racks’) design & installation**
- **Requirements for higher and higher pressures: on materials, size & wall thickness; weight; *fuel capacity*;**
- **New design item: Welded, seamed steel construction**

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ISSUES WITH PRDs & VALVES

- Activation: unwanted and design release (rapid/slow release & leak)
- Failures due to design
- Failures due to installation
- Understand in-service conditions for failure
  - Identify ways that a system can fail
  - Identify the likely consequences of those failures
  - Estimate the probability and severity of failures
- Understanding life-time limits

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ISSUES FOR CONSIDERATION

Installation & in-use practices

- Positioning cylinders on vehicles
- Positioning PRDs on cylinders and fuel lines
- Shields & protection
- Use of cylinder assemblies
- Periodic inspection of stationary cylinder cascades
- Moisture intrusion and collection within the PRD.

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ISSUES FOR CONSIDERATION

In-use Inspection, Maintenance & Compliance

- **Road hazards and the impact on cylinder integrity**
- **Periodic inspection *intervals* and *methods/techniques***
- **Making the decision to continue use or deactivate?**
- **Interpreting the results of cylinder failure analyses**
- **Handling of on-going hazard (fire fighter response!) (NFPA guidelines for CNG & H2)**

Non-Destructive Cylinder Examination Methods

- **Magnetic methods;** magnetic particle eddy; current pulsed eddy; current long range eddy; current magnetic flux leakage
- **Ultrasonic methods;** contact ultrasonic; contact-free ultrasonic
- **Imaging methods;** penetration testing; visual inspection; ultrasonic imaging; radiography; infrared thermography
- **Global methods;** guided wave acoustic emission

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OVER-THE-ROAD FUEL CARRIAGE (Large Cylinder Trucks)

- Cylinder ‘bundle’ design, placement of pipes, valves, etc.
- Roadworthiness of entire cylinder system (i.e. in-use leakage, etc.)
- Leak testing
- Regulations for carriage of hazardous materials
- Unplanned fuel release

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ISSUES FOR CONSIDERATION

Standards & Regulation Development & Implementation

- The strong link between CNG and hydrogen fuel storage systems (the equipment manufacturers are virtually the same for both) should foster synergies for mutual benefit to all stakeholders.
- Harmonisation should be a goal, to the extent it is possible (look to the standard or regulation of the highest level international body as possible)
- Adoption of ISO by UNECE: Amendment or reference
- Compliance in emerging markets

- Cost vs safety
- Inspecting
- Training

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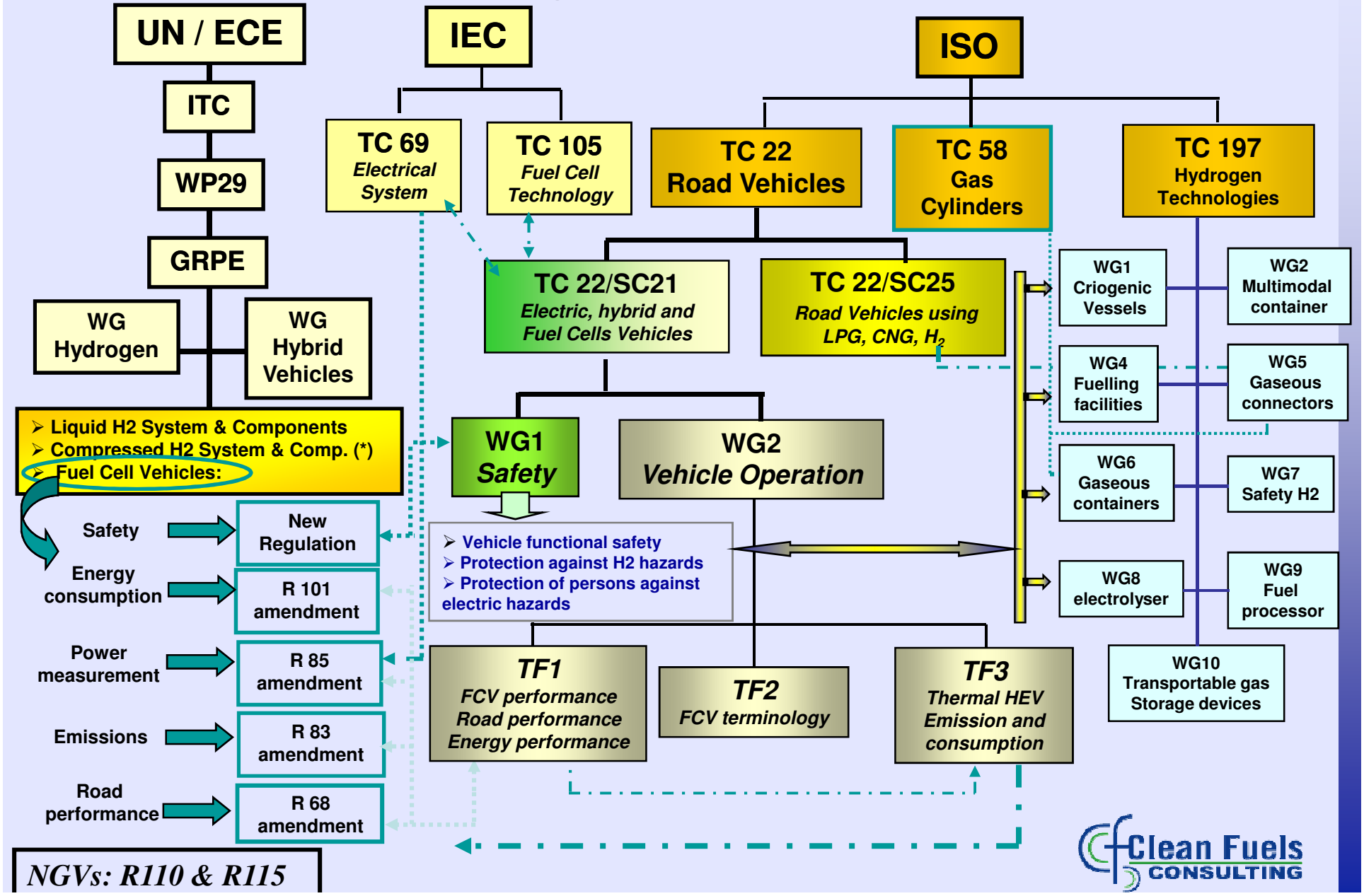
International Standard and Regulation Bodies Organisation and Links



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LEADERSHIP THROUGH INFORMATION & KNOWLEDGE

- Asking the tough questions
- Getting straight answers from the most qualified experts
- Identify and implement the best strategies to overcome challenges: political, marketing or technological

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CNG & H2 CYLINDERS:
Opportunities, Challenges & Strategies

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Session 5

STRATEGIES INTO THE FUTURE:

TECHNOLOGIES, MARKETS & REGULATIONS


CNG & H2 Cylinder Issues
Manufacturing & Testing
Welded, Seamed Steel
New Designs
Valves Design
Cylinder Assemblies
Meeting OEM Demands
Compliance with Testing Requirements
Workplace Accidents
Materials Integrity
Requirements for Higher Pressures
Materials
Size & Weight
Fuel Capacity
In-Use Inspection, Maintenance and Compliance
Accidents
Corrosion
Protection
Impacts of Road Hazards
Failure Analysis
Deactivate Y/N?
Inspection Methods
Hydro-Static
Magnetic
Ultra-Sonic
Global (Acoustic)
Imaging
Inspection Intervals
Handling Fires
Standards & Regulations: Development & Implementation
Harmonization
ISO & ECE
Ref / Amend
Synergies Between H2 & CNG
Lessons learned
Materials
Valves
Compliance in Emerging Markets
Inspection
Training
Costs vs. Safety
Over the Road Fuel Carriage
Unplanned Fuel Release
Roadworthiness of "Systems"
Leak Testing
Cylinder Assembly Designs
Pipes
Valves
Regulations
Roads Tunnels Bridges
Shield Protection
Cylinder Assemblies
Installation & In-Use Practice
Positioning PRDs on Cylinders & Fuel Lines
Positioning Cylinders on Vehicles
PRDs & Valves
Moisture
Other Damage
Inspection of Stationary Storage& vessels
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