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# Report on CNG Cylinders for Automotive Vehicle Applications



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## **Executive Summary**

Gas cylinders are the heavier portion of alternative fuel systems which adds more weight to vehicle unladen weight. In search of innovative materials for gas cylinders, composite material has been the front runner in reducing weight of the vehicle, thereby reducing fuel consumption significantly. This report describes the various types of composite cylinders, their design & test requirements, merits and demerits of each type of composite cylinder.

This report explains various new and effective technologies in Cylinders that are available internationally, its regulatory requirements and usage. In India Type 1, 2, 3 have been successfully used in Indian Automotive Industry. Chief Controller of Explosives (CCOE), Nagpur is the approval authority for CNG Cylinders in India.

This unique report will also provide you with valuable information, insights about vehicles with Type 4 Cylinders, history of composite cylinders and detailed analysis of all the four types of CNG Cylinders

Current status of adoption of composite cylinder technology in India and worldwide, such as number of composite cylinder manufacturers in world, level of introduction of composite cylinders in different types of vehicles and incidents happened due to composite cylinders are also described in this report. Based on review of composite cylinder technology, it is concluded that all-composite cylinder technology (i.e., Type-4 cylinders) is the best solution for light weighting of automotive heavy commercial vehicles such as buses without compromising on safety.

## **Table of Contents**

### **I. Introduction**

### ***Technical requirements***

### **II. Type of CNG Cylinders**

### **III. Material**

### **IV. Manufacturing Process of a CNG Cylinder**

### **V. Comparison of weight and cost of CNG Cylinders**

### **VI. CNG Composite Cylinders (Type IV)**

### **VII. Ultrasonic inspection**

### **VIII. Advantages & Benefits of using Type-4 Composite Cylinders**

### **IX. Fire Protection of Type 4 Tanks (Pressure Relief Valves)**

### **X. Type 4 Cylinder Manufacturers' Profiles**

### ***Global requirements***

### **XI. Comparison of test requirements in different countries**

### **XII. Global CNG Gas Cylinder Industry -Background and Characteristics**

### **XIII. CNG Cylinder Standards in different countries:**

### **XIV. Global CNG Cylinder market**

### **XV. Companies manufacturing Type 4 Cylinders**

### **XVI. New generation of Type 4 CNG cylinders**

### ***Legal requirements***

### **XVII. Indian & Overseas Regulatory Requirements of CNG cylinders**

### ***Indian context***

### **XVIII. SIAM letter to CCOE relating to approval for using Type IV cylinders in CNG, HCNG & H2 vehicles in India**

### **XIX. Composite Cylinders for On-Board Storage of Compressed Natural gas (CNG) as a Fuel for Automotive Vehicle – Specification**

### **XX. Conclusion**

## List of Tables

*Table 1: Type of CNG Cylinders*

*Table 2: Maximum content in % of elements*

*Table 3: Maximum Sulphur and Phosphorus Limit in Percentage*

*Table 4: Cylinder Material Advantages and Disadvantages*

*Table 5: Weight of CNG Cylinders*

*Table 6: Weight w.r.t cost of CNG Cylinder Types*

*Table 7: Comparison of Parameters for CNG Cylinder Types*

*Table 8: Features and Advantages of Type IV Cylinders*

*Table 9: Fibre type and Stress Ratio*

*Table 10: Comparison of CNG Cylinders (Cost aspects)*

*Table 11: Tests for CNG Cylinders*

*Table 12: No of Test Specimens*

*Table 13: Comparison of TUFFSHELL & LIGHTSTORE*

*Table 14: Comparison of worldwide standards on Composite Cylinders*

*Table 15: CNG Cylinder Regulations in different countries*

*Table 16: CNG Cylinder Market*

*Table 17: Type 4 Cylinder market position on city buses in Europe*

*Table 18: Type 4 Cylinder market position on city buses in North America*

*Table 19: Population of NGV's and Refuelling stations*

## List of Figures

*Figure 1: Interface design of a composite cylinder*

*Figure 2: Manufacturing process flow of a CNG Cylinder*

*Figure 3: Dimensions and shape of notches*

*Figure 4: Acid Environment test*

*Figure 5: Pressure Relief Valve*

*Figure 6: Bridge Impact*

*Figure 7: Curb Hit*

*Figure 8: Rear Impact*

*Figure 9: Bonfire Testing*

*Figure 10: Brands using Type 4 Composite Cylinders*

*Figure 11: Geographical overview of CNG Cylinder Market (Cylinder Type-wise)*

*Figure 12: Natural Gas Vehicle Count by Region (1991-2010)*

*Figure 13: Actual and Projected Volumes of NGV's*

*Figure 14: Average annual growth rate of NGV's by region*

*Figure 15: NGV Growth projection till 2014*

*Figure 16 A: New Type IV cylinder technologies*

*Figure 16 B: New Type IV cylinder technologies*

*Figure 16 C: New Type IV cylinder on the road*

*Figure 16 D: New Type IV cylinder on the road*

*Figure 16 E: New Type IV cylinder on the road*

*Figure 16 F: New Type IV cylinder on the road*

*Figure 16 G: New Type IV cylinder on the road*

*Figure 17: FMVSS 304 Bonfire Test for CNG Cylinder shorter than 65 inches*

*Figure 18: FMVSS 304 Bonfire test for cylinder longer than 65 inches*

*Figure 19: Estimated Production of Composite Reinforced CNG Cylinders*

# I. Introduction

Indian Auto Industry recognizes the need for upgrade of the technology in terms of light weighting and adopting well proven technologies such as composite cylinders (Type IV) which is prevailing in other countries. Indian Auto Industry recently initiated many R&D projects such as development of pure hydrogen vehicles, hydrogen fuel cell vehicles, light-weight vehicle, etc. Many initiatives are being taken on light weighting to improve fuel efficiency & range of vehicles. Type-IV composite cylinder is the most prominent options for pure hydrogen vehicles & light-weight vehicles, because Type-IV cylinders provide substantial weight reduction compared to Type-1, Type-2 & Type-3 cylinders.

The global cylinder industry has witnessed a gradual shift from the type-I steel cylinders to an increased use of composite cylinders in various segments. Type-1 steel cylinders were introduced in 19th century between 1870 to 1880 to store CO<sub>2</sub> in liquid state for industrial gas business. Use of composites cylinder started in the early 1960s by rocket motors, space shuttles, and other sonar equipments. High pressure composite cylinders were developed especially for space and military applications. Composite cylinders got commercialized during 1970's as it entered into the breathing apparatus market used by firemen. During 1980s these composite cylinders were used for scuba diving, fuel storage (mainly natural gas), and leisure applications. Composite cylinders are highly safe, corrosion resistant, light in weight and easily portable, even it has longer life cycle as compared to traditional steel tanks.

According to Lucintel's report "Growth Opportunities in Global Composites Cylinder Market 2011- 2016: Trends, Forecast and Market Share Analysis"- The composites cylinder market is expected to grow at double digit rate in coming five years with focus on weight reduction and better performance. Over the next 5 years, composites cylinder market is estimated to grow at a CAGR of 13.8% and the end product market is expected to surpass \$1.Bn by 2016.

Composites cylinder market holds promising present and future for light weight cylinders with an increased focus on environmental performance and fuel efficiency. Traditional cylinder manufacturers are repositioning their companies by customizing and widening their product offering. Significant regional shift, in the overall cylinder market is taking place. This new dimension is likely to provide tremendous growth to regional players and existing companies are expected to face fierce competition in the coming time.

This report discusses the subject on approval of Type 4 composite cylinder technology for on-board use of CNG, HCNG & Hydrogen vehicles in India and will provide valuable information, insights on CNG cylinder market. Type-4 cylinder technology is proven and well established since many years globally. Globally many reputed OEMs use this technology on many of their premium vehicles.

## *Technical requirements*

### II. Type of CNG Cylinders

Cylinder types include:

1. Type 1
2. Type 2
3. Type 3
4. Type 4

*Table 1: Type of CNG Cylinders*

<b>Type of Cylinder</b>	<b>Construction</b>	<b>Cost and Weight</b>
<b>Type 1</b>	All metal (aluminum or steel)	<ul style="list-style-type: none"> <li>• Cheap but heavy</li> </ul>
<b>Type 2</b>	Metal liner reinforced by composite wrap (glass or carbon fiber) around middle (“hoop wrapped”)	<ul style="list-style-type: none"> <li>• Liner takes 50% and composite takes 50% of the stress caused by internal pressurization</li> <li>• Less heavy, but more cost</li> </ul>
<b>Type 3</b>	Metal liner reinforced by composite wrap around entire tank (“full wrapped”)	<ul style="list-style-type: none"> <li>• Liner takes small amount of the stress</li> <li>• Light-weight, but expensive</li> </ul>
<b>Type 4</b>	Plastic gas-tight liner reinforced by composite wrap around entire tank (“full wrapped”)	<ul style="list-style-type: none"> <li>• Entire strength of tank is composite reinforcement</li> <li>• Light-weight, but expensive.</li> </ul>

#### 1. Type 1 Cylinders – All Metal.

Since the 1940’s seamless steel cylinders have been by far the most widely used for storage of CNG on vehicles. The introduction of Italian high-strength lightweight cylinders in the late 1970’s was a very significant step forward in the development of the industry and since then this type of product has been adopted all over the world.

Some standards also allow welded steel cylinders, but require a higher safety factor. Aluminium cylinders have also been used for on-board storage of CNG and can provide a lighter weight alternative.

Suppliers of Steel CNG containers include White Martins (Cilbras), Inflex and Faber. Luxfer offers a small range of 7000 series aluminium CNG cylinders.



## **2. Type 2 CNG Cylinders – Hoop Wrapped Composite.**

Type 2 fuel containers have a metal liner and a composite reinforcement on the straight side only; a hoop overwrap. Products on the market steel or aluminium liners and a glass, aramid, or carbon fibre reinforcement. Type 2 cylinders are designed to have a liner with sufficient thickness and strength to contain the service pressure, even without the composite overwrap. They provide a compromise between the low cost of Type 1 cylinders and the lightest weight Type 3 and 4 cylinders.

## **3. Type 3 CNG Cylinders – Fully Wrapped Composite with Metal Liners.**

Type 3 CNG cylinders have a seamless metal liner over wound on all surfaces by a composite reinforcement that provides between 75 and 90% of the strength to the vessel. The liner provides the rest of the strength, plus acts as a rigid membrane to hold the gas and provide extra impact resistance to the product.

There are over 2 million fully wrapped composite cylinders in use in portable applications such as breathing apparatus; medical oxygen storage and aircraft slide inflation.

Type 3 cylinders are used in a wide range of applications where weight reduction is important, for example in transit buses and delivery trucks. Type 3 cylinders have also been used on various OEM vehicles such as the Volvo and Volkswagen CNG cars. Suppliers of Type 3 containers include Luxfer, Dynetek, and Structural Composites, Inc.

## **4. Type 4 CNG Cylinders – Fully Wrapped Composite with Non-Metallic Liners.**

Type 4 fuel containers have a plastic liner and a full overwrap of carbon fibre or mixed fibre construction. The liners of Type 4 tanks provide no structural strength to the product and act only as a permeation barrier. Although these liners are not gas tight, the rate of permeation has been found acceptable for use with CNG.

As a rule Type 4 CNG cylinders are fitted with impact protection on the domes, as the plastic liner does not provide a rigid backing to the composite overwrap.

Again, Type 4 cylinders are used where weight is important such as on buses, trucks and OEM vehicles such as the Honda Civic. Suppliers of Type 4 containers include Quantum, Ullit, Lincoln Composites, and Ragasco

### III. Material:

#### 1. Steel:

Steel is used in Type-1, Type-2 & Type-3 cylinders. Following are the requirements for steels used in gas cylinders. The steel used shall be such that its properties meet the requirements of the finished product. The steel shall be aluminium or silicon killed with non-aging properties, other than rimming qualities. The chemical composition of all steels shall be declared and defined at least by:

- a) Carbon, manganese and silicon content in all, and
- b) The chromium, nickel, molybdenum, vanadium and that of any other alloying elements intentionally added to the steel.

The carbon, manganese and silicon contents and, where appropriate, the chromium, nickel and molybdenum contents shall meet the requirements in the table below

*Table 2: Maximum content in % of elements*

Sl No.	Element	Maximum Content in Percentage	Maximum Permissible Deviations in Percentage
(1)	(2)	(3)	(4)
i)	Carbon	< 0.30 ≥ 0.30	0.06 0.07
ii)	Manganese	All values	0.30
iii)	Silicon	All values	0.30
iv)	Chromium	< 1.50 > 1.50	0.30 0.50
v)	Nickel	All values	0.40
vi)	Molybdenum	All values	0.15

Sulphur and phosphorus in the cast analysis of material used for the manufacture of gas cylinders shall not exceed the values shown in Table below.

**Table 3: Maximum Sulphur and Phosphorus Limit in Percentage**

Sl No. (1)	Element (2)	Rm < 950 MPa (3)	Rm ≥ 950 MPa (4)
i)	Sulphur	0.020	0.010
ii)	Phosphorus	0.020	0.020
iii)	Sulphur + Phosphorus	0.030	0.025

Maximum tensile strength shall be limited to 1100 MPa and hardness should not exceed 330 BHN.

## 2. Composites

Composite materials are mix of the following materials:

1. Resin (Epoxy vinyl Ester)
2. Reinforcement (Carbon & Glass fabrics)
3. Special Additives

Resin: Reinforcement = 1: 0.8

The material for impregnation may be thermosetting or thermoplastic resin. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl ester thermosetting plastics, and polyethylene and polyamide thermoplastic material. The heat deflection temperature (HDT) of the resin material shall be determined in accordance with IS 13411.

Structural reinforcing filament material types shall be glass fibre, aramid fibre or carbon fibre. If carbon fibre reinforcement is used, the design shall incorporate means to prevent galvanic corrosion of the metallic components of the cylinder.

The polymeric material shall be compatible for the service conditions of the cylinders.

The starting point for design of an NGV fuel container is selection of materials, including the reinforcing fiber, liner, resin matrix, and boss materials. The components of the fuel container must be properly designed and integrated to meet all system performance requirements.

Design and selection of system components such as mounting brackets, valves, and pressure relief devices are important to the safe and effective usage of the fuel containers.

Current sizes range from 231 millimeters to 467 millimeters (9.1 to 18.4 inches) in diameter and up to 3 meters (120 inches) in length. Operating pressures are 200 bar and 240 bar at +15°C (3000 and 3600 psi at +70°F).

**a) Fibers**

The fibers selected for reinforcing the NGV fuel containers are carbon and E-glass. Carbon fiber was chosen as the primary reinforcing material because of its high strength, resistance to stress rupture, high cyclic fatigue life, and environmental resistance.

Resistance to stress rupture is a key aspect of determining factors of safety for pressure vessels. As an example, carbon fiber held at 80 percent of its average ultimate strength has a typical life of over 1 million years, while glass fiber would only have a typical lifetime of about 1 hour. At a 2.25 safety factor, the reliability of carbon fiber would be 0.999999 for a lifetime in excess of 100 years. Glass fibers require a safety factor of 3.5 to achieve similar levels of reliability.

Carbon fiber also has excellent cyclic fatigue properties. At a 2.25 safety factor, it would have fatigue life in excess of 10<sup>12</sup> cycles.

E-glass fiber is also used as a reinforcing material because of its impact resistance and low cost. The glass and carbon fibers are commingled in the same winding band when the fuel container is manufactured. The glass fiber amounts to about 40 percent of the structural wall.

One of the key aspects in its contribution to damage tolerance is simply the increased wall thickness it provides.

**b) Liner**

High density polyethylene (HDPE) was chosen as the liner material. HDPE is lightweight and corrosion resistant. It has a high cyclic fatigue life and low permeability. HDPE is low cost, readily available, and is easily molded and extruded. The dome portion of the liner is injection molded, while the cylinder section is extruded. The dome and cylinder sections are joined by butt fusion welding. This welding process is commonly used with HDPE and was refined from techniques used for assembly of gas pipelines. HDPE has been used for over 30 years in natural gas distribution pipelines, and is used in gasoline tanks and containers for petroleum products. This provides assurance of its long term suitability for use in containing natural gas fuels in an automotive environment.

**c) Resin**

Resin selection for an all-composite fuel container presented interesting challenges. The selected resin must have a cure temperature lower than the softening point of the plastic liner, about +120°C (+250°F), but the glass transition temperature must be greater than the maximum temperatures seen in service, which would be in the range of +82°C to +93°C (+180°F to +200°F). Investigation of commercially available resins did not locate a suitable system meeting these criteria.

**d) Boss**

The boss is the attachment point for valves and pressure relief devices. Aluminum alloy 6061-T6 was chosen as the boss material for the NGV fuel containers. This alloy is high strength, readily available, and relatively corrosion resistant. Stainless steel has also been used as a boss material in Lincoln Composites all-composite pressure vessels.

**e) Liner/Boss/Composite Interface**

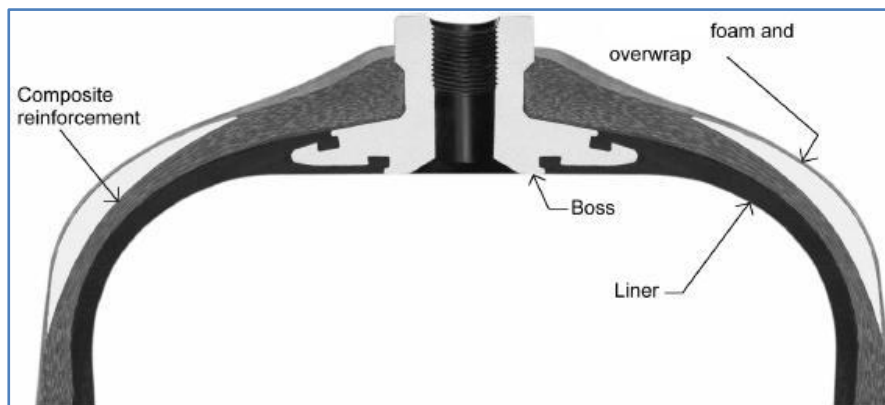
The design of a leak-free, structural interface between the boss, liner, and composite is a key design challenge. Lincoln Composites has patented an interface design that has proven to be highly reliable (Fig. 1). The boss is molded into the dome portion of the liner. The boss contains keyways that lock the plastic to the boss. A chemical bond is not required to maintain the seal between the liner and the boss.

The configuration of the liner/boss/composite interface is such that there is no tendency for the liner to creep under pressure, which provides assurance that leaks will not develop during the container's service life. There have been no instances of leakage to date associated with the liner/boss interface. The liner material does not extend into the center of the boss. By keeping the plastic material out of the gas flow stream, problems with buildup of electrostatic charges are avoided. The boss neck diameter at the outboard end is larger than at its base, and the boss neck has flats machined in the area where it interfaces with the composite. These features provide an axial and rotational lock between the boss and the composite that prevents motion when valves or relief devices are being installed.

**Table 4: Cylinder Material Advantages and Disadvantages**

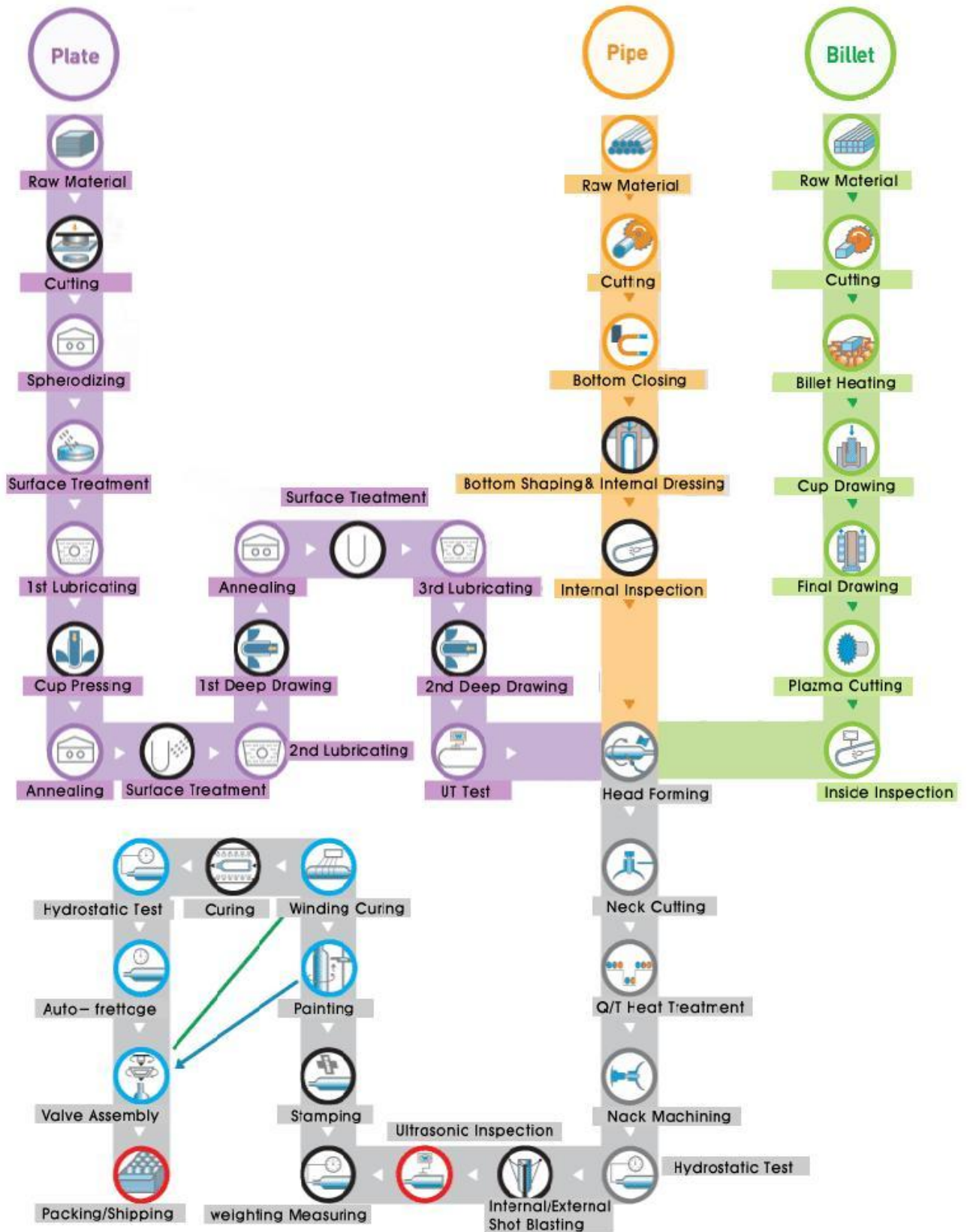
Cylinder and Material Advantages and Disadvantages		
Item	Advantages	Disadvantages
All-metal containers	Lowest cost Durable	Heaviest Potential for corrosion
Metal lined, Hoop overwrap	25-year experience base Liner can carry significant loads	Heavy Potential for corrosion Thermal stresses at elevated temperature Long lead times for metal liner
Metal lined, Full overwrap	30-year experience base	Low cyclic fatigue life of liner Thermal stresses at elevated temperatures Long lead times for metal liner
All-composite	30-year experience base Lightest weight Environmental resistance Short lead times	Design of boss to liner interface is important Limited operating temperature range (approx. -59°C to +104°C)
Glass fiber	30+ years of experience in cylinders Low cost for E-Glass	Low resistance to acid and other chemicals Affected by hot/wet conditions and UV Stress rupture can occur
Aramid fiber	High strength to weight ratio Durable	High cost Affected by acid and other chemicals
Carbon fiber	High strength to weight ratio Resistant to acid, environmental conditions Low risk of stress rupture Moderate cost	More brittle than glass or aramid Thinner walls are more easily damaged by impact
Carbon/glass hybrid	Good strength to weight ratio Carbon provides fatigue strength and environmental resistance Glass provides toughness and durability Improved cost/benefit ratio	

**Figure 1: Interface design of a composite cylinder**



## IV. Manufacturing Process of a CNG Cylinder

Figure 2: Manufacturing process flow of a CNG Cylinder





## V. Comparison of weight and cost of CNG Cylinders

*Table 5: Weight of CNG Cylinders*

Cylinder Type	Weight per litre	Weight Reduction
Type 1 - CrMo Steel	0.80 kg/litre	-
Type 1 - Modified CrMo Steel	0.72 kg/litre	-10%
Type 2 - Steel & Glass Fibre	0.68 kg/litre	-15%
Type 2 - Steel & Carbon Fibre	0.52 kg/litre	-35%
Type 3 - Steel & Carbon Fibre	0.41 kg/litre	-48%

*Table 6: Weight w.r.t cost of CNG Cylinder Types*

CNG Cylinder Type	Weight	Cost
Type 1-Metal Cylinders	100 %	40%
Type 2-Metal Liner-Hoop wrapped cylinders	55-65%	80-95%
Type 3-Metal Liner –Fully wrapper cylinders	25-45%	90-100%
Type 4-All Composite Cylinders	30%	90%

**Table 7: Comparison of Parameters for CNG Cylinder Types**

<b>Parameters</b>	<b>Type 1 Steel</b>	<b>Type 3 Al/Comp</b>	<b>Type 4 Comp</b>	<b>Remarks for Type 4</b>
<b>Weight</b>	1.01	0.73-0.75 (GF) 0.31-0.36 (CF)	0.34-0.48 (GF) 0.28-0.4 (CF)	Equal performance even with hybrid's
<b>Lifetime</b>	Hydraulic Pressure test every 5 years	20 years Pressure test reqd	20 years Visual inspection only	Tests have shown lifetime up to 30 years
<b>Max Pressure</b>	300 Bar	350 Bar	1050 Bar	Composite is the future when Hydrogen is used
<b>Fatigue</b>	Yes	Yes	No	No hydraulic retesting required
<b>Safety</b>	MEDIUM Pressure build up will lead to explosion	MEDIUM Pressure build up will lead to explosion	HIGH Pressure build up will lead to rupture	No fatigue, Burst pressure 600 bar plus! Higher Impact resistance. 14 Critical design tests
<b>Corrosion (Internal)</b>	HIGH Frequent problem	LOW	Very Low	Plastic liner – NIL corrosion
<b>Design to Space</b>	Fixed	Some variation	No restriction	Can be designed for space available

## VI. CNG COMPOSITE CYLINDERS (TYPE IV)

### 1. FEATURES

- Seamless polymer, welding free
- Internal shell is made of special gas tight PE.
- Special design boss
- Corrosion free PE liner
- High pressure resistant carbon fiber wrapped outer liner.
- 70% lighter than Type I, II and III.
- Light weight reduces transport and work costs
- Fatigue resistant non metallic liner
- 20 years service life
- Application on wide range vehicles; cars, buses, trucks, forklifts, boats, ships, locomotives, etc
- Tailor-made productions to meet costumers' need
- Production comply with certifications

*Table 8: Features and Advantages of Type IV Cylinders*

<b>Features</b>	<b>Advantages</b>
Light weighted	<ul style="list-style-type: none"> <li>❖ Wide range of usage</li> <li>❖ Suitable on buses, trucks and Lorries.</li> <li>❖ Producible at large volumes</li> <li>❖ Efficiency at energy and usage.</li> <li>❖ Profit is increased by getting more people on vehicle</li> </ul>
Robustness	High-pressure resistant because of completely carbon fiber wrapped special plastic inside of cylinder
Corrosion proof plastic inside shell	<ul style="list-style-type: none"> <li>❖ Special plastic inside shell provides long using life.</li> <li>❖ No corrosion during reloading and re unloading provides many years usage.</li> <li>❖ No performance degradations at any environment conditions.</li> <li>❖ Resistant to gas leakage</li> <li>❖ Flexible plastic inside shell is resistant to cracking and exploding</li> </ul>
High technology carbon fiber material	<ul style="list-style-type: none"> <li>❖ Excellent resistant to heat and aging</li> <li>❖ Leak proof under any circumstances</li> </ul>

Economic and Easy usage	Used vehicles can be converted easily and cheaply.
Processing suitable for customer	<ul style="list-style-type: none"> <li>❖ Processing according to customers' needs.</li> <li>❖ Processing high technologic and with best raw material</li> </ul>

## 2. REQUIREMENTS

### a) Materials

#### b) General requirements

Materials like plastic liners, metal end bosses used shall be suitable for the service conditions as detailed below. The design shall ensure that incompatible materials are not in contact.

#### c) Standard service conditions

The standard service conditions specified in this clause are provided as the basis for the design, manufacture, inspection, testing and approval of cylinders that are to be mounted permanently on vehicles and used to store natural gas at ambient temperatures for use as a fuel on the vehicles.

#### d) Use of cylinders

The service conditions specified are also intended to provide information on how cylinders manufactured in accordance with this International Standard may safely be used; this information is intended for

- ✓ Manufacturers of cylinders;
- ✓ Owners of cylinders;
- ✓ Designers or contractors responsible for the installation of cylinders;
- ✓ Designers or owners of equipment used to refuel vehicle cylinders;
- ✓ Suppliers of natural gas;
- ✓ Regulatory authorities who have jurisdiction over cylinder use.

**e) Service life**

- ✓ The service life for which cylinders are safe shall be specified by the cylinder manufacturer on the basis of use under service conditions specified herein. The maximum service life shall be 20 years.
- ✓ For metal and metal-lined cylinders, the service life shall be based upon the rate of fatigue crack growth. The ultrasonic inspection, or equivalent, of each cylinder or liner shall ensure the absence of flaws which exceed the maximum allowable size. This approach permits the optimized design and manufacture of light weight cylinders for natural gas vehicle service.
- ✓ For all-composite cylinders with non-metallic non-load bearing liners the service life shall be demonstrated by appropriate design methods, design qualification testing and manufacturing controls.

**f) Maximum pressures**

- ✓ This International Standard is based upon a working pressure of 200 bar settled at 15 °C for natural gas as a fuel with a maximum filling pressure of 260 bar. Other working pressures may be accommodated by adjusting the pressure by the appropriate factor (ratio); e.g., a 250 bar working pressure system will require pressures to be multiplied by 1, 25.
- ✓ Except where pressures have been adjusted in this way, the cylinder shall be designed to be suitable for the following pressure limits:
  - ✚ a pressure that would settle to 200 bar at a settled temperature of 15 °C;
  - ✚ The maximum shall not exceed 260 bar, regardless of filling conditions or temperature.

**g) Design number of filling cycles**

Cylinders shall be designed to be filled up to a settled pressure of 200 bar at a settled gas temperature of 15 °C for up to 1 000 times per year of service.

### **h) Gas temperature**

Cylinders shall be designed to be suitable for the following gas temperature limits:

- i. the settled temperature of gas in cylinders, which may vary from a low of - 40 °C to a high of + 65 °C.
- ii. The developed gas temperatures during filling and discharge, which may vary beyond these limits.

### **i) Cylinder temperatures**

Cylinders shall be designed to be suitable for the following material temperature limits:

- i. The temperature of the cylinder materials may vary from – 40 °C to + 82 °C.
- ii. temperatures over + 65 °C shall be sufficiently local, or of short enough duration, that the temperature of gas in the cylinder never exceeds + 65 °C, except the developed gas temperatures during filling and discharge, which may vary beyond these limits.

### **j) Dry gas composition**

Water vapour shall be limited to less than 32 mg/m<sup>3</sup> (i.e. a pressure dew point of - 9 °C at 200 bar).

Constituent maximum limits shall be:

- Hydrogen sulfide and other soluble sulfides - 23 mg/m<sup>3</sup>
- Oxygen - 1 % (volume fraction)
- Hydrogen, when cylinders are manufactured from a steel with an ultimate tensile strength exceeding 950 MPa - 2 % (volume fraction)

### **k) Wet gas composition**

This is gas that has higher water content than that of dry gas.

Constituent maximum limits shall be:

- Hydrogen sulfide and other soluble sulfides - 23 mg/m<sup>3</sup>
- Oxygen - 1 % (volume fraction)
- Carbon dioxide - 4 % (volume fraction)
- Hydrogen – 0.1 % (volume fraction)

**l) External surfaces**

It is not necessary for cylinders to be designed for continuous exposure to mechanical or chemical attack, e.g. leakage from cargo that may be carried on vehicles or severe abrasion damage from road conditions. However, cylinder external surfaces shall be designed to withstand inadvertent exposure to the following, consistent with installation being carried out in accordance with the instructions to be provided with the cylinder:

- i. water, either by intermittent immersion or road spray;
- ii. salt, due to the operation of the vehicle near the ocean or where ice-melting salt is used;
- iii. ultra-violet radiation from sunlight;
- iv. impact of gravel;
- v. solvents, acids and alkalis, fertilizers;
- vi. automotive fluids, including petrol, hydraulic fluids, battery acid, glycol and oils;
- vii. Exhaust gases.

**m) Resins**

The material for impregnation may be thermosetting or thermoplastic resins. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl ester thermosetting plastics, and polyethylene and polyamide thermoplastic material.

**n) Fibres**

Structural reinforcing filament material types shall be glass fibre, aramid fibre or carbon fibre. If carbon fibre reinforcement is used the design shall incorporate a means of preventing galvanic corrosion of metallic components of the cylinder.

The manufacturer shall keep on file the published specifications for composite materials, the material manufacturer's recommendations for storage, conditions and shelf life, and the material manufacturer's certification that each shipment conforms to said specification requirements. The fibre manufacturer shall certify that the fibre material properties conform to the manufacturer's specifications for the product.

### 3. Design requirements

#### a) Test pressure

The minimum test pressure used in manufacture shall be 300 bar (1,5 times working pressure).

#### b) Burst pressures and fibre stress ratios

The composite over-wrap shall be designed for high reliability under sustained loading and cyclic loading. Stress ratio is defined as the stress in the fibre at the specified minimum burst pressure divided by the stress in the fibre at working pressure. The burst ratio is defined as the actual burst pressure of the cylinder divided by the working pressure.

For type CNG-4 designs, the stress ratio is equal to the burst ratio.

Verification of the stress ratios may also be performed using strain gauges.

*Table 9: Fibre type and Stress Ration*

<b>Fibre type</b>	<b>Stress Ratio</b>	<b>Burst Pressure bar</b>
Glass	3.65	730
Aramid	3.10	620
Carbon	2.35	470

#### c) Stress analysis

A stress analysis shall be performed to justify the minimum design wall thicknesses. It shall include the determination of the stresses in liners and fibres of composite designs. The stresses in the tangential and longitudinal direction of the cylinder in the composite and in the liner shall be calculated. The pressures used for these calculations shall be 0 bar, 200 bar, test pressure and design burst pressure. The calculations shall use suitable analysis techniques to establish stress distribution throughout the cylinder.



**d) Openings**

Openings are permitted in the end bosses only. The centre line of openings shall coincide with the longitudinal axis of the cylinder.

**e) Fire protection**

The cylinder design shall be protected with pressure relief devices. The cylinder, its materials, pressure relief devices and any added insulation or protective material shall be designed collectively to ensure adequate safety during fire conditions in the Bonfire test as specified below. A manufacturer may specify alternative PRD locations for specific vehicle installations in order to optimize safety considerations. Pressure relief devices shall be approved to a standard acceptable to the Inspector in the country of use.

**f) Bonfire test**

**General**

The bonfire test is designed to demonstrate that finished cylinders, complete with the fire protection system (cylinder valve, pressure relief devices and/or integral thermal insulation) specified in the design, will prevent the rupture of the cylinder when tested under the specified fire conditions.

Precautions shall be taken during fire testing in the event that cylinder rupture occurs.

**g) Cylinder set-up**

The cylinder shall be placed horizontally with the cylinder bottom approximately 100 mm above the fire source. Metallic shielding shall be used to prevent direct flame impingement on cylinder valves, fittings, and/or pressure relief devices. The metallic shielding shall not be in direct contact with the specified fire protection system (pressure relief devices or cylinder valve).

Any failure during the test of a valve, fitting or tubing that is not part of the intended protection system for the design shall invalidate the result.

#### **h) Fire source**

A uniform fire source of 1.65 m length shall provide direct flame impingement on the cylinder surface across its entire diameter.

Any fuel may be used for the fire source provided it supplies uniform heat sufficient to maintain the specified test temperatures until the cylinder is vented. The selection of a fuel should take into consideration air pollution concerns. The arrangement of the fire shall be recorded in sufficient detail to ensure that the rate of heat input to the cylinder is reproducible.

Any failure or inconsistency of the fire source during a test shall invalidate the result.

#### **i) Temperature and pressure measurements**

Surface temperatures shall be monitored by at least three thermocouples located along the bottom of the cylinder and spaced not more than 0.75 m apart.

Metallic shielding shall be used to prevent direct flame impingement on the thermocouples.

Alternatively, thermocouples may be inserted into blocks of metal measuring less than 25 mm square. Thermocouple temperatures and the cylinder pressure shall be recorded at intervals of every 30 s or less during the test.

### **4. General test requirements**

The cylinder shall be pressurized to working pressure with natural gas or compressed air and tested in the horizontal position at working pressure and at 25 % of working pressure if a thermally activated PRD is not used.

Immediately following ignition, the fire shall produce flame impingement on the surface of the cylinder along the 1.65 m length of the fire source and across the cylinder diameter.

Within 5 min of ignition the temperature at least one thermocouple shall indicate a temperature  $\geq$  590 °C. This minimum temperature shall be maintained for the remainder of the test.

For cylinders of length 1.65 m or less, the centre of the cylinder shall be positioned over the centre of the fire source.

For cylinders of length greater than 1.65 m, the cylinder shall be positioned as follows:

- a) if the cylinder is fitted with a pressure relief device at one end, the fire source shall commence at the opposite end of the cylinder;
- b) if the cylinder is fitted with pressure relief devices at both ends, or at more than one location along the length of the cylinder, the centre of the fire source shall be centered midway between the pressure relief devices that are separated by the greatest horizontal distance;
- c) if the cylinder is additionally protected using thermal insulation, then two fire tests at service pressure shall be performed, one with the fire centered midway along the cylinder length, and the other with the fire commencing at one of the ends of a second cylinder.

## **5. Acceptable results**

The cylinder shall vent through a pressure relief device.

## **6. Construction and workmanship**

### **General**

The composite cylinder shall be manufactured from a liner over-wrapped with continuous filament windings. Fibre winding operations shall be computer or mechanically controlled. The fibres shall be applied under controlled tension during winding. After winding is complete, thermosetting resins shall be cured by heating, using a predetermined and controlled time-temperature profile.

### **7. Neck threads**

Threads shall be clean cut, even, without surface discontinuities, to gauge and comply with International Standards acceptable to the Inspector

### **8. Curing of thermosetting resins**

The curing temperature for thermosetting resins shall be at least 10 °C below the softening temperature of the plastic liner.

## **9. Exterior environmental protection**

The exterior of cylinders shall meet the requirements of the acid environment test as detailed below –

### **a) Acid environment test**

On a finished cylinder the following test procedure shall be applied:

- i. expose a 150 mm diameter area on the cylinder surface for 100 h to a 30 % sulfuric acid solution (battery acid with a specific gravity of 1.219) whilst the cylinder is hydrostatically pressurized to 260 bar;
- ii. Pressurize the cylinder to burst. The rate of pressurization shall not exceed 14 bar/s at pressures in excess of 80 % of the design burst pressure. If the rate of pressurization at pressures in excess of 80 % of the design burst pressure exceeds 3,5 bar/s, then either the cylinder shall be placed schematically between the pressure source and the pressure measurement device, or there shall be a 5 s hold at the minimum design burst pressure. The minimum required (calculated) burst pressure shall be at least 450 bar, and in no case less than the value necessary to meet the stress ratio requirements. Actual burst pressure shall be recorded. Rupture may occur in either the cylindrical region or the dome region of the cylinder.

The burst pressure shall exceed 85 % of the minimum design burst pressure.

Exterior protection may be provided by using any of the following:

- i. a surface finish giving adequate protection (e.g. metal sprayed on to aluminium, anodizing); or
- ii. the use of a suitable fibre and matrix material (e.g. carbon fibre in resin); or
- iii. a protective coating (e.g. organic coating, paint) (explained below);
- iv. a covering impervious to the chemicals

### **b) Coating tests**

Coatings shall be evaluated using the following test methods, or using equivalent standards acceptable to the Inspector in the country of use:

- a) Adhesion testing, in accordance with ISO 4624:—, using method A or B as applicable.  
The coating shall exhibit an adhesion rating of either 4A or 4B, as applicable;

- b) Flexibility, in accordance with ASTM D522-93, using test method B with a 12,7 mm (0,5 in) mandrel at the specified thickness at 20 °C. Samples for the flexibility test shall be prepared in accordance with ASTM D522-93. There shall be no visually apparent cracks;
- c) impact resistance, in accordance with ASTM D2794-93. The coating at room temperature shall pass a forward impact test of 18 J (13,3 ft-lb's);
- d) chemical resistance, in accordance with ASTM D1308-87 except as identified in the following. The tests shall be conducted using the open spot test method and 100 h exposure to a 30 % sulfuric acid solution (battery acid with a specific gravity of 1,219) and 24 h exposure to a polyalkalene glycol (e.g. brake fluid). There shall be no evidence of lifting, blistering or softening of the coating. The adhesion shall meet a rating of 3 when tested in accordance with ISO 4624:—;
- e) Minimum 1000 h exposure, in accordance with ASTM G53-93. There shall be no evidence of blistering, and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624:—. The maximum gloss loss allowed is 20 %;
- f) Minimum 500 h exposure in accordance with ISO 9227. Undercutting shall not exceed 2 mm at the scribe mark, there shall be no evidence of blistering and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624:—;
- g) Resistance to chipping at room temperature, in accordance with ASTM D3170-87. The coating shall have a rating of 7A or better and there shall be no exposure of the substrate.

## **10. Prototype testing procedure**

### **General**

Prototype testing shall be conducted on each new design, on finished cylinders which are representative of normal production and complete with identification marks. The test cylinders or liners shall be selected and the prototype tests. If more cylinders or liners are subjected to the tests than are required by this International Standard, all results shall be documented.

### **a) Prototype tests**

### **Tests required**

In the course of the type approval, the Inspector shall select the necessary cylinders or liners for testing and witness the following tests:

**b) Material tests for plastic liners**

The tensile yield strength and ultimate elongation of plastic liner material shall be determined at - 50 °C in accordance with ISO 527-2. The test results shall demonstrate the ductile properties of the plastic liner material at temperatures of - 50 °C or lower by meeting the values specified by the manufacturer.

Polymeric materials from finished liners shall be tested in accordance with a method described in ISO 306. The softening temperature shall be at least 100 degrees.

This test is required for all type CNG-4 designs, and all type CNG-2 and CNG-3 designs in which the glass transition temperature of the resin matrix does not exceed 102 °C.

One finished cylinder shall be tested as follows:

- a) the cylinder shall be pressurized to 260 bar and held at a temperature of 100 °C for not less than 200 h;
- b) following the test, the cylinder shall meet the requirements of the hydrostatic expansion test, the leak test and the hydrostatic pressure burst test.

**c) Hydrostatic pressure burst test**

The rate of pressurization shall not exceed 14 bar/s at pressures in excess of 80 % of the design burst pressure. If the rate of pressurization at pressures in excess of 80 % of the design burst pressure exceeds 3.5 bar/s, then either the cylinder shall be placed schematically between the pressure source and the pressure measurement device, or there shall be a 5 s hold at the minimum design burst pressure.

The minimum required (calculated) burst pressure shall be at least 450 bar, and in no case less than the value necessary to meet the stress ratio requirements. Actual burst pressure shall be recorded. Rupture may occur in either the cylindrical region or the dome region of the cylinder.

**d) Ambient temperature pressure cycling**

Pressure cycling shall be performed in accordance with the following procedure:

- i. fill the cylinder to be tested with a non-corrosive fluid such as oil, inhibited water or glycol;

- ii. cycle the pressure in the cylinder between 20 bar and 260 bar at a rate not exceeding 10 cycles per minute.

The number of cycles to failure shall be reported, along with the location and description of the failure initiation.

**e) Leak-before-break (LBB) test**

Three finished cylinders shall be pressure cycled between 20 bar and 300 bar at a rate not to exceed 10 cycles per minute.

All cylinders shall either fail by leakage or exceed 45 000 pressure cycles.

**f) Bonfire test – Refer design requirements**

**g) Penetration tests**

A cylinder pressurized to 200 bar  $\pm$  10 bar with compressed gas shall be penetrated by an armour piercing bullet with a diameter of 7.62 mm or greater. The bullet shall completely penetrate at least one side wall of the cylinder. For type CNG-2, CNG-3 and CNG-4 designs, the projectile shall impact the sidewall at an approximate angle of 45°. The cylinder shall not rupture.

**h) Acid environment test**

On a finished cylinder the following test procedure shall be applied:

- i. expose a 150 mm diameter area on the cylinder surface for 100 h to a 30 % sulfuric acid solution (battery acid with a specific gravity of 1,219) whilst the cylinder is hydrostatically pressurized to 260 bar;
- ii. pressurize the cylinder to burst.

The burst pressure shall exceed 85 % of the minimum design burst pressure.

**i) Composite flaw tolerance tests**

For type CNG-2, CNG-3 and CNG-4 designs only, one finished cylinder, complete with protective coating, shall have flaws cut into the composite in the longitudinal direction. The flaws shall be greater than the visual inspection limits as specified by the manufacturer. As a minimum, one flaw shall be 25 mm long and 1.25 mm in depth and another flaw shall be 200 mm long and 0,75 mm in depth, cut in the longitudinal direction into the cylinder sidewall.

The flawed cylinder shall then be pressure cycled between 20 bar and 260 bar at ambient temperature, initially for 3 000 cycles, then followed by an additional 12 000 cycles.

The cylinder shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further 12 000 cycles. All cylinders which complete this test shall be destroyed.

**j) High temperature creep test**

This test is required for all type CNG-4 designs, and all type CNG-2 and CNG-3 designs in which the glass transition temperature of the resin matrix does not exceed 102 °C. One finished cylinder shall be tested as follows:

- i. the cylinder shall be pressurized to 260 bar and held at a temperature of 100 °C for not less than 200 h;
- ii. following the test, the cylinder shall meet the requirements of the hydrostatic expansion test, the leak test and the hydrostatic pressure burst test

**k) Accelerated stress rupture test**

For type CNG-2, CNG-3 and CNG-4 designs only, one cylinder shall be hydrostatically pressurized to 260 bar at 65 °C. The cylinder shall be held at this pressure and temperature for 1 000 h. The cylinder shall then be pressured to burst in accordance with the procedure described in A.12, except that the burst pressure shall exceed 85 % of the minimum design burst pressure.

**l) Extreme temperature pressure cycling**

Finished cylinders, with the composite wrapping free of any protective coating, shall be cycle tested, as follows:

- i. Condition for 48 h at zero pressure, 65 °C or higher, and 95 % or greater relative humidity. The intent of this requirement shall be deemed met by spraying with a fine spray or mist of water in a chamber held at 65 °C;
- ii. hydrostatically pressurize for 500 cycles multiplied by the specified service life in years between 20 bar and 260 bar at 65°C or higher, and 95 % or greater relative humidity;
- iii. condition the cylinder and fluid at – 40 °C or lower as measured in the fluid and on the cylinder surface;
- iv. Pressurize from 20 bar to 200 bar for 500 cycles multiplied by the specified service life in years at – 40 °C or lower. Adequate recording instrumentation shall be provided to ensure the minimum temperature of the fluid is maintained during the low temperature cycling.



The pressure cycling rate of b) shall not exceed 10 cycles per minute. The pressure cycling rate of d) shall not exceed 3 cycles per minute unless a pressure transducer is installed directly within the cylinder.

During this pressure cycling, the cylinder shall show no evidence of rupture, leakage or fibre unraveling.

Following pressure cycling at extreme temperatures, cylinders shall be hydrostatically pressured to failure and achieve a minimum burst pressure of 85 % of the minimum design burst pressure. For type CNG-4 designs, prior to the hydrostatic burst test the cylinder shall be leak tested.

**m) Resin shear strength**

Resin materials shall be tested on a sample coupon representative of the composite overwrap in accordance with ISO 14130, or an equivalent standard acceptable to the Inspector in the country of use. Following 24 h boiling in water the composite shall have minimum shear strength of 13.8 MPa.

**n) Impact damage test**

One or more finished cylinders shall be drop tested at ambient temperature without internal pressurization or attached valves. The surface on to which the cylinders are dropped shall be a smooth, horizontal concrete pad or flooring. One cylinder shall be dropped in a horizontal position with the bottom 1.8 m above the surface on to which it is dropped. One cylinder shall be dropped vertically on each end at a sufficient height above the floor or pad so that the potential energy is 488 J, but in no case shall the height of the lower end be greater than 1.8 m. One cylinder shall be dropped at a 45° angle on to a dome, from a height such that the centre of gravity is at 1.8 m; however, if the lower end is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0,6 m and a centre of gravity of 1.8 m.

Following the drop impact, the cylinders shall then be pressure cycled between 20 bar and 260 bar at ambient temperature, initially for 3 000 cycles, then followed by an additional 12 000 cycles.

The cylinder shall not leak or rupture within the first 3 000 cycles, but may fail by leakage during the further 12 000 cycles. All cylinders which complete this test shall be destroyed.

**o) Boss torque test**

The body of the cylinder shall be restrained against rotation and a torque of twice the valve or PRD installation torque specified by the manufacturer shall be applied to each end boss of the cylinder. The torque shall be applied first in the direction of tightening a threaded connection, then in the untightening direction, and finally again in the tightening direction.

The cylinder shall then be subjected to a leak test

**p) Permeation test**

This test is only required on type CNG-4 designs. One finished cylinder shall be filled with compressed natural gas to working pressure, placed in an enclosed sealed chamber at ambient temperature, and monitored for leakage for 500 h. The permeation rate shall be less than 0.25 ml of natural gas per hour per litre water capacity of the cylinder. The cylinder shall be sectioned and the internal surfaces inspected for any evidence of cracking or deterioration.

**q) Natural gas cycling test**

Special consideration shall be given to safety when conducting this test. Prior to conducting this test, cylinders of this design shall have successfully passed the test requirements of leak test, hydrostatic pressure burst test, ambient temperature pressure cycling test and permeation test.

One finished type CNG-4 cylinder shall be pressure cycled using compressed natural gas between less than 20 bar and working pressure for 1 000 cycles. The filling time shall be 5 min maximum. Unless otherwise specified by the manufacturer, care should be taken to ensure that temperatures during venting do not exceed the defined service conditions.

The cylinder shall be leak tested in accordance with and meet the requirements therein. Following the completion of the natural gas cycling the cylinder shall be sectioned and the liner and liner/end boss interface inspected for evidence of any deterioration, such as fatigue cracking or electrostatic discharge.

**r) Batch tests**

## General requirements

Batch testing shall be conducted on finished cylinders which are representative of normal production and are complete with identification marks. The cylinder(s) and liner(s) required for testing shall be randomly selected from each batch. If more cylinders are subjected to the tests than are required by this International Standard, all results shall be documented.

### s) Required tests

At least the following tests shall be carried out on each batch of cylinders:

- a) On one cylinder:
  - 1) One hydrostatic pressure burst test in accordance
- b) On one cylinder, or liner, or witness sample representative of a finished cylinder:
  - 1) A check of the critical dimensions against the design
  - 2) One tensile test of the plastic liner
  - 3) the melt temperature of the plastic liner
  - 4) When a protective coating is a part of the design, a coating batch test shall be 100 % inspected to remove similarly defectively coated cylinders. The coating on all defectively coated cylinders may be stripped using a method that does not affect the integrity of the composite wrapping then recoated. The coating batch test shall then be repeated.

Additionally, a periodic pressure cycling test shall be carried out on finished cylinders

a) Initially, on one cylinder from each batch the end boss shall be torque tested. The cylinder shall then shall be pressure cycled for a total of 1 000 times the specified service life in years, with a minimum 15 000 cycles. Following the required pressure cycling, the cylinder shall be leak tested

b) if on 10 sequential production batches of a design family, none of the pressure cycled cylinders in a) above leaks or ruptures in less than 1 500 cycles multiplied by the specified life in years (minimum 22 500 cycles) then the pressure cycle test may be reduced to one cylinder from every 5 batches of production;

c) if on 10 sequential production batches of a design family, none of the pressure cycled cylinders in a) above leaks or ruptures in less than 2 000 cycles multiplied by the specified service

life in years (minimum 30 000 cycles) then the pressure cycle test can be reduced to one cylinder from every 10 batches of production;

d) should more than 3 months have expired since the last pressure cycle test, then a cylinder from the next batch of production shall be pressure cycle tested in order to maintain the reduced frequency of batch testing in b) or c) above;

e) should any reduced frequency pressure cycle test cylinder in b) or c) above fail to meet the required number of pressure cycles (minimum 22 500 or 30 000 pressure cycles, respectively), then it shall be necessary to repeat the batch pressure cycle test frequency in a) for a minimum of 10 production batches in order to re-establish the reduced frequency of batch pressure cycle testing in b) or c) above.

Should any cylinder in a), b), or c) above fail to meet the minimum cycle life requirement of 1 000 cycles multiplied by the specified service life in years (minimum 15 000 cycles), then the cause of failure shall be determined and corrected. The pressure cycle test shall then be repeated on an additional three cylinders from that batch. Should any of the three additional cylinders fail to meet the minimum pressure cycling requirement of 1 000 cycles multiplied by the specified service life in years, then the batch shall be rejected.

**t) Tests on every cylinder**

Production examinations and tests shall be carried out on all cylinders produced in a batch.

Each cylinder shall be examined during manufacture and after completion, as follows:

a) by inspection of liners to confirm that the maximum defect size present is smaller than the size specified in the design;

b) to verify that the critical dimensions and mass of the completed cylinder and of any liner and overwrapping are within design tolerances;

c) to verify compliance with specified surface finish;

d) to verify the markings;

e) by hydraulic test of finished. The manufacturer shall define the appropriate limit of elastic expansion for the test pressure used, but in no case shall the elastic expansion of any cylinder exceed the average batch value by more than 10 %;

f) by leak test in accordance with A.10, and shall meet the requirements therein.

**u) Batch acceptance certificate**

If the results of batch testing are satisfactory, the manufacturer and the Inspector shall sign an acceptance certificate. An example of an acceptance certificate (referred to as a “Report of Manufacture and Certificate of Conformance”)

**v) Failure to meet test requirements**

In the event of failure to meet test requirements re-testing or re-heat treatment and re-testing shall be carried out as follows:

a) if there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed; if the result of this test is satisfactory, the first test shall be ignored;

b) if the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

- All defective cylinders shall be rejected or repaired by an approved method. Provided that the repaired cylinders pass the test(s) required for the repair, they shall be re-instated as part of the original batch.

- The new batch shall be retested. All the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all cylinders of the batch shall be rejected.

## VII. Ultrasonic inspection

### 1. Scope

This is based on techniques used by cylinder manufacturers. Other techniques of ultrasonic inspection may be used, provided these have been demonstrated to be suitable for the manufacturing method.

### 2. General requirements

The ultrasonic testing equipment shall be capable of at least detecting the reference standard. It shall be serviced regularly in accordance with the manufacturer's operating instructions to ensure that its accuracy is maintained. Inspection records and approval certificates for the equipment shall be maintained.

The operation of the test equipment shall be by trained personnel and supervised by qualified and experienced personnel certified to level 2 of ISO 9712:1999.

The outer and inner surfaces of any cylinder which is to be tested ultrasonically shall be in a condition suitable for an accurate and reproducible test.

For flaw detection the pulse echo system shall be used. For thickness measurement either the resonance method or the pulse echo system shall be used. Either contact or immersion techniques of testing shall be used.

A coupling method which ensures adequate transmission of ultrasonic energy between the testing probe and the cylinder shall be used.

### 3. Flaw detection of the cylindrical parts

#### a) Procedure

The cylinders to be inspected and the search unit shall have a rotating motion and translation relative to one another such that a helical scan of the cylinder is described. The velocity of rotation and translation shall be constant within  $\pm 10\%$ . The pitch of the helix shall be less than the width covered by the probe (at least a 10 % overlap shall be guaranteed) and be related to the

effective beam width such as to ensure 100 % coverage at the velocity of rotation and translation used during the calibration procedure.

An alternative scanning method may be used for transverse defect detection, in which the scanning or relative movement of the probes and the work piece is longitudinal, the sweeping motion being such as to ensure a 100 % surface coverage with about 10 % overlap of the sweeps.

The cylinder wall shall be tested for longitudinal defects with the ultrasonic energy transmitted in both circumferential directions and for transverse defects in both longitudinal directions.

In this case, or when optional testing is carried out on the transition areas between the wall and neck and/or wall and base, this may be conducted manually if not carried out automatically.

The effectiveness of the equipment shall be periodically checked by passing a reference standard through the test procedure. This check shall be carried out at least at the beginning and end of each shift. If during this check the presence of the appropriate reference notch is not detected then all cylinders tested subsequent to the last acceptance check shall be retested after the equipment has been reset.

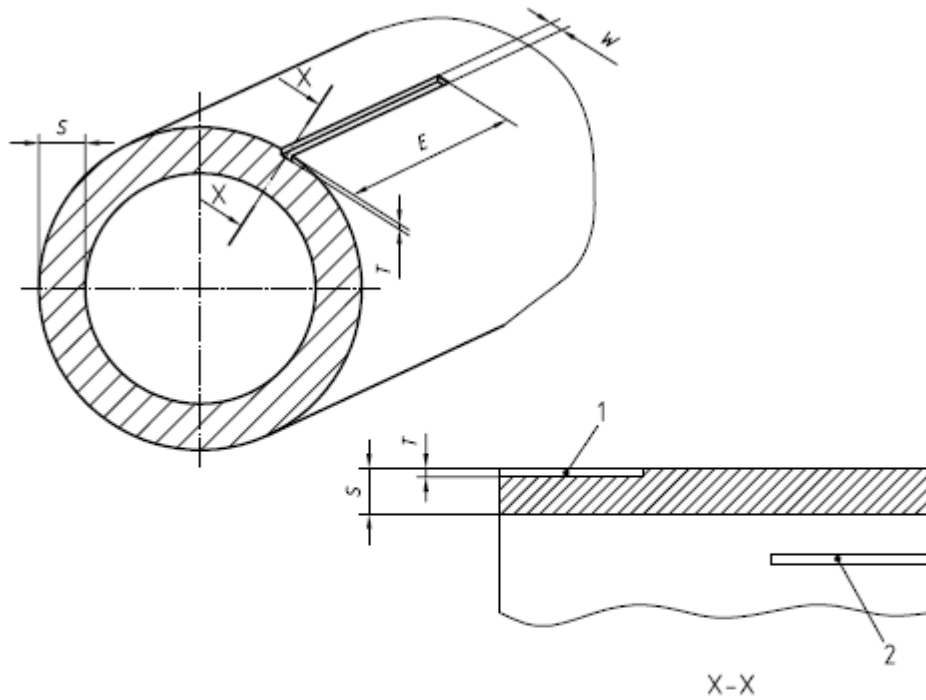
**b) Reference standard**

A reference standard of convenient length shall be prepared from a cylinder of similar diameter and wall thickness range, and from material with the same acoustic characteristics and surface finish as the cylinder to be inspected. The reference standard shall be free from discontinuities which may interfere with the detection of the reference notches.

Reference notches, both longitudinal and transverse, shall be machined on the outer and inner surface of the standard. The notches shall be separated such that each notch can be clearly identified.

Dimensions and shape of notches are of crucial importance for the adjustment of the equipment.

*Figure 3 Dimensions and shape of notches*

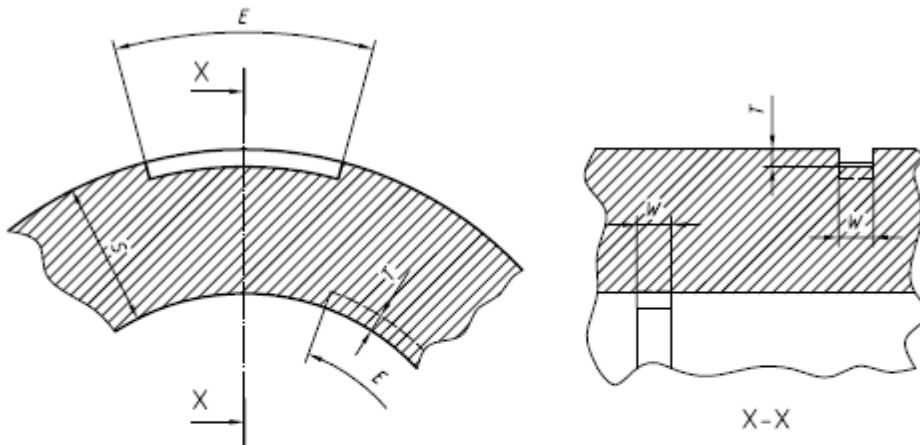


**Key**

- 1 External reference notch
- 2 Internal reference notch

NOTE  $T \leq (5 \pm 0,75) \% S$  but  $0,2 \text{ mm} \leq T \leq 1 \text{ mm}$   
 $R \leq 2T$ , but if not possible then  $R \leq 1 \text{ mm}$   
 $E \leq 50 \text{ mm}$





NOTE  $T \leq (5 \pm 0,75) \% S$  but  $0,2 \text{ mm} \leq T \leq 1 \text{ mm}$   
 $W \leq 2T$ , but if not possible then  $W \leq 1 \text{ mm}$   
 $E \leq 50 \text{ mm}$

- the length of the notches (E) shall be no greater than 50 mm;
- the width (W) shall be no greater than twice the nominal depth (T). However, where this condition cannot be met a maximum width of 1 mm is acceptable;
- the depth of the notches (T) shall be 5 %  $\pm$  0,75 % of the nominal thickness (S) with a minimum of 0.2 mm and a maximum of 1 mm, over the full length of the notch. Run outs at each end are permissible;.
- the notch shall be sharp edged at its intersection with the surface of the cylinder wall. The cross section of the notch shall be rectangular except where spark erosion machining methods are used; then it is acknowledged that the bottom of the notch will be rounded;
- the shape and dimensions of the notch shall be demonstrated by an appropriate method.

### c) Calibration of equipment

Using the reference standard, the equipment shall be adjusted to produce clearly identifiable indications from inner and outer reference notches. The amplitude of the indications shall be as near equal as possible. The indication of smallest amplitude shall be used as the rejection level and for setting visual, audible, recording or sorting devices. The equipment shall be calibrated with the reference standard or probe, or both, moving in the same manner, in the same direction

and at the same speed as will be used during the inspection of the cylinder. All visual, audible, recording or sorting devices shall operate satisfactorily at the test speed.

**d) Wall thickness measurement**

If the measurement of the wall thickness is not carried out at another stage of production, the cylindrical part shall be 100 % examined to ensure that the thickness is not less than the guaranteed minimum value.

**e) Interpretation of results**

Cylinders with indications which are equal to or greater than the lowest of the indications from the reference notches shall be withdrawn. Surface defects may be removed; after removal the cylinders shall be re subjected to ultrasonic flaw detection and thickness measurement. Any cylinder which is shown to be below the guaranteed minimum wall thickness shall be rejected.

**f) Certification**

The ultrasonic testing shall be certified by the cylinder manufacturer. Every cylinder, which has passed the ultrasonic testing in accordance with this specification, shall be stamp-marked with the symbol "UT".

**4. Approval and certification procedures**

**a) General**

Certification of the manufacturer, cylinder approval and monitoring of the quality control/inspection procedures is typically performed by either the regulatory authority or by an independent inspection authority approved and designated by the regulatory authority. This annex describes the processes involved in such procedures. There can be more than one independent inspection authority within a country and an inspection authority can be from another country.

**b) Manufacturer's certification**

To obtain certification in a country, the manufacturer applies to the regulatory authority for certification. The application contains documentation on design, process and quality control/inspection.

The regulatory authority certifies the manufacturer by the following actions and issues a “certificate of approval”:

- The regulatory authority carries out or causes to be carried out by an independent inspection authority, an onsite examination of the manufacturing plant, including equipment and quality control. This includes observations of manufacture, testing and inspection operations. This is to verify that the plant, equipment, personnel and systems are adequate to produce cylinders in accordance with this International Standard.
- The regulatory authority tests or causes to be tested cylinders from a prototype production batch. These tests fulfill the requirements of design qualification testing as specified in this International Standard, depending upon the specific type of cylinder design under consideration.

### **c) Cylinder type approval**

Following an application for cylinder type approval, the regulatory authority or the independent inspection authority:

- examines the technical documentation to verify that the cylinder has been manufactured in conformity with the technical documentation and that the design is in accordance with the relevant provisions of this International Standard;
- agrees with the applicant the facility at which to carry out the examinations and tests;
- performs or cause to be performed the examinations and tests specified to determine that this International Standard has been applied, and that the procedures adopted by the manufacturer meet the requirements of this International Standard;

When the cylinder type meets the requirements of this International Standard, the regulatory authority issues an approval certificate to the applicant. The certificate contains the name and address of the manufacturer, results and conclusions of the examination and the necessary data for identification of the approved cylinder. A list of the relevant parts of the technical documentation is annexed to the certificate and a copy kept by the regulatory authority and the manufacturer.

An identification symbol/number, which can be stamped or suitably marked on the cylinder, is specified for each manufacturer.

If the manufacturer is denied an ISO cylinder approval, the regulatory authority provides written detailed reasons for such denial.

The manufacturer is required to inform the regulatory authority that issued the cylinder approval certification, of all modifications to the approved equipment or procedures. An additional approval is to be requested where such changes affect the conformity of cylinders with the original approval, and is given in the form of an amendment to the original cylinder approval certificate.

Upon request, each regulatory authority communicates to any other regulatory authority the relevant information concerning each ISO cylinder approval, approved modifications and withdrawn approvals.

## **VIII. Advantages & Benefits of using Type-4 Composite Cylinders**

Type-IV all-composite cylinders are used in CNG vehicles world-wide since 1992 and the technology is well demonstrated in many countries for last 20 years. These cylinders are also used in Hydrogen & HCNG vehicles where weight of the cylinder is a constraint.

### **General benefits of using Type-IV gas cylinders:**

- Type-IV gas cylinders provide substantial weight reduction (up to 75% weight reduction potential compared to steel cylinders) and hence reduction in carbon emissions when used on vehicles.
- Zero damage due to chemical/UV/ impurities
- Zero corrosion – irrespective of fuel quality and ideal in coastal areas
- High impact strength
- Infinite fatigue life
- Highest cycle life
- Permeation and leakage far lower than all established standards
- Traceability across its life cycle
- Meets standards that are far higher than those for steel: generally designed and tested as per the standards ISO 11439 & ECE R-110 which requires severe testing than steel

cylinders. Above standards require 13 additional tests specific to Type-IV cylinders compared to steel cylinders.

- Tested for 30 years life cycle, assured for 20 years, no retesting required
- Tested against bullet fire
- Type-4 cylinders are absolutely safe;
- Proven track record in the most demanding applications – Space/ defense
- Longest composite history in the world – 48 years
- No record of an explosion till date
- Futuristic – Ideal for Hydrogen application – the fuel for the future
- Fast fill and vent
- Capable of being custom designed for applications

**Benefits for buses because of use of Type 4 Cylinders:**

- No structural changes required.
- Longer bus structural life.
- Weight Saving translating to Fuel Saving.
- Improved fuel efficiency (5 to 10% improvement)
- Reduction in carbon emissions
- No Corrosion Issues.
- Higher Tyre and Aggregate life.
- Superior Strength
- Higher payload – substantial in India
- Higher capacity tanks 1200 ~ 1800 ltr water capacity can be installed (450 ~ 528 Kgs)
- Significantly increases vehicle range (450 ~ 500 Kms)
- Lower downtime for refilling
- Less maintenance and wear / tear
- Easy Reparability

Lightweight composite cylinder design mainly depends on carbon fibre for its outstanding elastic modulus, density and strength. At present, the cost of carbon-fibre-wrapped tanks is three times higher than conventional metal cylinders.

A 20-30% reduction in carbon fibre prices is expected in the upcoming years as a result of improved manufacturing processes being introduced to the market.

Composite cylinder benefits to the user include:

- reduced fuel consumption,
- Fast filling,
- Non-permeability,
- Size flexibility,
- Increased vehicle payload capacity,
- Less expansion and contraction under various pressures,
- Resistance to acids, oils, alkalis and UV rays.

These lightweight cylinders are being used in buses where they save more than 60% weight in comparison to metal cylinders. For this reason, lightweight composite CNG cylinders have a distinct edge over their competitors in the bus sector. Many NGV accidents are due to faulty design of the valve, or pressure relief device, and/or improper handling and maintenance of the cylinders.

The accident ratio of composite cylinders is very low when compared with metal cylinders. The NGV industry has now matured to a point where proper installation and inspection systems have reduced the number of potential accidents. Many countries in Europe, America and Asia have started applying very stringent testing procedures and regulations. Due to the significant changes in regulations and testing processes, the NGV industry is better equipped for significant growth in coming years.

### Financial Benefits of using Type-4 Composite Cylinders

Type 4 tanks are significantly lower in cost than Type 3 tanks. In comparison with steel tanks it is estimated that ROI is about 4 years. Table X provides the cost comparison of Type 4 cylinders with Type 1, 2 & 3 cylinders.

*Table 10: Comparison of CNG Cylinders (Cost aspects)*

Criteria	Type 1/2	Type 3	Type 4
<b>Cost vs. Steel</b>			
- Initial	1.0	2.5 to 3.5	1.5 to 2.0
- Life cycle	1.0	0.8 to 1.5	0.3 to 1.0

### Main Applications:

- Gas storage systems for Automotive applications (CNG, Hydrogen)
  - Passenger cars
  - Light Commercial Vehicles
  - Buses
  - Trucks
- Non automotive applications:
  - Aerospace (*in plan, especially with fuel cells*)
  - Various (e.g. cartridges for respirators)

## ➤ Tests for CNG Cylinders

*Table 11: Tests for CNG Cylinders*

	Type I	Type III	Type IV
Tensile tests for steel and aluminium cylinders and liners	X	X	
Impact test for steel cylinders and steel liners	X	X	
Sulfide stress cracking test for steel	X	X	
Corrosion tests for aluminium	X	X	
Sustained load cracking (SLC) tests for aluminium	X	X	
Leak-before-break (LBB) test	X	X	X
Extreme temperature pressure cycling		X	X
Brinell hardness test	X	X	
Coating tests	X	X	X
Leak test			X
Hydraulic test	X	X	X
Hydrostatic pressure burst test	X	X	X
Ambient temperature pressure cycling	X	X	X
Acid environment test	X	X	X
Bonfire test	X	X	X
Penetration tests	X	X	X
Composite flaw tolerance tests		X	X
High temperature creep test		X	X
Accelerated stress rupture test		X	X
Impact damage test		X	X
Permeation test			X
Tensile properties of plastics			X
Softening temperature of plastics			X
Coating batch tests	X	X	X
Boss torque test			X
Resin shear strength		X	X
Natural gas cycling test			X

From the above Table, it is obvious that the following additional tests are carried out on composite gas cylinders compared to steel cylinders:

- Extreme temperature pressure cycling test
- High temperature creep test
- Accelerated stress rupture test
- Impact damage test (Drop test)
- Permeation test
- Composite flaw tolerance test
- Acid environment test
- Ambient temperature pressure cycling test
- Leak Test
- Boss torque test



- Resin shear test
- Natural gas cycling test

ECE R-110 & ISO 11439 specifies the test requirements for Composite gas cylinders. The following table shows no. of test specimens used in testing.

**Table 12: No of Test Specimens**

Tests	No. of Test specimens
Extreme temperature cycle test	One cylinder
Burst test	Three cylinders
Ambient cycle test	Two cylinders
Bonfire test	Two cylinders
Drop test	One cylinder

### ➤ **Extreme Temperature Pressure cycling test**

Cylinder to be subjected to the extreme temperature cycle test. The following conditions to be applied:

- The cylinder to be filled with water
- Cylinder to be heated to 65 °C
- Environment is to be held above 95% relative humidity by spraying water mist on cylinder
- the cylinder to be allowed to acclimate to above conditions for 48 hours

After the acclimation period the cylinder to be tested for 10,000 cycles (500 cycles multiplied by no. of service life, 20 years) with the following upper and lower pressure limits:

Upper Limit  $p_{max} = 260$  bar

Lower limit  $p_{min} = 20$  bar

Then the water in the cylinder to be replaced with hydraulic oil and the cylinder to be cooled to -40 °C. Another cycle test to be performed for an additional 10,000 cycles (500 cycles multiplied by no. of service life, 20 years) with the following upper and lower pressure limits:

Upper Limit  $p_{max} = 200$  bar

Lower limit  $p_{min} = 20$  bar

After both cycle tests are completed the cylinder to be ruptured for a burst test.

**Requirements:**

The cylinder has to remain leak-tight for the 10,000 cycles at 65 °C and for the 10,000 cycles at -40 °C. It also is not permitted to show signs of fibre fracture, nor is the cylinder permitted to rupture during these tests except the rupture test.

**a) High Temperature Creep test**

This test is required for all type CNG 4 designs, and all type CNG-2 and CNG-3 designs in which the glass transition temperature of the resin matrix does not exceed 102°C.

One finished cylinder shall be tested as follows:

- i. The cylinder shall be pressurized to 260 bar and held at a temperature of 100°C for not less than 200 h;
- ii. Following the test, the cylinder shall meet the requirements of the hydrostatic expansion test, the leak test and the hydrostatic pressure burst test

**b) Accelerated Stress Rupture test**

For type CNG-2, CNG-3 and CNG-4 designs only, one cylinder shall be hydrostatically pressurized to 260 bar at 65°C. The cylinder shall be held at this pressure and temperature for 1000 h. The cylinder shall then be pressured to burst and achieve a **minimum burst pressure of 85%** of the minimum design burst pressure.

**c) Impact Damage Test (Drop Test)**

An unpressurized cylinder to be dropped from a height of 1.8 m measured at the bottom of the cylinder. The same cylinder to be dropped vertically on both ends at a sufficient height above the floor so that the potential energy is 488 Joules, but the height of the lower end to be greater than 1.8 m. The same cylinder again to be dropped at 1.8 m at an angle of 45° from its center of gravity.

Then the cylinder to be subjected to a pressure cycle test of 20,000 cycles. The upper and lower pressure limits are as follows:

Upper Limit  $p_{max} = 260$  bar

Lower limit  $p_{min} = 20$  bar

**Requirements:**

The cylinder is permitted to leak but not to rupture.

One or more finished cylinders shall be drop tested at ambient temperature without internal pressurization. One cylinder shall be dropped in a horizontal position with the bottom 1.8 m above the surface on to which it is dropped.

One cylinder shall be dropped vertically on each end at a sufficient height above the floor or pad so that the potential energy is 488 J but in no case shall the height of the lower end be greater than 1.8 m. One cylinder shall be dropped at a 45° angle on to a dome, from a height such that the centre of gravity is at 1.8 m;

Following the drop impact the cylinders shall be pressure cycled between 20 bar and 260 bar at ambient temperature, initially for 3000 cycles, then followed by an additional 12 000 cycles.

The cylinder shall not leak or rupture within the first 3000 cycles, but may fail by leakage during the further 12000 cycles.

**d) Permeation Test**

Type 4 tanks have low gas permeability & perform without leakage. Leak tightness are verified on every tank by helium leak test at service pressure

There are designs of Type-4 cylinders that have met acceptance criteria for production leak test 100 times lower than NGV2 allowable permeation, equivalent to less than 0.5 psi pressure reduction in one year.

This test is only required on Type CNG-4 designs. One finished cylinder shall be filled with compressed natural gas to working pressure, placed in an enclosed sealed chamber at ambient temperature, and monitored for leakage for 500 h. The permeation rate shall be less than 0.25 ml of natural gas per hour per litre water capacity of the cylinder.

The cylinder shall be sectioned and the internal surfaces inspected for any evidence of cracking or deterioration.

### **e) Flaw Tolerance Test**

One finished cylinder complete with protective coating, shall have flaws cut into the composite in the longitudinal direction. The flaws shall be greater than the visual inspection limits as specified by the manufacturer.

One flaw shall be 25 mm long and 1.25 mm in depth, another flaw shall be 200 mm long and 0.75 mm in depth cut in the longitudinal direction into the cylinder sidewall.

The flawed cylinder shall then be pressure cycled between 20 bar and 260 bar at ambient temperature, initially for 3000 cycles then followed by an additional 12000 cycles

### **f) Acid environment test**

On a finished cylinder the following test procedure shall be applied

-expose a 150 mm diameter area on the cylinder surface for 100 h to a 30 % sulphuric acid solution whilst the cylinder is hydrostatically pressurized to 260 bar;

-pressurized the cylinder to burst: the burst pressure shall exceed 85% of the minimum design burst pressure.

Different chemicals can be used:

- Road salt
- Battery acid
- Gasoline
- Fertilizer solution

*Figure 4: Acid Environment test*



### **g) Ambient Temperature Pressure Cycle test**

The ambient cycle test to be conducted on two cylinders with water at room temperature. The number of cycles to be less than 10 per minute. The upper and lower pressure limits to be as follows:

Upper Limit  $p_{max} = 260$  bar

Lower limit  $p_{min} = 20$  bar

#### **Requirements:**

The cylinder to sustain a minimum of 20,000 cycles without leakage. After 20,000 cycles the cylinder is permitted to leak but not rupture. The test shall be stopped after 45,000 cycles.

### **h) Burst test**

The cylinders to be pressurized with water at room temperature until burst.

### **i) Bon-fire Test**

The bonfire test to be conducted on two cylinders outfitted with the safety devices such as Pressure relief device (fusible plug), Automatic cylinder valve with PRD integrated

The following conditions to be applied to cylinder # 5:

- Horizontal mounting
- Pressurized to 52 bar with methane
- Ignition of fuel until safety device vents cylinder
- Fuel: propane, coverage of propane fire: 1.65m x 0.84m.
- Distance of tanks above fire: 0.1 m.

The following conditions to be applied to cylinder # 6:

- Horizontal mounting
- Pressurized to 212 bar with methane
- Ignition of fuel until safety device vents cylinder
- Fuel: propane, coverage of propane fire: 1.65m x 0.84m.
- Distance of tanks above fire: 0.1 m.

**Requirements:**

No rupture.

**j) Internal/External Corrosion**

Due to all polymeric structure with non corroding materials (liner and composite) composite tanks have excellent resistance to corrosive fluids and environmental conditions

**k) Chemical and UV Resistance**

Carbon/glass fiber and formulated resin are not affected by acid, bases, solvents, salts or UV.

**l) Fatigue in cycling**

Type 4 Tanks are normally cycled for over 1,000,000 cycles without leak or rupture and 1,00,000 times after impact damage without leak or rupture. Plastic liner is in compression when tank is pressurized, significantly limiting crack formation and growth. NO cycle failures in service.

### **m) Overpressure during Filling or due to temperature changes**

1 degree C temperature change relates to 1.5 bar pressure change. Typical burst pressure in lot sample testing exceeds 600 bar with 200 bar service pressure.

### **n) Impact and Abrasion**

Even in the case of heavy accidents, NO reported leak or explosion in the history of composite cylinders. Damage tolerance is addressed by performance testing:

- Penetration (Gunfire)
  - 7.68 mm armour piercing bullet must completely penetrate wall
  - Tank cannot rupture as result of wall penetration
- Drop test
- Impact from objects
- Flaw tolerance

## IX. Fire Protection of Type 4 Tanks (Pressure Relief Valves)

In fire, composite cylinders have a restricted heat transfer capability due to the insulating performance of the composites. The following rules therefore apply for the system design:

- PRDs have to perform with min. 6 mm internal opening
- Melting PRDs have to stay safely open during discharge of the gas - alternative glass bulb
- The likely path of fire has to be protected (e.g. on buses with emergency exits on the roof)

*Figure 5: Pressure Relief Valve*





## X. Type 4 Cylinder Manufacturers' Profiles

### Ragasco & Lincoln Composites

Ragasco& Lincoln composites are part of M/s. Hexagon Composites, a Norway based company. It has plants both in Norway & USA. Experienced in making composite cylinders since 1963 and Type-4 cylinders since 1993.Over 1, 50,000 cylinders are in operation globally. Following are some of the products of M/s. Ragasco& M/s. Lincoln Composites:

1. TUFFSHELL™
2. LIGHTSTORE™
3. TITAN (for bulk transport of CNG)

Following Table provides the comparison of the first two products.

*Table 13: Comparison of TUFFSHELL & LIGHTSTORE*

<b>Criteria</b>	<b>The TUFFSHELL™</b>	<b>The LIGHTSTORE™</b>
<b>Volume</b>	100 L to 8,400 L	12 L to 100 L
<b>Service Pressure</b>	200 bar to 1,050 bar	200 bar to 350 bar
<b>Weight Ratio vs. steel</b>	0.28 to 0.35	
<b>Mounting</b>	Neck and Strap	Strap
<b>Applications</b>	Bus/HCV/Gas transport	Passenger car/LCV (high serial production)

## *Global requirements*

### **XI. Comparison of Test Requirements in Different Countries**

*Table 14: Comparison of worldwide standards on Composite Cylinders*

Title	Automotive Cylinders NGV			Transportable Cylinders		Note
	ECE R-110	ISO 11439	NGV 2-2007 CSA B51 - Part 2	EN 12245	ISO 11119-3	
Burst	Glas 2, 75 x working pressure Carbon 2, 35 x working pressure Aramid 2,35 x working pressure Hybrid tbd. according stress ratio	Glas 2, 75 x working pressure Carbon 2, 35 x working pressure Aramid 2,35 x working pressure Hybrid tbd. according stress ratio	Glas 2, 75 x working pressure Carbon 2, 35 x working pressure Aramid 2,35 x working pressure Hybrid tbd. according stress ratio	2 x test pressure	2 x test pressure	<u>EN 12245 / ISO 11119-3</u> : scope one burst pressure for all ("easy to use") <u>ECE/NGV/ISO 11439 etc.</u> : automotive regulations provide the different degradations of the different winding materials over lifetime
Pressure Cycling	2 to 20 Mpa, Cycles according lifetime	2 to 20 Mpa, Cycles according lifetime	2 to 20 Mpa, Cycles according lifetime	2 to 30 Mpa, Cycles according lifetime	2 to 30 Mpa, Cycles according lifetime	-
Chemical resistance	battery acid	battery acid	battery acid	salt water	salt water	
Accelerated stress rupture test	30 MPa, 1000h @ 65°C	30 MPa, 1000h @ 65°C	30 MPa, 1000h @ 65°C	30 MPa, 1000h @ 70°C	30 MPa, 1000h @ 70°C	-

Title	Automotive Cylinders NGV			Transportable Cylinders		Note
	ECE R-110	ISO 11439	NGV 2-2007 CSA B51 - Part 2	EN 12245	ISO 11119-3	
Drop test	3 directions (1 or 3 Cylinders) after drop Cycling	3 directions (1 or 3 Cylinders) after drop Cycling	3 directions (1 or 3 Cylinders) after drop Cycling	6 directiones (2 Cylinders), watterfilled, 1 Cylinder burst, 1 Cylinder Cycling	6 directiones (2 Cylinders), watterfilled, 1 Cylinder burst, 1 Cylinder Cycling	<u>differences depends on the different usage</u> portable Cylinder: Drop during use = normal therefore water filled cylinders automotive Cylinders: Drop during mounting = normal therefore empty cylinders
Composite flaw tolerance tests	1 chamfer 25mm long, 1.25 mm deep 1 chamfer 200mm long, 0.75mm deep	1 chamfer 25mm long, 1.25 mm deep 1 chamfer 200mm long, 0.75mm deep	1 chamfer 25mm long, 1.25 mm deep 1 chamfer 200mm long, 0.75mm deep	2 chamfers radial and axial 120° 5 x wallthickness long 40% wallthickness deep	2 chamfers radial and axial 120° 5 x wallthickness long 40% wallthickness deep	<u>differences depends on the different usage</u> portable Cylinder: unprotected use automotive Cylinders: protected area in the car
Pressure Cycling under extreme conditiones	48 h @65 °C and 95% humidity 500 x Lifetime Cycles @+65°C 48 h @-40 °C 500 x Lifetime Cycles @-40°C Burst (0,85 x burst pressure of the virgin cylinders)	48 h @65 °C and 95% humidity 500 x Lifetime Cycles @+65°C 48 h @-40 °C 500 x Lifetime Cycles @-40°C	48 h @65 °C and 95% humidity 500 x Lifetime Cycles @+65°C 48 h @-40 °C 500 x Lifetime Cycles @-40°C	Vacuum Cycle @60°C 48 h @60 °C and 95% humidity 500 x Lifetime Cycles @+65°C 48 h @-40 °C 500 x	Vacuum Cycle @60°C 48 h @60 °C and 95% humidity 500 x Lifetime Cycles @+65°C 48 h @-40 °C 500 x	<u>differences depends on the different usage</u> portable Cylinder: can be complete empty  automotive Cylinders: cannot be complete empty

Title	Automotive Cylinders NGV			Transportable Cylinders		Note
	ECE R-110	ISO 11439	NGV 2-2007 CSA B51 - Part 2	EN 12245	ISO 11119-3	
		Burst (0,85 x burst pressure of the virgin cylinders)	Burst (0,85 x burst pressure of the virgin cylinders)	Lifetime Cycles @-40°C Burst (0,85 x burst pressure of the virgin cylinders)	Lifetime Cycles @-40°C Burst (0,85 x burst pressure of the virgin cylinders)	
Fire resistance test	working pressure Fire 1.65 m long >590°C	working pressure Fire 1.65 m long >590°C	working pressure Fire 1.65 m long >590°C	working pressure Fire over the hole length if possible >590°C	working pressure Fire over the hole length if possible >590°C	-
Gunfire	working pressure 45°, caliber 7.62 mm	working pressure 45°, caliber 7.62 mm	working pressure 45°, caliber 7.62 mm	working pressure 45°, caliber 7.62 mm	working pressure 45°, caliber 7.62 mm	-
Permeation	0.25 Ncm <sup>3</sup> /h and Liter Volume of the Cylinder	0.25 Ncm <sup>3</sup> /h and Liter Volume of the Cylinder	0.25 Ncm <sup>3</sup> /h and Liter Volume of the Cylinder	0.25 Ncm <sup>3</sup> /h and Liter Volume of the Cylinder	0.25 Ncm <sup>3</sup> /h and Liter Volume of the Cylinder	-
turning moment	-	-	-	110% maximum allowable turning moment	-	-
Torque test on cylinder neck boss	200% maximum allowable turning moment	200% maximum allowable turning moment	200% maximum allowable turning moment	150% maximum allowable turning moment	150% maximum allowable turning moment	-
Pneumatic	1000 Cycles	1000	1000	-	100 Cycles	-

Title	Automotive Cylinders NGV			Transportable Cylinders		Note
	ECE R-110	ISO 11439	NGV 2-2007 CSA B51 - Part 2	EN 12245	ISO 11119-3	
Cycling	CH <sub>4</sub>	Cycles CH <sub>4</sub>	Cycles CH <sub>4</sub>			
creep test	200h @100°C @26MPa	200h @100°C @26MPa	-	-	-	-

## 1. Composite Cylinder Safety –Field Experiences

3 incidents are illustrated which shows composite cylinders are much safer than metal gas cylinders.

### a) Bridge Impact

- Bus speed approx 70 Kmph
- Type 4 cylinders mounted transversal on roof
- Interference with bridge was 15 Cms
- Front tank was severely damaged
  - No rupture
  - Vehicle travelled 100 ft past
- Tank was burst tested after incident
  - Minimum requirement was 559 bar
  - Burst pressure achieved was 597 bar

*Figure 6: Bridge Impact*





## b) Under Vehicle Installation – Curb Hit

- Tank Dropped from, dragged by and over run by heavy duty vehicle
- Visible damage to Dome
- Cylinder still met burst requirements

*Figure 7: Curb Hit*





### c) Rear Impact

- Rear impact Type 4 CNG tank mounted in trunk
- Impacted by fully loaded gasoline transport
- No leakage or rupture
- Investigator stated that tank strength likely saved the driver's life

*Figure 8: Rear Impact*





## d) Bon fire

- Partial insulation or immersion of the PRD side of the cylinder has to be accounted for and has been simulated in OEM bonfire testing
- Even when tested by GM with no PRD and with fire at one end, cylinder did NOT BURST – This demonstrates the highest level of safety

*Figure 9: Bonfire Testing*



## **XII. Global CNG Gas Cylinder Industry -Background and Characteristics**

High pressure composite vessels were introduced more than 70 years before and were especially developed for space and military applications. The experimentation of composite vessels started in the 50s but the first high pressure vessels used for space and military applications started actually in the 60s in the US. In the late 1980's, experimental applications of composite reinforced plastic liners in CNG service occurred in Sweden, Russia and France. Following the development of natural gas vehicle cylinder standards in North America, fully-wrapped designs with relatively thin aluminum liners or plastic liners reinforced with a full wrapping of glass fiber and/or carbon fiber reinforcement were introduced into CNG service commencing in 1992.

### XIII. CNG Cylinder Standards in different countries:

*Table 15: CNG Cylinder Regulations in different countries*

Countries	Regulations / Standards
Germany, France, Italy, Netherlands, Sweden, Belgium, Hungary, Czech Republic, Spain , Serbia, Great Britain , Austria, Luxemburg, Switzerland, Norway, Finland, Denmark, Romania, Poland, Portugal Greece, Slovenia, Slovakia, Belarus, Estonia Bosnia and Herzegovina, Latvia, Bulgaria Lithuania, Turkey, Azerbaijan, Tunisia, European Union, South Africa, Cyprus, Malta South Korea, Thailand, Montenegro, Macedonia	ECER-110 ISO11439
New Zealand	AS/NZS 2739 ECE R-110 ISO 11439
Chile	Nch 2109
Japan	JGA NGV02
USA	ANSI/CSA NGV 2
Canada	CSA B51 Part 2
Brazil	ISO 11439
Mexico	NOM-004-SECRE
Australia	AS/NZS 2739 ECE R-110 ANSI/NGV 2 (US- Standard) CSA B51 (Canadian Regulation) ISO11439

## XIV. Global CNG Cylinder market

*Table 16: CNG Cylinder Market*

<b>CNG Cylinder Market</b>					
<b>Sl No</b>	<b>Country Name</b>	<b>Type I</b>	<b>Type II</b>	<b>Type III</b>	<b>Type IV</b>
1	Algeria	√	X	X	X
2	Argentina	√	√	√	X
3	Austria	√	√	X	X
4	Belgium	√	√	X	X
5	Brazil	√	X	X	X
6	Chile	√	X	X	X
7	Croatia	√	X	X	X
8	Egypt	√	X	X	X
9	Finland	X	X	√	X
10	France	√	√	X	√
11	Germany	√	√	√	X
12	India	√	X	X	X
13	Iran	√	X	X	X
14	Italy	√	√	X	X
15	Japan	√	X	√	√
16	Macedonia	√	X	X	X
17	Malaysia	√	√	X	√
18	Netherlands	√	X	X	√
19	Poland	√	√	X	X
20	Russia	√	√	√	√
21	Spain	√	X	X	X
22	Sweden	√	√	√	√
23	Switzerland	√	X	X	√

<b>Country</b>	<b>Type 4 Allowed?</b>	<b>Type 4 Used?</b>
Albania	<b>YES</b>	<b>YES</b>
Antilles, Netherlands	<b>YES</b>	<b>YES</b>
Arabia, Saudi	<b>YES</b>	<b>YES</b>
Argentina	<b>YES</b>	<b>NO</b>
Australia	<b>YES</b>	<b>YES</b>
Austria	<b>YES</b>	<b>YES</b>
Azerbaijan	<b>YES</b>	<b>YES</b>
Bahrain	<b>YES</b>	<b>YES</b>
Bangladesh	<b>NO</b>	<b>NO</b>
Belarus	<b>YES</b>	<b>YES</b>
Belgium	<b>YES</b>	<b>YES</b>
Bhutan	<b>NO</b>	<b>NO</b>
Bolivia	<b>YES</b>	<b>NO</b>
Bosnia and Herzegovina	<b>YES</b>	<b>YES</b>
Brazil	<b>YES</b>	<b>NO</b>
British Virgin Islands	<b>YES</b>	<b>YES</b>
Brunei Darussalam	<b>YES</b>	<b>NO</b>
Bulgaria	<b>YES</b>	<b>YES</b>
Cambodia	<b>YES</b>	<b>NO</b>
Canada	<b>YES</b>	<b>YES</b>
Chile	<b>YES</b>	<b>NO</b>
China	<b>NO</b>	<b>NO</b>
Christmas Island	<b>YES</b>	<b>YES</b>
Colombia	<b>YES</b>	<b>YES</b>
Croatia	<b>YES</b>	<b>YES</b>
Cyprus	<b>YES</b>	<b>YES</b>
Czech Republic	<b>YES</b>	<b>YES</b>
Denmark	<b>YES</b>	<b>YES</b>
Dominican Republic	<b>YES</b>	<b>YES</b>
Egypt	<b>YES</b>	<b>YES</b>
Estonia	<b>YES</b>	<b>YES</b>
Falkland Islands (Malvinas)	<b>YES</b>	<b>YES</b>
Finland	<b>YES</b>	<b>YES</b>
France	<b>YES</b>	<b>YES</b>
French Guiana	<b>YES</b>	<b>YES</b>
French Polynesia	<b>YES</b>	<b>YES</b>
French Southern Territories - TF	<b>YES</b>	<b>YES</b>
Georgia	<b>YES</b>	<b>YES</b>
Germany	<b>YES</b>	<b>YES</b>
Greece	<b>YES</b>	<b>YES</b>
Greenland	<b>YES</b>	<b>YES</b>
Guiana, French	<b>YES</b>	<b>YES</b>

Heard and McDonald Islands	<b>YES</b>	<b>YES</b>
Hong Kong, (China)	<b>NO</b>	<b>NO</b>
Hungary	<b>YES</b>	<b>YES</b>
Iceland	<b>YES</b>	<b>YES</b>
India	<b>NO</b>	<b>NO</b>
Indonesia	<b>YES</b>	<b>YES</b>
Ireland	<b>YES</b>	<b>YES</b>
Israel	<b>YES</b>	<b>YES</b>
Italy	<b>YES</b>	<b>YES</b>
Japan	<b>YES</b>	<b>YES</b>
Kazakhstan	<b>YES</b>	<b>YES</b>
Korea, (South) Republic of	<b>YES</b>	<b>YES</b>
Kuwait	<b>YES</b>	<b>YES</b>
Lao People's Democratic Republic	<b>YES</b>	<b>NO</b>
Latvia	<b>YES</b>	<b>YES</b>
Lebanon	<b>YES</b>	<b>YES</b>
Liechtenstein	<b>YES</b>	<b>YES</b>
Lithuania	<b>YES</b>	<b>YES</b>
Luxembourg	<b>YES</b>	<b>YES</b>
Macedonia, TFYR	<b>YES</b>	<b>YES</b>
Malaysia	<b>YES</b>	<b>YES</b>
Maldives	<b>YES</b>	<b>YES</b>
Malta	<b>YES</b>	<b>YES</b>
Man, Isle of	<b>YES</b>	<b>YES</b>
Mexico	<b>YES</b>	<b>YES</b>
Moldova, Republic of	<b>YES</b>	<b>YES</b>
Monaco	<b>YES</b>	<b>YES</b>
Mongolia	<b>YES</b>	<b>YES</b>
Montenegro	<b>YES</b>	<b>YES</b>
Montserrat	<b>YES</b>	<b>YES</b>
Morocco	<b>YES</b>	<b>YES</b>
Myanmar (ex-Burma)	<b>YES</b>	<b>NO</b>
Nepal	<b>NO</b>	<b>NO</b>
Netherlands (Holland)	<b>YES</b>	<b>YES</b>
Netherlands Antilles	<b>YES</b>	<b>YES</b>
New Caledonia	<b>YES</b>	<b>YES</b>
New Zealand	<b>YES</b>	<b>YES</b>
Nicaragua	<b>YES</b>	<b>YES</b>
Nigeria	<b>YES</b>	<b>YES</b>
Norway	<b>YES</b>	<b>YES</b>
Peru	<b>YES</b>	<b>YES</b>
Philippines	<b>YES</b>	<b>NO</b>
Poland	<b>YES</b>	<b>YES</b>
Portugal	<b>YES</b>	<b>YES</b>
Puerto Rico	<b>YES</b>	<b>YES</b>

Qatar	<b>YES</b>	<b>YES</b>
Romania	<b>YES</b>	<b>YES</b>
Russia (Russian Federation)	<b>YES</b>	<b>YES</b>
San Marino	<b>YES</b>	<b>YES</b>
Saudi Arabia	<b>YES</b>	<b>YES</b>
Serbia	<b>YES</b>	<b>YES</b>
Singapore	<b>YES</b>	<b>YES</b>
Slovakia	<b>YES</b>	<b>YES</b>
Slovenia	<b>YES</b>	<b>YES</b>
Solomon Islands	<b>YES</b>	<b>YES</b>
South Africa	<b>YES</b>	<b>YES</b>
S. Georgia and S. Sandwich Is.	<b>YES</b>	<b>YES</b>
Spain	<b>YES</b>	<b>YES</b>
Sri Lanka	<b>NO</b>	<b>NO</b>
Svalbard and Jan Mayen Islands	<b>YES</b>	<b>YES</b>
Sweden	<b>YES</b>	<b>YES</b>
Switzerland	<b>YES</b>	<b>YES</b>
Taiwan	<b>NO</b>	<b>NO</b>
Thailand	<b>YES</b>	<b>YES</b>
Trinidad & Tobago	<b>YES</b>	<b>NO</b>
Tunisia	<b>YES</b>	<b>YES</b>
Turkey	<b>YES</b>	<b>YES</b>
Ukraine	<b>YES</b>	<b>YES</b>
United Arab Emirates	<b>YES</b>	<b>YES</b>
United Kingdom	<b>YES</b>	<b>YES</b>
United States	<b>YES</b>	<b>YES</b>
US Minor Outlying Islands	<b>YES</b>	<b>YES</b>
Vatican City State (Holy See)	<b>YES</b>	<b>YES</b>
Viet Nam	<b>YES</b>	<b>YES</b>
Virgin Islands, British	<b>YES</b>	<b>YES</b>
Virgin Islands, U.S.	<b>YES</b>	<b>YES</b>

## **XV. Companies manufacturing Type 4 Cylinders:**

- Xperion (Germany)
- MCS (Germany)
- Hexagon (Norway, Canada) with Ragasco& Lincoln brand
- Ullit (France)
- Dynetek Industries (Canada)
- Worthington (U.S.)
- KCR (S.-Korea)
- Various Chinese supplier (not known in detail)
- Magna Steyr (Austria)

## **Penetration of Type-4 Composite Cylinders in Auto Industry**

Following are list of some Bus manufacturers who are using Type-IV gas cylinders:

- New Flyer (North America) since 1996
- Volvo (Europe) since 1999
- Eldorado (North America) since 1999
- Bredamenarini (Europe) since 2006
- Solaris (Europe) since 2006
- NABI (North America) since 2006
- Irisbus (Europe) since 2007



**Table 17: Type 4 Cylinder market position on city buses in Europe**

OEM	Main/sole supplier	Optional supplier	Remarks
<b>MAN</b>	Lincoln T4 (70%) standard offer	Dynetek T3 in Europe MCS T4 for Australia	Since 2007
<b>DAIMLER/EVOBUS</b>	MCS T4 (100%)	-	
<b>VOLVO BUS</b>	Lincoln T4 (100%)	-	Since 1999
<b>IRISBUS/IVECO</b>	Lincoln T4 (70%) standard offer	Dynetek T3	Since 2007
<b>SOLARIS</b>	Lincoln T4 (100%)	-	Since 2006
<b>BREDAMENARINI</b>	Lincoln T4 (80%) standard offer	Dynetek T3	Since 2006

**Table 18: Type 4 Cylinder market position on city buses in North America**

OEM	Main/sole supplier	Optional supplier	Remarks
<b>NABI</b>	Lincoln T4 (98%) standard offer	None	Since 2006
New Flyer Bus	Lincoln T4 (100%) standard offer	None	Since 1996
ElDorado	Lincoln T4 (100%)	None	Since 1999
Daimler NA/Orion*	SCI T3, Luxfer T3	Dynetek T3	Since 2001

\* Less than 5% of overall market capacity

Following are some of the brands that are using Type-4 cylinders:

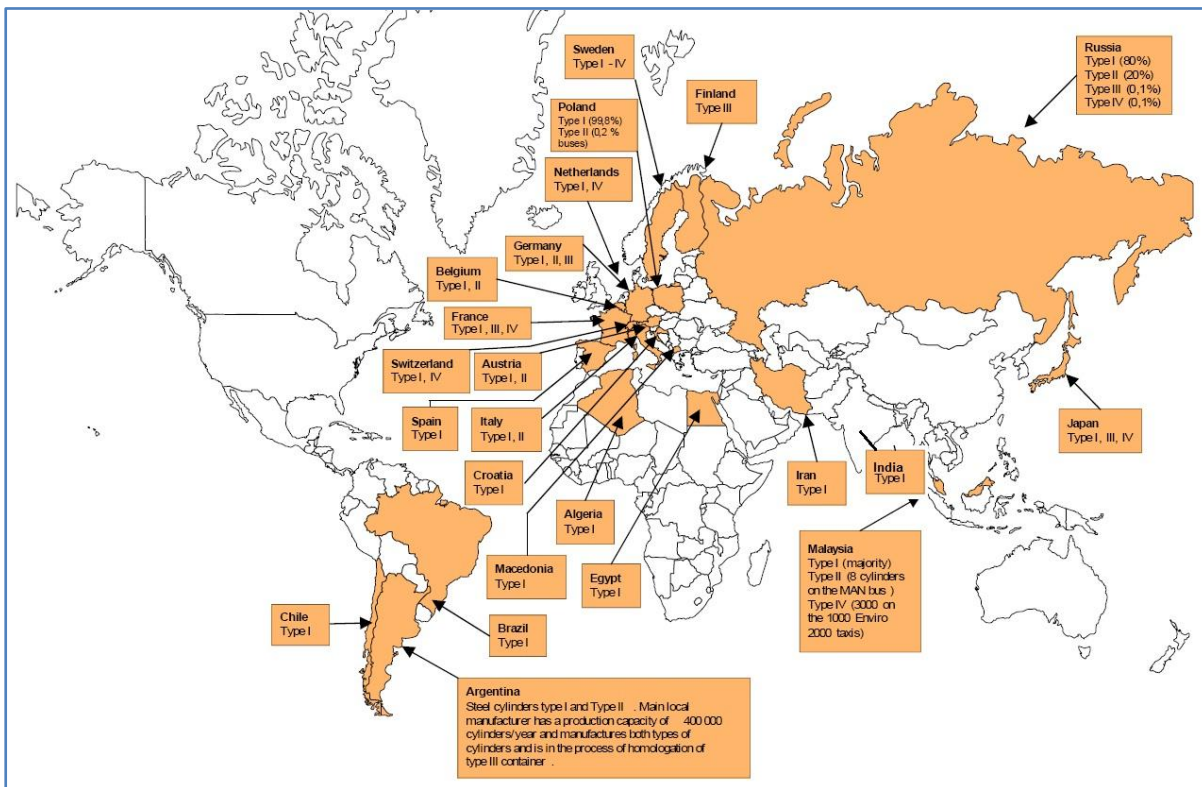
Figure 10: Brands using Type 4 Composite Cylinders



## Global CNG Gas Cylinder Market

Following figure shows the global overview of CNG cylinder technologies in different countries. Many countries are allowing Type 4 cylinders.

Figure 11: Geographical overview of CNG Cylinder Market (Cylinder Type-wise)



## 1. Natural Gas Vehicles data for IANGV:

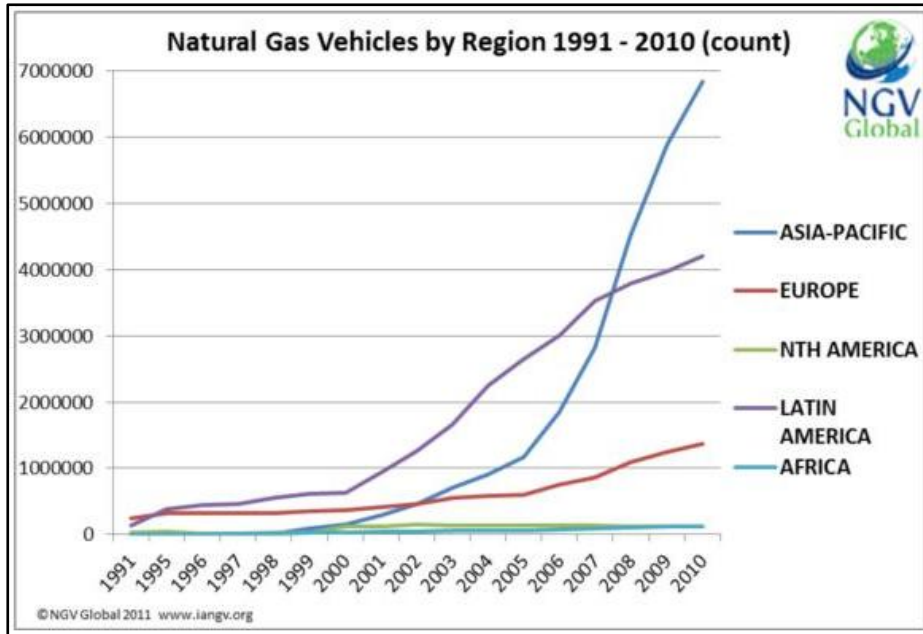
*Table 19: Population of NGV's and Refuelling stations*

	<b>Belgium</b>	<b>Natural Gas Vehicles</b>	<b>Refuelling Stations</b>	<b>Data Year</b>	<b>Month data received</b>
<b>1</b>	<b>Pakistan</b>	2,740,000	3,285	2010	December
<b>2</b>	<b>Iran</b>	1,954,925	1,574	2010	December
<b>3</b>	<b>Argentina</b>	1,901,116	1,878	2010	September
<b>4</b>	<b>Brazil</b>	1,664,847	1,725	2010	December
<b>5</b>	<b>India</b>	1,080,000	571	2010	December
<b>6</b>	<b>Italy</b>	730,000	790	2010	December
<b>7</b>	<b>China</b>	450,000	1,350	2009	December
<b>8</b>	<b>Colombia</b>	340,000	614	2010	December
<b>9</b>	<b>Thailand</b>	218,459	426	2010	November
<b>10</b>	<b>Ukraine</b>	200,000	285	2006	December
<b>11</b>	<b>Bangladesh</b>	193,521	546	2010	December
<b>12</b>	<b>Bolivia</b>	140,400	156	2010	December
<b>13</b>	<b>Egypt</b>	122,271	119	2009	December
<b>14</b>	<b>United States</b>	112,000	1,000	2010	December
<b>15</b>	<b>Peru</b>	103,712	137	2010	December
<b>16</b>	<b>Armenia</b>	101,352	297	2010	October
<b>17</b>	<b>Russia</b>	100,000	244	2009	December
<b>18</b>	<b>Germany</b>	91,500	900	2010	December
<b>19</b>	<b>Bulgaria</b>	60,270	81	2009	June
<b>20</b>	<b>Uzbekistan</b>	47,000	133	2010	June
<b>21</b>	<b>Malaysia</b>	46,701	159	2010	June
<b>22</b>	<b>Venezuela</b>	43,000	144	2010	December
<b>23</b>	<b>Japan</b>	39,623	342	2010	September
<b>24</b>	<b>Sweden</b>	32,000	155	2010	December
<b>25</b>	<b>Korea, South</b>	28,628	165	2010	December
<b>26</b>	<b>Myanmar (Burma)</b>	22,821	38	2008	December
<b>27</b>	<b>France</b>	12,450	125	2008	December
<b>28</b>	<b>Canada</b>	12,000	80	2009	December

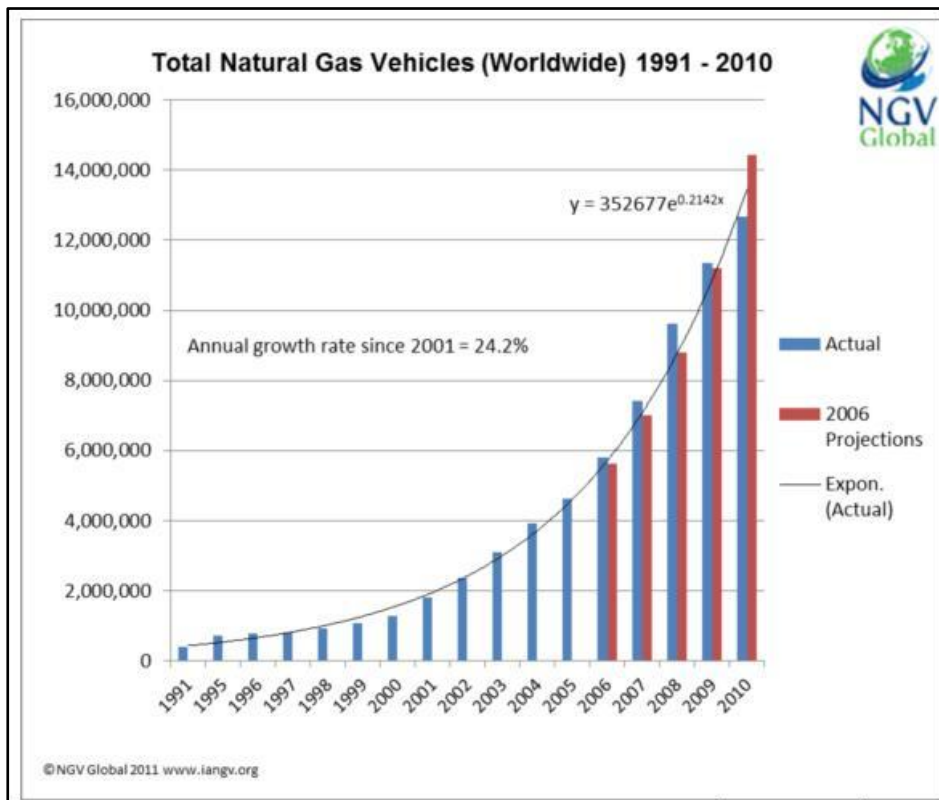
29	Tajikistan	10,600	53	2006	December
30	Switzerland	9,600	126	2010	December
31	Kyrgyzstan	6,000	6	2007	March
32	Austria	5,611	223	2009	December
33	Belarus	5,500	24	2006	December
34	Singapore	5,348	4	2010	December
35	Moldova	5,000	14	2006	December
36	Trinidad and Tobago	4,500	9	2010	December
37	Chile	4,061	15	2010	December
38	Turkey	3,056	12	2010	January
39	Mexico	3,037	3	2005	October
40	Georgia	3,000	42	2007	December
41	Australia	2,750	47	2007	March
42	Czech Republic	2,700	33	2010	December
43	Spain	2,539	44	2010	December
44	Poland	2,106	32	2010	January
45	Indonesia	2,000	9	2006	October
46	Netherlands	1,502	56	2010	December
47	Dominican Republic	1,200	3	2010	October
48	Finland	700	13	2009	December
49	Greece	520	2	2009	August
50	Slovakia	426	7	2008	December
51	Portugal	407	5	2008	December
52	Norway	375	10	2010	December
53	United Arab Emirates	305	2	2010	December
54	Vietnam	282	3	2010	December
55	Mozambique	251	2	2010	December
56	United Kingdom	221	12	2007	March
57	Serbia	210	7	2007	December

58	<b>Luxembourg</b>	203	7	2009	July
59	<b>New Zealand</b>	201	14	2007	February
60	<b>Kazakhstan</b>	200	1	2010	December
61	<b>Latvia</b>	200	1	2010	December
62	<b>Belgium</b>	176	5	2010	December
63	<b>Croatia</b>	152	1	2008	December
64	<b>Lithuania</b>	133	2	2009	June
65	<b>Algeria</b>	125	3	2004	October
66	<b>Hungary</b>	110	13	2006	April
67	<b>Liechtenstein</b>	101	1	2007	February
68	<b>Iceland</b>	77	1	2007	December
69	<b>Nigeria</b>	60	3	2005	May
70	<b>Macedonia</b>	50	1	2007	March
71	<b>Cuba</b>	45	1	2001	December
72	<b>Philippines</b>	36	3	2006	February
73	<b>Tunisia</b>	34	2	2007	August
74	<b>Tanzania</b>	31	1	2009	December
75	<b>South Africa</b>	22	1	2005	December
76	<b>Uruguay</b>	20	-	2008	December
77	<b>Bosnia &amp; Herzegovina</b>	7	-	2007	February
78	<b>Montenegro</b>	6	-	2006	March
79	<b>Korea, North</b>	4	1	2006	December
80	<b>Taiwan</b>	4	1	2005	April
81	<b>Ireland</b>	2	1	2008	September
82	<b>Denmark</b>	-	1	2007	May
	<b>Total</b>	<b>12,674,402</b>	<b>18,202</b>		

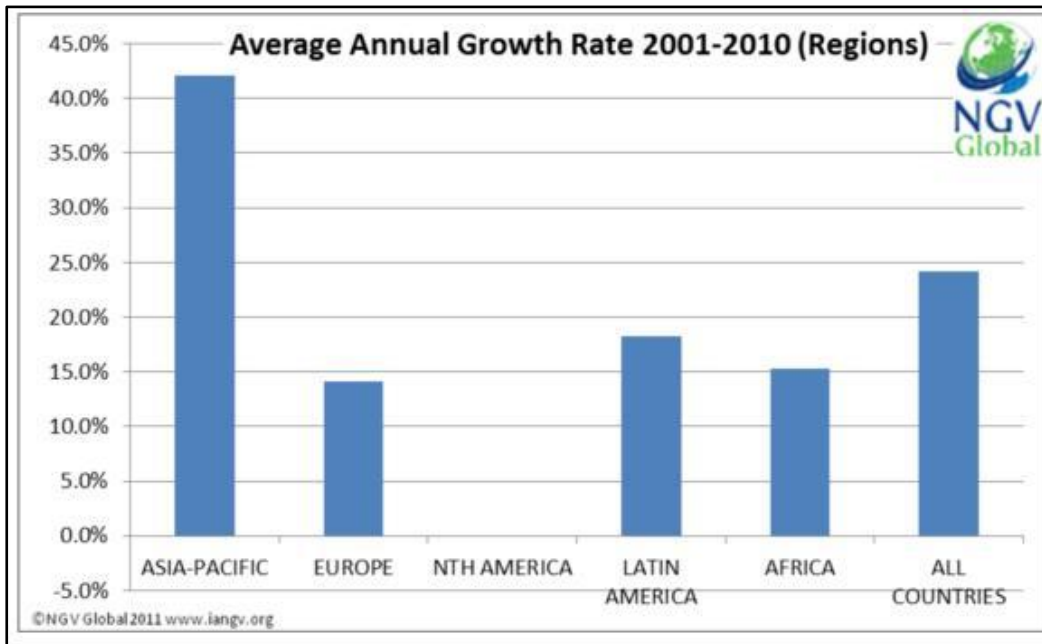
*Figure 12: Natural Gas Vehicle Count by Region (1991-2010)*



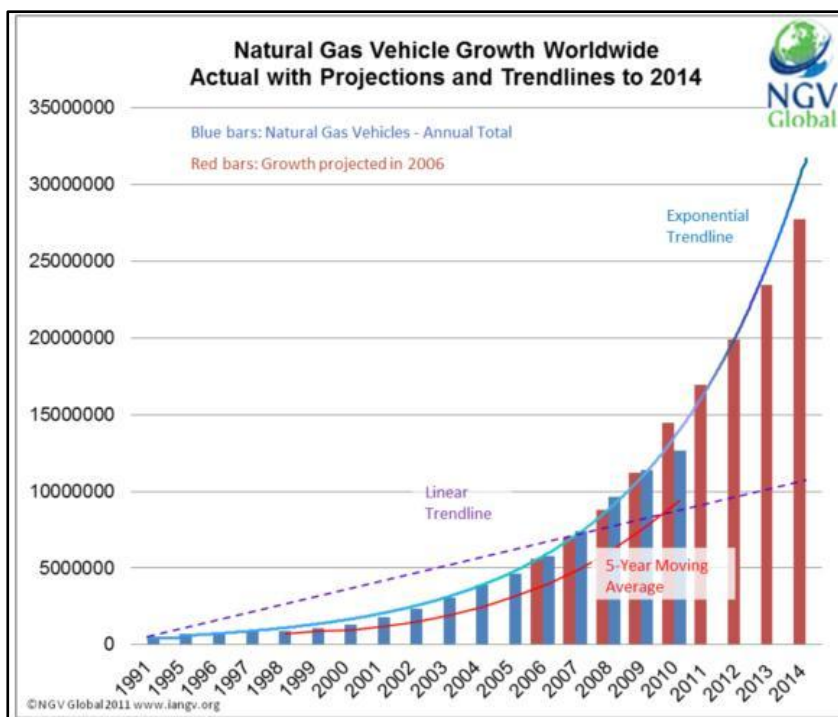
*Figure 13: Actual and Projected Volumes of NGV's*



*Figure 14: Average annual growth rate of NGV's by region*



*Figure 15: NGV Growth projection till 2014*



## XVI. New generation of Type IV CNG cylinders

### New Type IV cylinder technologies

- Use of the latest filament winding technologies
- New resin systems developed
- New fibre glass grades developed by 3B:
  - a. on Advantex® E-CR glass (corrosion resistance)
  - b. on HiPer-tex™ fibre (High mechanical performance & corrosion resistance)

*Figure 16 A: New Type IV cylinder technologies*

<p>HYBRID* Carbon &amp; Glass</p>		<p>Carbon fibre (15%) 3B's Advantex® Glass</p>
<p>Manufacturer: XPerion GmbH (Germany)</p>		<p>✓ R110 Certified ✓ 0,47 kg/l ✓ 60% lighter than steel</p>

\* Includes thermoplastic liner

Advantex® is a registered trademark of Owens Corning used under license



Figure 16 B: New Type IV cylinder technologies

 <p>HiPer-tex™ Glass*</p>	 <p>HiPer tex highperformance fibre</p>
<p>Manufacturer: GASTANK (Sweden)</p>	
<p>✓ R110 Certified ✓ 0,53 kg/l ✓ 55% lighter than steel ✓ US Composite Industry Award in 2011</p>	<p>☐ + 30% Strength ☐ + 17% Stiffness ☐ x 10 Fatigue ☐ Corrosion Resistant</p>

\* Includes thermoplastic liner

HiPer-tex™ is a trademark of 3B the fibreglass company

Figure 16 C: New Type IV cylinders on the road

### SPORTS CAR (Volkswagen Scirocco NGV GT 24 )



Cylinder: XPerion (Germany)

Glass fibre: 3B's Advantex®



Advantex® is a registered trademark of Owens Corning used under license

*Figure 16 D: New Type IV cylinders on the road*

## GAS TRANSPORTATION



Cylinder: XPerion (Germany)

Glass fibre: 3B's Advantex®



Advantex® is a registered trademark of Owens Corning used under license

*Figure 16 E: New Type IV cylinders on the road*

## COMMERCIAL VAN (Iveco, Fiat)



Cylinder: Gastank (Sweden)



HiPer-tex™ is a trademark of 3B the fibreglass company

*Figure 16 F: New Type IV cylinders on the road*

PASSENGER CAR (Opel Astra, VW Golf)



Cylinder: Gastank (Sweden)

HiPer-tex™ is a trademark of 3B the fibreglass company

*Figure 16 G: New Type IV cylinders on the road*

## PASSANGER CAR (Renault Laguna)



Cylinder: Gastank (Sweden)

HiPer-tex™ is a trademark of 3B the fibreglass company

New Safe Type IV cylinders approved to ECE R110

- ❖ Glass Reinforced
- ❖ Possible Expertise & Technology transfers
- ❖ EU Regulations force OEMs to move to light weight
- ❖ Leverage on cylinder producers, globally

## *Legal requirements*

### **XVII. Indian & overseas regulatory requirements**

#### **NGV CYLINDER DESIGN STANDARDS DEVELOPMENT**

Up until the late 1970's countries adopted industrial gas cylinder standards to approve NGV cylinders for vehicle fuel storage. However it became apparent that these standards were not the best in terms of either safety or ensuring the optimum performance of the product. At that time new Italian regulations for lighter-weight high-strength steel cylinders were introduced and these proved to be very successful. Many hundreds of thousands of NGV Cylinders made to these Italian specifications have since been used in service around the world.

In North America, the large-scale conversion of vehicles to natural gas fuel commenced in the 1980's. In 1982, hoop wrapped cylinders made from aluminium liners and a glass fibre composite began to be used in NGV service. Steel cylinder manufacturers followed this trend to lighter-weight designs in 1985, producing steel hoop-wrapped cylinders with glass fibre reinforcement. These products were approved by exemption from the DOT, as no dedicated NGV cylinder standard was available.

**NZS 5454.** New Zealand published the first cylinder standard specifically for NGV service in 1989. Although this was mainly concerned with steel cylinders, it did allow for approval of hoop wrapped composite cylinders for the first time.

**CSA B51-1995.** In 1991 Canada issued the CSA B51-1991 Appendix G standard "Requirements for CNG Refuelling Station Pressure Piping Systems and Containers for CNG". This adopted a number of principles from NZS 5454, but also specifically allowed the use of fully wrapped composite cylinders for the first time in NGV service.

In 1994 after failures of composite-wrapped cylinders in NGV service in the US Canada revised their requirements based on the NGV2 1992 standard. The new document was reissued as the CSA B51-95 standard

**NGV2 – 2000.** In 1992, the US developed their ANSI/AGA NGV2 "American National Standard for Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers". This is a voluntary standard that was initiated by the industry when there were concerns about the lack of regulation for NGV cylinders. It was initially based on the DOT industrial standards for steel and aluminium and the DOT FRP standards for composite designs. In addition to defining the NGV cylinder service conditions and defining appropriate performance tests, the NGV2 standard was the first that defined testing specifically for Type 4 cylinders with plastic liners.

NGV2 was revised in 1998 and again in 2000. This documents is used where companies want to demonstrate that their cylinders are suitable for use over the life of the Natural Gas Vehicle and it has also been adopted as a regulation in various states including California. A number of the principles of NGV2 were used in the drafting of ISO 11439, and in turn, the draft of ISO 11439 was used in harmonizing the NGV2 2000 issue.

Japan's Ministry of Economy, Trade and Industry (METI) enacted regulations in March 1998 that have similar in requirements to NGV2-1998.

Canada now also accepts NGV cylinders produced to NGV2 2000.

**ISO 11439.** In 1987 ISO set up a working group to start development of a design safety standard for NGV cylinders but it would take until 2000 to be formally issued as ISO 11439 “Gas cylinders - High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles”

ISO 11439 took the US NGV2 standard as it’s starting point, but it was modified by consensus to accept the views of the industry in Europe and Asia. It provides a series of tests for type approval and batch approval of NGV cylinders, as well as guidance on cylinder design, service conditions and exterior environmental protection. A summary of the important tests and requirements is presented in the Section 4.

The finished document was first issued in September 2000 and this version has not been fully adopted by any country as yet, although the UN adopted a working draft of 11439 into the ECE R110 regulation. However since it’s development 11439 has been influential on a number of other standards around the world, as well as the new draft ISO standard for High-pressure Hydrogen Tanks for use on vehicles, ISO 15869.

**ECE R110.** This regulation was issued in 2000 by the United Nations to define “Uniform Provisions concerning the Approval of “Specific Components of Motor vehicles using Compressed Natural Gas (CNG) in their Propulsion System”. As the title suggests, this document considers all of the components in the fuelling system of Natural Gas Vehicles, including the CNG cylinders.

There are a number of differences between R110 and the final version of ISO 11439. The differences are not very significant, but a comparison between the two documents was issued by ISO as ISO TC58/SC3 document N1036. Ultimately there will be convergence between ISO 11439 and ECE R110, as was the original intention.

The original version of the ECE R110 was issued in December 2000 with a revised version issued on March 2001. This document is used to regulate NGV cylinders in the European Union, Brazil, Argentina and other countries. As yet the USA has not adopted this UN Regulation.

**FMVSS 304.**

In the USA cylinders used for fuel on NGV have to comply with the FMVSS 304 regulation of the National Highway Traffic Safety Administration (DOT-NHTSA). FMVSS has few prescriptive guidelines and relatively few performance tests, requiring only burst, cycle, bonfire, and permeation tests.

NHTSA regularly withdraws NGV cylinders from the field and ensures compliance with the regulation. Instances of non-compliance with the regulation can be seen at <http://www.nhtsa.dot.gov/cars/problems/comply/equfmvs2.dbm>

Over the past ten years there has been a growing consensus as to what constitutes a safe and reliable NGV cylinder and the national and international standards organizations have been working to harmonize the documents to ensure a high level of efficiency and a high degree of product safety. Complete harmonization has not been achieved however and there are still some differences between the three major NGV cylinder standards to be resolved.

➤ **ECE R 110**

*Specific components for vehicles of Categories M and N using compressed natural gas (CNG) in their propulsion system*

<b>CNG components classification</b>	<b>Working pressure and function</b>
Class 0	High pressure parts including tubes and fittings containing CNG at a pressure higher than 3 MPa and up to 26 MPa.
Class 1	Medium pressure parts including tubes and fittings containing CNG at a pressure higher than 450 kPa and up to 3,000 kPa (3 MPa).
Class 2	Low pressure parts including tubes and fittings containing CNG at a pressure higher than 20 kPa and up to 450 kPa.
Class 3	Medium pressure parts as safety valves or protected by safety valve including tubes and fittings containing CNG at a pressure higher than 450 kPa and up to 3,000 kPa (3 MPa).
Class 4	Parts in contact with gas subject to the pressure lower than 20 kPa.

➤ **Application for Approval:**

The application for approval of specific component or multifunctional component shall be submitted by the holder of the trade name or mark or by his duly accredited representative.

It shall be accompanied by the under-mentioned documents in triplicate and by the following particulars:

- ✓ description of the vehicle comprising all the relevant particulars
- ✓ detailed description of the type of the specific component,
- ✓ a drawing of the specific component, sufficiently detailed and on an appropriate scale,
- ✓ verification of compliance with the specifications

At the request of the Technical Service responsible for conducting approval tests, samples of the specific component shall be provided. Supplementary samples shall be supplied upon request (3 maximum)

- ✓ During pre-production of containers, containers of each 50 pieces shall be subjected to non-destructive tests

➤ **Markings:**

The samples of specific component submitted for approval shall bear the trade name or mark of the manufacturer and the type, including one concerning designation regarding operating temperatures ("M" or "C" for moderate or cold temperatures as appropriate); and for flexible hoses also the manufacturing month and year; this marking shall be clearly legible and indelible.

All components shall have a space large enough to accommodate the approval mark;

Every container shall also bear a marking plate with the following data clearly legible and indelible:

- a. a serial number;
- b. the capacity in litres;
- c. the marking "CNG";
- d. operating pressure/test pressure [MPa];
- e. mass (kg);
- f. year and month of approval (e.g. 96/ 01);
- g. approval mark



***Vehicles of Categories M and N with regard to the installation of specific components, for the use of compressed natural gas (CNG) for propulsion, of an approved type.***

➤ **Application for Approval:**

The application for approval of a vehicle type with regard to the installation of specific components for the use of compressed natural gas in its propulsion system shall be submitted by the vehicle manufacturer or by his duly accredited representative.

It shall be accompanied by the under-mentioned documents in triplicate: description of the vehicle comprising all the relevant particulars.

A vehicle representative of the vehicle type to be approved shall be submitted to the Technical Service conducting the approval tests.

➤ **Approval:**

If the vehicle submitted for approval is provided with all the necessary specific components for the use of compressed natural gases in its propulsion system, approval of that vehicle type shall be granted.

An approval number shall be assigned to each type of vehicle approved. Its first two digits shall indicate the series of amendments incorporating the most recent major technical amendments made at the time of issue of the approval.

Notice of approval or of refusal or of extension of approval of a CNG vehicle type pursuant shall be communicated to the Parties, by means of a form

There shall be affixed, conspicuously and in a readily accessible space specified on the approval form, to every vehicle type-approved under international approval mark consisting of:

- ✓ A circle surrounding the Letter "E" followed by the distinguishing number of the country which has granted approval;
- ✓ The number of this Regulation, followed by the Letter "R", a dash and the approval number to the right of the circle

The approval mark shall be clearly legible and be indelible.

The approval mark shall be placed close to or on the vehicle data plate

***Requirements for the installation of specific components for the use of compressed natural gas in the propulsion test of a vehicle***

➤ **General**

The CNG system of the vehicle shall function in a good and safe manner at the working pressure and operating temperatures for which it has been designed and approved.

All components of the system shall be type-approved as individual parts

The materials used in the system shall be suitable for use with CNG.

All components of the system shall be fastened in a proper way.

The CNG system shall show no leaks, i.e. stay bubble-free for 3 minutes.

The CNG system shall be installed such that it has the best possible protection against damage, such as damage due to moving vehicle components, collision, grit or due to the loading or unloading of the vehicle or the shifting of those loads.

No appliances shall be connected to the CNG system other than those strictly required for the proper operation of the engine of the motor vehicle.

No component of the CNG system, including any protective materials which form part of such components, shall project beyond the outline of the vehicle, with the exception of the filling unit if this does not project more than 10 mm beyond its point of attachment.

No component of the CNG system shall be located within 100 mm of the exhaust or similar heat source, unless such components are adequately shielded against heat.

➤ **The CNG System**

A CNG system shall contain at least the following components:

- ✚ Container(s) or cylinder(s);
- ✚ Pressure indicator or fuel level indicator;
- ✚ Pressure relief device (temperature triggered);
- ✚ Automatic cylinder valve;
- ✚ Manual valve;
- ✚ Pressure regulator;
- ✚ Gas flow adjuster;
- ✚ Excess flow limiting device;
- ✚ Gas supply device;
- ✚ Filling unit or receptacle;
- ✚ Flexible fuel line;
- ✚ Rigid fuel line;
- ✚ Electronic control unit;
- ✚ Fittings;
- ✚ Gas-tight housing for those components installed inside the luggage and passenger compartment. If the gas-tight housing will be destroyed in case of fire, the pressure relief device may be covered by the gas-tight housing.
- ✚ Non-return valve;
- ✚ Pressure relief valve;

- ✚ CNG filter;
- ✚ Pressure and/or temperature sensor;
- ✚ Fuel selection system and electrical system;
- ✚ PRD (pressure triggered).
- ✚ An additional automatic valve may be combined with the pressure regulator.

➤ **Installation of the Container**

The container shall be permanently installed in the vehicle and shall not be installed in the engine compartment.

The container shall be installed such that there is no metal to metal contact, with the exception of the fixing points of the container(s).

When the vehicle is ready for use the fuel container shall not be less than 200 mm above the road surface. This shall not apply if the container is adequately protected, at the front and the sides and no part of the container is located lower than this protective structure.

The fuel container(s) or cylinder(s) must be mounted and fixed so that the following accelerations can be absorbed (without damage occurring) when the containers are full:

- ❖ Vehicles of Categories M2 and N2:
  - (a) 10 g in the direction of travel
  - (b) 5 g horizontally perpendicular to the direction of travel
- ❖ Vehicles of Categories M3 and N3:
  - (a) 6.6 g in the direction of travel
  - (b) 5 g horizontally perpendicular to the direction of travel

A calculation method can be used instead of practical testing if its equivalence can be demonstrated by the applicant for approval to the satisfaction of the Technical Service.

➤ **Accessories Fitted to the Container(s) or Cylinder(s)**

**Automatic Valve**

- ✚ An automatic cylinder valve shall be installed directly on each container.
- ✚ The automatic cylinder valve shall be operated such that the fuel supply is cut off when the engine is switched off, irrespective of the position of the ignition switch, and shall remain closed while the engine is not running. A delay of 2 seconds is permitted for diagnostic.

**Pressure Relief Device**

The pressure relief device (temperature triggered) shall be fitted to the fuel container(s) in such a manner that can discharge into the gas-tight housing if that gas-tight housing fulfils the requirements

**Excess Flow Valve on the Container**

The excess flow limiting device shall be fitted to the fuel container(s) on the automatic cylinder valve.

**Manual Valve**

A manual valve is rigidly fixed to the cylinder which can be integrated into the automatic cylinder valve.

### **Gas-tight Housing on the Container(s)**

- ✚ A gas-tight housing over the container(s) fittings shall be fitted to the fuel container, unless the container(s) is installed outside the vehicle.
- ✚ The gas-tight housing shall be in open connection with the atmosphere, where necessary through a connecting hose and a lead-through which shall be resistant against CNG.
- ✚ The ventilation opening of the gas-tight housing shall not discharge into a wheel arch, nor shall it be aimed at a heat source such as the exhaust.
- ✚ Any connecting hose and lead-through in the bottom of the bodywork of the motor vehicle for ventilation of the gas-tight housing shall have a minimum clear opening of 450 mm<sup>2</sup>.
- ✚ The housing over the container(s) fittings and connecting hoses shall be gas-tight at a pressure of 10 kPa without any permanent deformations. In these circumstances a leak not exceeding 100 cm<sup>3</sup> per hour may be accepted.
- ✚ The connecting hose shall be secured by clamps, or other means, to the gas-tight housing and the lead-through to ensure that a gas-tight joint is formed.
- ✚ The gas-tight housing shall contain all the components installed into the luggage or passenger compartment.

### **PRD (Pressure Triggered)**

- ✚ The PRD (pressure triggered) shall be activated and shall vent the gas independently from the PRD (temperature triggered).
- ✚ The PRD (pressure triggered) shall be fitted to the fuel container(s) in such a manner that it can discharge into the gas-tight housing

### **Rigid and Flexible Fuel Lines**

- ✚ Rigid fuel lines shall be made of seamless material: either stainless steel or steel with corrosion-resistant coating.
- ✚ The rigid fuel line may be replaced by a flexible fuel line if used in Class 0, 1 or 2.
- ✚ Rigid fuel lines, shall be secured such that they shall not be subjected to vibration or stresses.
- ✚ Flexible fuel lines shall be secured such that they shall not be subjected to vibration or stresses.
- ✚ At the fixing point, the fuel line, flexible or rigid, shall be fitted in such a way that there is no metal to metal contact.
- ✚ Rigid and flexible fuel gas line shall not be located at jacking points.

- ✚ At passages the fuel lines shall be fitted with protective material.

### **Fitting or Gas Connections between the Components**

- ✚ Soldered joints and bite-type compression joints are not permitted.
- ✚ Stainless steel tubes shall only be joined by stainless steel fittings.
- ✚ Distributing-blocks shall be made of corrosion-resistant material.
- ✚ Rigid fuel lines shall be connected by appropriate joints, for example, two-part compression joints in steel tubes and joints with olives tapered on both sides.
- ✚ The number of joints shall be limited to a minimum.
- ✚ Any joints shall be made in locations where access is possible for inspection.
- ✚ In a passenger compartment or enclosed luggage compartment the fuel lines shall be no longer than reasonably required, and in any case shall be protected by a gas-tight housing. This shall not apply to vehicles of Categories M2 or M3 where the fuel lines and connections are fitted with a sleeve which is resistant against CNG and which has an open connection to the atmosphere.

### **Automatic Valve**

- ✚ An additional automatic valve may be installed in the fuel line as close as possible to the pressure regulator.

### **Filling Unit or Receptacle**

- ✚ The filling unit shall be secured against rotation and shall be protected against dirt and water.
- ✚ When the CNG container is installed in the passenger compartment or an enclosed (luggage) compartment the filling unit shall be located at the outside of the vehicle or in engine compartment.

### **Fuel Selection System and Electrical Installation**

- ✚ The electrical components of the CNG system shall be protected against overloads.
- ✚ Vehicles with more than one fuel system shall have a fuel selection system to ensure that no more than one fuel at the same time is supplied to the engine for more than 5 seconds. "Dual-fuel" vehicles, using diesel as the primary fuel for igniting the air/gas mixture, are allowed in cases where these engines and vehicles meet mandatory emission standards.
- ✚ The electrical connections and components in the gas-tight housing shall be constructed such that no sparks are generated.

***Gas cylinders – High pressure cylinder for the on-board storage of natural gas as a fuel for automotive vehicles***

➤ **Scope:**

This sets out minimum requirements for light-weight refillable gas cylinders. The cylinders are intended only for the on-board storage of high pressure compressed natural gas as a fuel for automotive vehicles to which the cylinders are to be fixed. Cylinders may be of any steel, aluminium or non-metallic material, design or method of manufacture suitable for the specified service conditions. This also covers stainless steel metal liners of seamless or welded construction

Cylinders covered are -

- ✚ CNG-1 Metal
- ✚ CNG-2 Metal liner reinforced with resin impregnated continuous filament (hoop wrapped)
- ✚ CNG-3 Metal liner reinforced with resin impregnated continuous filament (fully wrapped)
- ✚ CNG-4 Resin impregnated continuous filament with a non-metallic liner (all composite)

This subject is based upon a working pressure for natural gas as a fuel of 20 MPa settled at 15°C with a maximum filling pressure of 26 MPa. Other working pressures can be accommodated by adjusting the pressure by the appropriate factor (ratio). For example, a 25 MPa working pressure system will require pressures to be multiplied by 1.25.

The service life of the cylinder shall be defined by the manufacturer and may vary with applications. Definition of service life is based upon filling the cylinders 1,000 times a year for a



minimum of 15,000 fills. The maximum service life shall be 20 years

For metal and metal-lined cylinders, the cylinder life is based upon the rate of fatigue crack growth. The ultrasonic inspection, or equivalent, of each cylinder or liner is required to ensure the absence of flaws which exceed the maximum allowable size. This approach permits the optimized design and manufacture of light weight cylinders for natural gas vehicle service.

For all-composite cylinders with non-metallic non-load bearing liners the "safe life" is demonstrated by appropriate design methods, design qualification testing and manufacturing controls.

➤ **Definitions:**

**auto-frettage:** A pressure application procedure used in manufacturing composite cylinders with metal liners, which strains the liner past its limit of elasticity, sufficiently to cause permanent plastic deformation which results in the liner having compressive stresses and the fibres having tensile stresses at zero internal pressure.

**Auto-frettage pressure:** The pressure within the over-wrapped cylinder at which the required distribution of stresses between the liner and the over-wrap is established.

**Batch - composite cylinders:** A "batch" shall be a group of cylinders successively produced from qualified liners having the same size, design, specified materials of construction and process of manufacture.

**Batch - metal cylinders and liners:** A "batch" shall be a group of metal cylinders or liners successively produced having the same nominal diameter, wall thickness, design, specified material of construction, process of manufacture, equipment for manufacture and heat treatment, and conditions of time, temperature and atmosphere during heat treatment.

**batch non-metallic liners:** A "batch" shall be a group of non-metallic liners successively produced having the same nominal diameter, wall thickness, design specified material of construction and process of manufacture.

**Batch limits:** In no case shall a "batch" be permitted to exceed 200 finished cylinders or liners (not including destructive test cylinders or liners), or one shift of successive production, whichever is greater.

**Composite cylinder:** A cylinder made of resin impregnated continuous filament wound over a metallic or non-metallic liner. Composite cylinders using non-metallic liners are referred to as all-composite cylinders.

**Controlled tension winding:** A process used in manufacturing hoop wrapped composite cylinders with metal liners by which compressive stresses in the liner and tensile stresses in the over-wrap at zero internal pressure are obtained by winding the reinforcing filaments under significant high tension.

**Filling pressure:** The gas pressure in the cylinder immediately upon completion of filling.

**Finished cylinders:** Completed cylinders which are ready for use, typical of normal production, complete with identification marks and external coating including integral insulation specified by the manufacturer, but free from non-integral insulation or protection.

**Full-wrap:** An over-wrap having a filament wound reinforcement both in the circumferential and axial direction of the cylinder.

**Gas temperature:** The temperature of gas in a cylinder.

**Hoop-wrap:** An over-wrap having a filament wound reinforcement in a substantially circumferential pattern over the cylindrical portion of the liner so that the filament does not carry any significant load in a direction parallel to the cylinder longitudinal axis.

**Liner:** A container that is used as a gas-tight, inner shell, on which reinforcing fibres are filament wound to reach the necessary strength. Two types of liners are described in this standard: Metallic liners that are designed to share the load with the reinforcement, and non-metallic liners that do not carry any part of the load.

**Manufacturer:** The person or organization responsible for the design, fabrication and testing of

the cylinders

**Maximum developed pressure:** The settled pressure developed when gas in a cylinder filled to the working pressure is raised to the maximum service temperature.

**Over-wrap:** The reinforcement system of filament and resin applied over the liner.

**Prestressing:** The process of applying auto-frettage or controlled tension winding.

**Service life:** The life in years during which the cylinders may safely be used in accordance with the standard service conditions.

**Settled pressure:** The gas pressure when a given settled temperature is reached.

**Settled temperature:** The uniform gas temperature after any change in temperature caused by filling has dissipated.

**Test pressure:** The pressure at which the cylinder is hydrostatically tested

**Working pressure:** The settled pressure of 20 MPa at a uniform temperature of 15°C.

➤ **Service conditions**

**Standard Service Conditions**

The standard service conditions specified in this section are provided as a basis for the design, manufacture, inspection, testing, and approval of cylinders that are to be mounted permanently on vehicles and used to store natural gas at ambient temperatures for use as a fuel on vehicles.

**Use of Cylinders**

The service conditions specified are also intended to provide information on how cylinders made to this Regulation may safely be used to:

- (a) manufacturers of cylinders;
- (b) owners of cylinders;
- (c) designers or contractors responsible for the installation of cylinders;

- (d) designers or owners of equipment used to refuel vehicle cylinders;
- (e) suppliers of natural gas; and
- (f) regulatory authorities who have jurisdiction over cylinder use.

### **Service Life**

The service life for which cylinders are safe shall be specified by the cylinder designer on the basis of use under service conditions specified herein. The maximum service life shall be 20 years.

### **Periodic Re-qualification**

Recommendations for periodic re-qualification by visual inspection or testing during the service life shall be provided by the cylinder manufacturer on the basis of use under service conditions specified herein. Each cylinder shall be visually inspected at least every 48 months after the date of its entry into service on the vehicle (vehicle registration), and at the time of any re-installation, for external damage and deterioration, including under the support straps. The visual inspection shall be performed by a competent agency approved or recognised by the Regulatory Authority, in accordance with the manufacturers specifications: Cylinders without label containing mandatory information, or with labels containing mandatory information that are illegible in any way shall be removed from service. If the cylinder can be positively identified by manufacturer and serial number, a replacement label may be applied, allowing the cylinder to remain in service.

### **Cylinders involved in collisions**

Cylinders which have been involved in a vehicle collision shall be re-inspected by an agency authorized by the manufacturer, unless otherwise directed by the Authority having jurisdiction. Cylinders which have not experienced any impact damage from the collision may be returned to service, otherwise the cylinder shall be returned to the manufacturer for evaluation.

### **Cylinders involved in fires**

Cylinders which have been subject to the action of fire shall be re-inspected by an agency authorized by the manufacturer, or condemned and removed from service.

### **Maximum Pressures**

The cylinder pressure shall be limited to the following:

- (a) a pressure that would settle to 20 MPa at a settled temperature of 15°C;

(b) 26 MPa, immediately after filling, regardless of temperature;

### **Maximum Number of Filling Cycles**

Cylinders are designed to be filled up to a settled pressure of 20 MPa bar at a settled gas temperature of 15°C for up to 1,000 times per year of service.

### **Temperature Range**

#### *Settled Gas Temperature*

Settled temperature of gas in cylinders may vary from a minimum of -40°C to a maximum of 65°C;

#### *Cylinder Temperatures*

- ✚ The temperature of the cylinder materials may vary from a minimum of -40°C to a maximum of +82°C;
- ✚ Temperatures over +65°C may be sufficiently local, or of short enough duration, that the temperature of gas in the cylinder never exceeds +65°C

### **Gas Composition**

Methanol and/or glycol shall not be deliberately added to the natural gas. Cylinder should be designed to tolerate being filled with natural gas meeting either of the following three conditions:

(a) SAE J1616

(b) Dry gas

Water vapour would normally be limited to less than 32 mg/m<sup>3</sup> a pressure dew point of -9°C at 20 MPa. There would be no constituent limits for dry gas, except for:

Hydrogen sulfide and other soluble sulfides: 23 mg/m<sup>3</sup>

Oxygen: 1% by volume

Hydrogen shall be limited to 2% by volume when cylinders are manufactured from a steel with an ultimate tensile strength exceeding 950 MPa;

### **Wet gas**

Gas that contains water content higher than b) normally meets the following constituent limits;

Hydrogen sulfide and other soluble sulfides: 23 mg/m<sup>3</sup>

Oxygen: 1% by volume

Carbon dioxide: 4% by volume

Hydrogen: 0.1% by volume

Under wet gas conditions, a minimum of 1 mg of compressor oil per kg of gas is necessary to protect metallic cylinders and liners.

### **External Surfaces**

Cylinders are not designed for continuous exposure to mechanical or chemical attack. e.g. leakage from cargo that may be carried on vehicles or severe abrasion damage from road conditions, and shall comply with recognized installation standards. However, cylinder external surfaces may be inadvertently exposed to:

- (a) water, either by intermittent immersion or road spray;
- (b) salt, due to the operation of the vehicle near the ocean or where ice melting salt is used;
- (c) ultra-violet radiation from sunlight;
- (d) impact of gravel;
- (e) solvents, acids and alkalis, fertilizers; and
- (f) automotive fluids, including gasoline, hydraulic fluids, glycol and oils.

### **Gas Permeation or Leakage**

Cylinders may be located in enclosed spaces for extended periods of time. Permeation of gas through the cylinder wall or leakage between the end connections and the liner shall be considered in the design.

### **Design Data**

#### *Drawings*

Drawings shall show the following as a minimum:

- (a) Title, reference number, date of issue, and revision numbers with dates of issue if applicable;

- (b) Reference to this Regulation and the cylinder type;
- (c) All dimensions complete with tolerances, including details of end closure shapes with minimum thicknesses and of openings;
- (d) Mass, complete with tolerance, of cylinders;
- (e) Material specifications complete with minimum mechanical and chemical properties or tolerance ranges and, for metal cylinders or metal liners, the specified hardness range;
- (f) Other data such as, auto-fretage pressure range, minimum test pressure, details of the fire protection system and of the exterior protective coating.

#### *Stress Analysis Report*

- A finite element stress analysis or other stress analysis shall be provided;
- A table summarizing the calculated stresses in the report shall be provided.

#### *Material Test Data*

A detailed description of the materials and tolerances of the materials properties used in the design shall be provided. Test data shall also be presented characterizing the mechanical properties and the suitability of the materials for service.

#### *Design Qualification Test Data*

The cylinder material, design, manufacture and examination shall be provided to be adequate for their intended service by meeting the requirements of the tests required for the particular cylinder design

The test data shall also document the dimensions, wall thicknesses and weights of each of the test cylinders.

#### *Fire Protection*

The arrangement of pressure relief devices that will protect the cylinder from sudden rupture when exposed to the fire conditions shall be specified. Test data shall substantiate the effectiveness of the specified fire protection system.

#### **Manufacturing Data**

Details of all fabrication processes, non-destructive examinations, production tests and batch tests shall be provided; The tolerances for all production processes such as heat treatment, end

forming, resin mix ratio, filament winding tension and speed, curing times and temperatures, and auto-fretage procedures shall be specified; Surface finish, thread details, acceptance criteria for ultrasonic scanning (or equivalent), and maximum lot sizes for batch tests shall also be specified.

### **Fracture Performance and NDE Defect Size**

#### *Fracture Performance*

The manufacturer shall demonstrate the Leak-Before-Break performance of the design

#### *NDE Defect Size*

The manufacturer shall establish the maximum defect size for non-destructive examination which will prevent the failure of the cylinder during its service life due to fatigue, or failure of the cylinder by rupture.

### **Specification Sheet**

The title, reference number, revision numbers and dates of original issue and version issues of each document shall be given. All documents shall be signed or initialed by the issuer; The specification sheet shall be given a number, and revision numbers if applicable, that can be used to designate the cylinder design and shall carry the signature of the engineer responsible for the design. Space shall be provided on the specification sheet for a stamp indicating registration of the design.

### ***Requirements applicable to all cylinder types***

#### ➤ **Design**

This does not provide design formulas nor permissible stresses or strains, but requires the adequacy of the design to be established by appropriate calculations and demonstrated by



cylinders being capable of consistently passing the materials, design qualification, production and batch tests specified in this Regulation; All designs shall ensure a "leakage before break" failure mode under feasible degradation of pressure parts during normal service. If leakage of metal cylinders or metal liners occurs, it shall be only by the growth of a fatigue crack.

➤ **Materials**

*Steel*

Composition

- Steels shall be aluminium and/or silicon killed and produced to predominantly fine grain practice. The chemical composition of all steels shall be declared and defined at least by:
- (a) carbon, manganese, aluminium and silicon contents in all cases;
  - (b) nickel, chromium, molybdenum, boron and vanadium contents, and any other alloying elements intentionally added. The following limits shall not be exceeded in the cast analysis:

Tensile strength	< 950 MPa	≥ 950 MPa
Sulfur	0.020%	0.010%
Phosphorus	0.020%	0.020%
Sulfur and Phosphorus	0.030%	0.025%

Tensile properties

- The elongation for steel shall be at least 14%

*Aluminium*

Composition

Aluminium alloys shall be quoted in line with Aluminium Association practice for a given alloy system. The impurity limits for lead and bismuth in any aluminium alloy shall not exceed 0.003%;

## *Resins*

### General

The material for impregnation may be thermosetting or thermoplastic resins. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinyl ester thermosetting plastics, and polyethylene and polyamide thermoplastic material;

## *Fibres*

Structural reinforcing filament material types shall be glass fibre, aramid fibre or carbon fibre. If carbon fibre reinforcement is used the design shall incorporate means to prevent galvanic corrosion of metallic components of the cylinder. The manufacturer shall keep on file the published specifications for composite materials, the material manufacturer's recommendations for storage, conditions and shelf life and the material manufacturer's certification that each shipment conforms to said specification requirements. The fibre manufacturer shall certify that the fibre material properties conform to the manufacturer's specifications for the product.

### ➤ **Test Pressure**

The minimum test pressure used in manufacture shall be 30 MPa;

### ➤ **Burst Pressures and Fibre Stress Ratios**

For Type CNG-2, CNG-3 and CNG-4 designs the composite over-wrap shall be designed for high reliability under sustained loading and cyclic loading. This reliability shall be achieved by meeting or exceeding the composite reinforcement stress ratio values given in Table 6.3 of this annex. Stress ratio is defined as the stress in the fibre at the specified minimum burst pressure divided by the stress in the fibre at working pressure. The burst ratio is defined as the actual burst pressure of the cylinder divided by the working pressure; For Type CNG-4 designs, the stress ratio is equal to the burst ratio; For Type CNG-2 and CNG-3 designs (metal-lined, composite over-wrapped) stress ratio calculations must include:

- (a) An analysis method with capability for non-linear materials (special purpose computer program or finite element analysis program);
- (b) Elastic-plastic stress-strain curve for liner material must be known and correctly

modelled;

(c) Mechanical properties of composite materials must be correctly modelled;

(d) Calculations must be made at: auto-fretage, zero after auto-fretage, working and minimum burst pressures;

(e) Prestresses from winding tension must be accounted for in the analysis;

(f) Minimum burst pressure must be chosen such that the calculated stress at minimum burst pressure divided by the calculated stress at working pressure meets the stress ratio requirements for the fibre used;

➤ **Stress Analysis**

A stress analysis shall be performed to justify the minimum design wall thicknesses. It shall include the determination of the stresses in liners and fibres of composite designs.

➤ **Openings**

*General*

Openings are permitted in heads only. Centre line of openings shall coincide with the longitudinal axis of the cylinder. Threads shall be clean cut, even, without surface discontinuities, and to gauge.

➤ **Cylinder Supports**

The manufacturer shall specify the means by which cylinders shall be supported for installation on vehicles. The manufacturer shall also supply support installation instructions, including clamping force and torque to provide the required restraining force but not cause unacceptable stress in the cylinder or damage to the cylinder surface.

➤ **Exterior Environmental Protection**

Exterior protection may be provided by using any of the following:

(a) a surface finish giving adequate protection (e.g. metal sprayed on aluminium, anodising);

or

(b) the use of a suitable fibre and matrix material (e.g. carbon fibre in resin); or

(c) a protective coating (e.g. organic coating, paint)

Any coatings applied to cylinders shall be such that the application process does not adversely affect the mechanical properties of the cylinder. The coating shall be designed to facilitate subsequent in service inspection and the manufacturer shall provide guidance on coating treatment during such inspection to ensure the continued integrity of the cylinder

➤ **Design Qualification Tests**

For the approval of each cylinder type the material, design, manufacture and examination shall be proved to be adequate for their intended service by meeting the appropriate requirements of the material qualification tests and the cylinder qualification. The test cylinders or liners shall be selected and the tests witnessed by the Competent Authority.

➤ **Production Examinations and Tests**

Production examinations and tests shall be carried out on all cylinders produced in a batch. Each cylinder shall be examined during manufacture and after completion by the following means:

- (a) ultrasonic scanning (or demonstrated equivalent) of metallic cylinders and liners in accordance with BS 5045, Part 1, , or demonstrated equivalent method, to confirm that the maximum defect size present is smaller than the size specified in the design;
- (b) verification that the critical dimensions and mass of the completed cylinder and of any liner and over-wrapping are within design tolerances;
- (c) verification of compliance with specified surface finish with special attention to deep drawn surfaces and folds or laps in the neck or shoulder of forged or spun end enclosures or openings;
- (d) verification of markings;
- (e) hardness tests of metallic cylinders and liners shall be carried out after the final heat treatment and the values thus determined shall be in the range specified for the design;
- (f) hydrostatic proof test

➤ **Failure to Meet Test Requirements**

In the event of failure to meet test requirements retesting or reheat treatment and retesting shall be carried out as follows:

- (a) if there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed. If the result of this test is satisfactory, the first test shall be ignored;

(b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders of the batch to a further heat treatment.

If the failure is not due to the heat treatment applied, all the identified defective cylinders shall be rejected or repaired by an approved method. The non-rejected cylinders are then considered as a new batch.

In both cases the new batch shall be retested. All the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all cylinders of the batch shall be rejected.

#### ➤ **FMVSS 304**

U.S. federal requirements for CNG vehicle fuel tank integrity are described in FMVSS304. The stated purpose of FMVSS 304 is “to reduce deaths and injuries occurring from fires that result from fuel leakage during and after motor vehicle crashes.” The FMVSS 304 container requirements, which were developed based on the ANSI standard NGV2, include ambient temperature pressure cycling tests without leakage, a hydrostatic burst test, and a bonfire test. The hydrostatic burst pressure is required to be at least 2.25 times the cylinder service pressure for non-welded cylinders, and at least 3.5 times the service pressure for welded containers. There are also detailed cylinder labeling requirements in FMVSS 304. This specifies requirements for the integrity of compressed natural gas (CNG) motor vehicle fuel containers designed to store CNG as motor fuel on-board any motor vehicle.

#### **Definitions:**

**Brazing** means a group of welding processes wherein coalescence is produced by heating to a suitable temperature above 800°F and by using a nonferrous filler metal, having a melting point below that to the base metals. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

**Burst pressure** means the highest internal pressure reached in a CNG fuel container during a burst test at a temperature of 21°C (70°F).

**CNG fuel container** means a container designed to store CNG as motor fuel onboard a motor vehicle.

**Fill pressure** means the internal pressure of a CNG fuel container attained at the time of filling. Fill pressure varies according to the gas temperature in the container which is dependent on the charging parameters and the ambient conditions.

**Full wrapped** means applying the reinforcement of a filament or resin system over the entire liner, including the domes.

**Hoop wrapped** means winding of filament in a substantially circumferential pattern over the cylindrical portion of the liner so that the filament does not transmit any significant stresses in a direction parallel to the cylinder longitudinal axis.

**Hydrostatic pressure** means the internal pressure to which a CNG fuel container is taken during testing set forth in S5.4.1.

**Liner** means the inner gas tight container or gas cylinder to which the overwrap is applied.

**Service pressure** means the internal settled pressure of a CNG fuel container at a uniform gas temperature of 21°C (70°F) and full gas content. It is the pressure for which the container has been constructed under normal conditions.

**Stress ratio** means the stress in the fiber at minimum burst pressure divided by the stress in the fiber at service pressure.

**Container and material requirements.**

Type 1- Non-composite metallic container means a metal container.

Type2- Composite metallic hoop wrapped container means a metal liner reinforced with resin impregnated continuous filament that is "hoop wrapped."

Type 3- Composite metallic full wrapped container means a metal liner reinforced with resin impregnated continuous filament that is "full wrapped."

Type 4- Composite non-metallic full wrapped container means resin impregnated continuous filament with a non-metallic liner "full wrapped."

**Test requirements**

❖ Hydrostatic burst test

Each Type 1 CNG fuel container shall not leak when subjected to burst pressure. Burst pressure shall not be less than 2.25 times the service pressure for non-welded containers and shall not be less than 3.5 times the service pressure for welded containers.

Each Type 2, Type 3, or Type 4 CNG fuel container shall not leak when subjected to burst pressure. Burst pressure shall not be less than the value specified in Table 1 times the service pressure, as follows:

**Table 1 — Stress Ratios**

Material	Type 2	Type 3	Type 4
E-Glass.....	2.65	3.5	3.5
S-Glass.....	2.65	3.5	3.5
Aramid.....	2.25	3.0	3.0
Carbon.....	2.25	2.25	2.25

❖ Bonfire test

Each CNG fuel container shall be equipped with a pressure relief device. Each CNG fuel container shall completely vent its contents through a pressure relief device or shall not burst while retaining its entire contents

❖ Labeling

Each CNG fuel container shall be permanently labeled with the information specified in paragraphs (a) through (h) of this section. Any label affixed to the container in compliance with this section shall remain in place and be legible for the manufacturer's recommended service life of the container. The information shall be in English and in letters and numbers that are at least 6.35mm (1/4in.) high.

- (a) The statement: "If there is a question about the proper use, installation, or maintenance of this container, contact \_\_\_\_\_," inserting the *CNG fuel container manufacturer's name, address, and telephone number*.
- (b) The statement: "Manufactured in \_\_\_\_\_," inserting the month and year of manufacture of the CNG fuel container.
- (c) The statement: "Service pressure \_\_\_\_\_ kPa, (\_\_\_\_\_ psig)."
- (d) The symbol DOT, constituting a certification by the CNG container manufacturer that the container complies with all requirements of this standard.
- (e) The container designation (e.g., Type 1, 2, 3, 4).
- (f) The statement: "CNG Only."
- (g) The statement: "This container should be visually inspected after a motor vehicle accident or fire and at least every 36 months or 36,000 miles, whichever comes first, for damage and deterioration.
- (h) The statement: "Do Not Use After \_\_\_\_\_" inserting the month and year that mark the end of the manufacturer's recommended service life for the container.

❖ Pressure cycling test

Hydrostatically pressurize the CNG container to the service pressure, then to not more than 10% of the service pressure, for 13,000 cycles.

After being pressurized, hydrostatically pressurize the CNG container to 125% of the service pressure, then to not more than 10% of the service pressure, for 5,000 cycles.

The cycling rate shall be any value up to and including 10 cycles per minute.

The cycling is conducted at ambient temperature.

❖ Hydrostatic burst test



Hydrostatically pressurize the CNG fuel container, as follows: The pressure is increased up to the minimum prescribed burst pressure and held constant at the minimum burst pressure for 10 seconds.

The pressurization rate throughout the test shall be any value up to and including 1,379kPa (200psi) per second.

❖ Bonfire test

The CNG fuel container is filled with compressed natural gas and tested at (1) 100% of service pressure and (2) 25% of service pressure. Manufacturers may conduct these tests using the same container or with separate containers.

The CNG fuel container is positioned so that its longitudinal axis is horizontal. Attach three thermocouples to measure temperature on the container's bottom side along a line parallel to the container longitudinal centerline. Attach one at the midpoint of the container, and one at each end at the point where the dome end intersects the container sidewall. Subject the entire length to flame impingement, except that the flame shall not be allowed to impinge directly on any pressure relief device. Shield the pressure relief device with a metal plate.

If the test container is 165cm (65in.) in length or less, place it in the upright position. Attach three thermocouples to measure temperature on the container's bottom side along a line which intersects the container longitudinal centerline. Attach one at the midpoint of the bottom of the container, and one each at the point where the dome end intersects the container sidewall. Subject the container to total fire engulfment in the vertical. The flame shall not be allowed to impinge directly on any pressure relief device. For containers equipped with a pressure relief device on one end, the container is positioned with the relief device on top. For containers equipped with pressure relief devices on both ends, the bottom pressure relief device shall be shielded with a metal plate.

The lowest part of the container is suspended at a distance above the fire such that the container bottom surface temperatures are achieved.

The CNG fuel container is tested with the valve and pressure relief device or devices in place

The fire is generated by any fuel that maintains a flame temperature between 850° and 900°C for the duration of the test, as verified by each of the three thermocouples

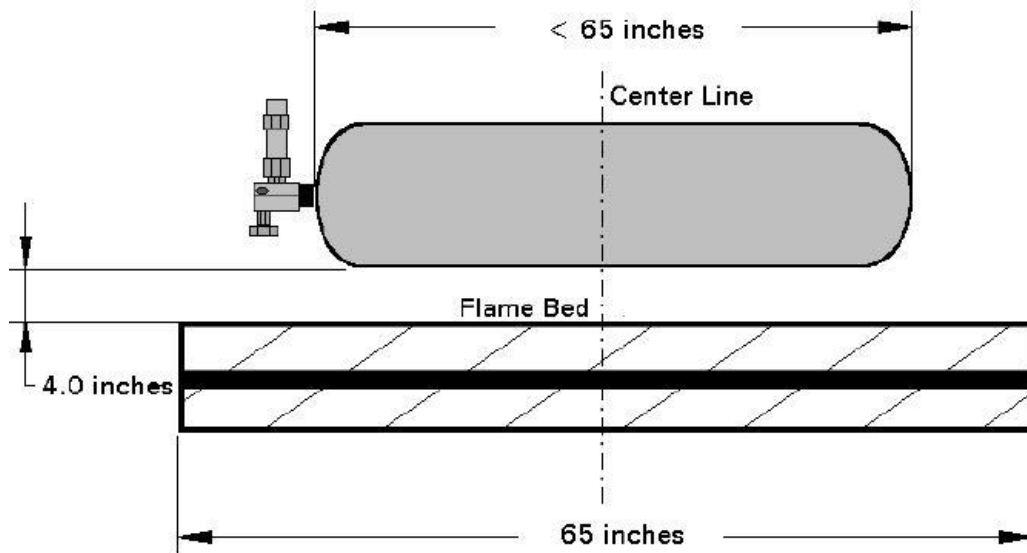
The fuel specified in S8.3.6. is such that there is sufficient fuel to burn for at least 20 minutes. To ensure that the sides of the fuel container are exposed to the flame, the surface area of the fire on a horizontal plane is such that it exceeds the fuel container projection on a horizontal plane by at least 20cm (8in.) but not more than 50cm (20in.).

Time-pressure readings are recorded at 30 second intervals, beginning when the fire is lighted and continuing until the container is completely tested.

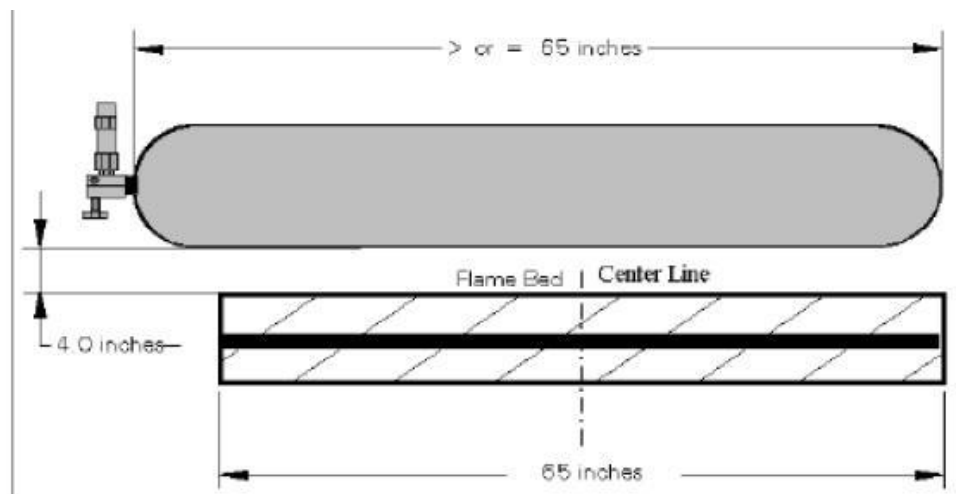
The CNG fuel container is exposed to the bonfire for 20 minutes or until its contents are completely vented.

The average wind velocity at the container is any velocity up to and including 2.24m/s (5mph).

***Figure 17: FMVSS 304 Bonfire Test for CNG Cylinder shorter than 65 inches***



*Figure 18: FMVSS 304 Bonfire test for cylinder longer than 65 inches*



➤ **ISO 11439**

### **Introduction**

Cylinders for the on-board storage of fuel for natural gas vehicle service are required to be light-weight, at the same time maintaining or improving on the level of safety currently existing for other pressure vessels. These requirements are achieved by:

- a) specifying service conditions precisely and comprehensively as a firm basis for both cylinder design and use;
- b) using an appropriate method to assess cyclic pressure fatigue life and to establish allowable defect sizes in metal cylinders or liners;
- c) requiring design qualification tests;
- d) requiring non-destructive testing and inspection of all production cylinders;
- e) requiring destructive tests on cylinders and cylinder material taken from each batch of cylinders produced;
- f) requiring manufacturers to have a comprehensive quality system documented and implemented;
- g) requiring periodic re-inspection and, if necessary, retesting in accordance with the manufacturer's instructions;
- h) requiring manufacturers to specify as part of their design, the safe service life of their cylinders.

Cylinder designs that meet the requirements of this International Standard:

- a) will have a fatigue life which exceeds the specified service life;
- b) when pressure cycled to failure, will leak but not rupture;
- c) when subject to hydrostatic burst tests, will have factors of "stress at burst pressure" over "stress at working pressure" that exceed the values specified for the type of design and the materials used.

Owners or users of cylinders designed to this International Standard should note that the cylinders are designed to operate safely if used in accordance with specified service conditions for a specified finite service life only. The expiry date is marked on each cylinder and it is the responsibility of owners and users to ensure that cylinders are not used after that date, and that they are inspected in accordance with the manufacturer's instructions.

### **Scope**

This International Standard specifies minimum requirements for serially produced light-weight refillable gas cylinders intended only for the on-board storage of high pressure compressed natural gas as a fuel for automotive vehicles to which the cylinders are to be fixed. The service conditions do not cover external loadings which may arise from vehicle collisions, etc.

This International Standard covers cylinders of any steel, aluminium or non-metallic material construction, using any design or method of manufacture suitable for the specified service conditions. This International Standard does not cover cylinders of stainless steel or of welded construction.

Cylinders covered by this International Standard are designated as follows:

CNG-1 Metal

CNG-2 Metal liner reinforced with resin impregnated continuous filament (hoop wrapped)

CNG-3 Metal liner reinforced with resin impregnated continuous filament (fully wrapped)

CNG-4 Resin impregnated continuous filament with a non-metallic liner (all composite)

### **Definitions**

#### **authorized inspection authority**

competent inspection authority, approved or recognized by the regulatory authority of the user country, for the supervision of construction and testing of cylinders

#### **auto-frettage**

pressure application procedure used in manufacturing composite cylinders with metal liners, which strains the liner past its yield point sufficient to cause permanent plastic deformation

NOTE This results in the liner having compressive stresses and the fibres having tensile stresses at zero internal pressure.

#### **auto-frettage pressure**

pressure within the over-wrapped cylinder at which the required distribution of stresses between the liner and the over-wrap is established

**batch**

(composite cylinders) group of not more than 200 cylinders plus cylinders for destructive testing, or if greater, one shift of successive production of cylinders, successively produced from qualified liners having the same size, design, specified materials of construction and process of manufacture

**batch**

(of metal cylinders/liners) group of not more than 200 cylinders/liners plus cylinders/liners for destructive testing, or if greater, one shift of successive production of metal cylinders/liners, successively produced having the same nominal diameter, wall thickness, design, specified material of construction, process of manufacture, equipment for manufacture and heat treatment, and conditions of time, temperature and atmosphere during heat treatment

**burst pressure**

highest pressure reached in a cylinder during a burst test composite cylinder made of resin-impregnated continuous filament wound over a metallic or non-metallic liner

**controlled tension winding**

process used in manufacturing hoop-wrapped composite cylinders with metal liners by which compressive stresses in the liner and tensile stresses in the over-wrap at zero internal pressure are obtained by winding the reinforcing filaments under significant high tension

**filling pressure**

pressure to which a cylinder is filled

**finished cylinders**

completed cylinders which are ready for use, typical of normal production, complete with identification marks and external coating including integral insulation specified by the manufacturer, but free from non-integral insulation or protection

**fully-wrapped cylinder**

cylinder with an over-wrap having a filament-wound reinforcement both in the circumferential and axial direction of the cylinder

**gas temperature**

temperature of gas in a cylinder

**hoop-wrapped cylinder**

cylinder with an over-wrap having a filament-wound reinforcement in a substantially circumferential pattern over the cylindrical portion of the liner so that the filament does not carry any significant load in a direction parallel to the cylinder longitudinal axis

**liner**

container that is used as a gas-tight, inner shell, on which reinforcing fibres are filament-wound to reach the necessary strength

NOTE Two types of liner are described in this International Standard – metallic liners that are designed to share the load with the reinforcement, and non-metallic liners that do not carry any part of the load.

**manufacturer**

person or organization responsible for the design, fabrication and testing of the cylinders

**over-wrap**

reinforcement system of filament and resin applied over the liner

**prestress**

process of applying auto-frettage or controlled tension winding

**service life**

life, in years, during which the cylinders may safely be used in accordance with the standard service conditions

**settled pressure**

gas pressure when a given settled temperature is reached

**settled temperature**

uniform gas temperature after the dissipation of any change in temperature caused by filling

**test pressure**

required pressure applied during a pressure test

**working pressure**

settled pressure of 200 bar at a uniform temperature of 15 °C

**Service conditions**

**Standard service conditions**

The standard service conditions specified in this clause are provided as the basis for the design, manufacture, inspection, testing and approval of cylinders that are to be mounted permanently on vehicles and used to store natural gas at ambient temperatures for use as a fuel on the vehicles.

**Use of cylinders**

The service conditions specified are also intended to provide information on how cylinders manufactured in accordance with this International Standard may safely be used; this information is intended for

- a) manufacturers of cylinders;
- b) owners of cylinders;
- c) designers or contractors responsible for the installation of cylinders;
- d) designers or owners of equipment used to refuel vehicle cylinders;
- e) suppliers of natural gas;
- f) regulatory authorities who have jurisdiction over cylinder use.

**Service life**

The service life for which cylinders are safe shall be specified by the cylinder manufacturer on the basis of use under service conditions specified herein. The maximum service life shall be 20 years.

For metal and metal-lined cylinders, the service life shall be based upon the rate of fatigue crack growth. The ultrasonic inspection, or equivalent, of each cylinder or liner shall ensure the absence



of flaws which exceed the maximum allowable size. This approach permits the optimized design and manufacture of light weight cylinders for natural gas vehicle service.

For all-composite cylinders with non-metallic non-load bearing liners the service life shall be demonstrated by appropriate design methods, design qualification testing and manufacturing controls.

### **Maximum pressures**

This International Standard is based upon a working pressure of 200 bar settled at 15 °C for natural gas as a fuel with a maximum filling pressure of 260 bar. Other working pressures may be accommodated by adjusting the pressure by the appropriate factor (ratio); e.g., a 250 bar working pressure system will require pressures to be multiplied by 1,25.

Except where pressures have been adjusted in this way, the cylinder shall be designed to be suitable for the following pressure limits:

- a) a pressure that would settle to 200 bar at a settled temperature of 15 °C;
- b) the maximum shall not exceed 260 bar, regardless of filling conditions or temperature.

### **Design number of filling cycles**

Cylinders shall be designed to be filled up to a settled pressure of 200 bar at a settled gas temperature of 15 °C for up to 1 000 times per year of service.

### **Gas temperature ranges**

Cylinders shall be designed to be suitable for the following gas temperature limits:

- a) the settled temperature of gas in cylinders, which may vary from a low of - 40 °C to a high of +65 °C.
- b) the developed gas temperatures during filling and discharge, which may vary beyond these limits.

### **Cylinder temperatures**

Cylinders shall be designed to be suitable for the following material temperature limits:

- a) the temperature of the cylinder materials may vary from - 40 °C to + 82 °C.
- b) temperatures over + 65 °C shall be sufficiently local, or of short enough duration, that the temperature of gas in the cylinder never exceeds + 65 °C

## Gas composition

Cylinders shall be designed to tolerate being filled with natural gas meeting the specification either of dry gas or wet gas as follows. Methanol and/or glycol shall not be deliberately added to the natural gas.

### Dry gas

Water vapour shall be limited to less than 32 mg/m<sup>3</sup> (i.e. a pressure dewpoint of \_\_\_\_\_ 9 °C at 200 bar).

Constituent maximum limits shall be:

Hydrogen sulfide and other soluble sulfides 23 mg/m<sup>3</sup>

Oxygen 1 % (volume fraction)

Hydrogen, when cylinders are manufactured from a steel with an ultimate tensile strength exceeding 950 MPa

### Wet gas

This is gas that has a higher water content than that of dry gas.

Constituent maximum limits shall be:

Hydrogen sulfide and other soluble sulfides 23 mg/m<sup>3</sup>

Oxygen 1 % (volume fraction)

Carbon dioxide 4 % (volume fraction)

Hydrogen 0,1 % (volume fraction)

## External surfaces

It is not necessary for cylinders to be designed for continuous exposure to mechanical or chemical attack, e.g. leakage from cargo that may be carried on vehicles or severe abrasion damage from road conditions. However, cylinder external surfaces shall be designed to withstand inadvertent exposure to the following, consistent with installation being carried out in accordance with the instructions to be provided with the cylinder:

- a) water, either by intermittent immersion or road spray;
- b) salt, due to the operation of the vehicle near the ocean or where ice-melting salt is used;
- c) ultra-violet radiation from sunlight;

- d) impact of gravel;
- e) solvents, acids and alkalis, fertilizers;
- f) automotive fluids, including petrol, hydraulic fluids, battery acid, glycol and oils;
- g) exhaust gases.

### **Environmental test**

#### ➤ General

This optional test is applicable to types CNG-2, CNG-3, and CNG-4 cylinders only.

#### ➤ **Cylinder set-up and preparation**

Two cylinders are tested in a condition representative of installed geometry including coating (if applicable), brackets and gaskets, and pressure fittings using the same sealing configuration (i.e. O-rings) as that used in service. Brackets may be painted or coated prior to installation in the immersion test if they are painted or coated prior to vehicle installation.

The cylinders are subjected to preconditioning and then exposed to a sequence of environments, pressures and temperatures.

Although preconditioning and fluid exposure is performed on the cylindrical section of the cylinder, all of the cylinder, including the domed sections, should be as resistant to the exposure environments as are the exposed areas.

As an alternative, a single cylinder approach may be used in which both the immersion environment and other fluids exposure tests are carried out on one cylinder. In this case, care should be taken to prevent cross contamination among the fluids.

➤ **Preconditioning**

The following types of apparatus are needed for preconditioning the test cylinder by pendulum and gravel impact.

a) Pendulum impact apparatus, comprising:

- an impact body of steel having the shape of a pyramid with equilateral triangle faces and a square base, the summit and the edges being rounded to a radius of 3 mm;
- a pendulum, the centre of percussion of which coincides with the centre of gravity of the pyramid; its distance from the axis of rotation of the pendulum being 1 m and the total mass of the pendulum referred to its centre of percussion being 15 kg;
- a means of determining that the energy of the pendulum at the moment of impact is not less than 30 N.m and is as close to that value as possible;
- a means of holding the cylinder in position during impact by the end bosses or by the intended mounting brackets.

b) Gravel impact machine, comprising:

- an impact machine capable of being operated in accordance with ASTM D3170-87 except that the cylinder may be at ambient temperature during gravel impact;
- gravel, comprising alluvial road gravel passing through a 16 mm space screen but retained on a 9,5 mm space screen. Each application is to consist of 550 ml of graded gravel (approximately 250 to 300 stones).

**Preconditioning for the immersion environment test**

Preconditioning by both pendulum impact and gravel impact is required for the portion of the container to be used for the “immersion environment” test

With the cylinder unpressurized, precondition the central section of the cylinder that will be submerged, by an impact of the pendulum body at three locations spaced approximately 150 mm apart. Following impact, precondition each of the three locations by gravel impact application.

Additionally, precondition a location within the submerged portion of each domed section and 50 mm (measured axially) from the tangent by a single impact of the pendulum body.

**Preconditioning for the other fluid exposure test**

Preconditioning by gravel impact only is required for the portion of the container to be used for the “other fluid exposure” test

Divide the upper section of the cylinder used for the “other fluids exposure” test into 5 distinct areas of nominal diameter 100 mm and mark these for preconditioning and fluid exposure.

Ensure that the areas do not overlap on the cylinder surface and, for the single cylinder approach, do not overlap the immersed section of the cylinder. While convenient for testing, the areas need not be oriented along a single line.

With the cylinder unpressurized, precondition each of the 5 areas identified in Figure F.2 for other fluid exposure on the cylinder by gravel impact application.

➤ **Test conditions**

**Pressure cycle**

At the appropriate stage in the test sequence subject the cylinder to hydraulic pressure cycles of between 20 bar and 260 bar for the ambient and high temperature steps, and between 20 bar and 160 bar for the lower temperature steps. Hold the maximum pressure for a minimum of 60 s and ensure that each full cycle takes no less than 66 s.

**High and low temperature exposure**

At the appropriate stages in the test sequence, bring the surface of the cylinder to a high or low temperature in air. The low temperature shall be no higher than  $-35\text{ }^{\circ}\text{C}$  and the high temperature shall be  $82\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$  as measured on the surface of the cylinder.

➤ **Acceptable results**

The test is considered to be satisfied if the burst pressure of the cylinders (or cylinder) is no less than 1,8 times the service pressure.

**Verification of stress ratios using strain gauges**

This part describes a procedure that may be used to verify stress ratios by use of strain gauges.

- a) The stress-strain relationship for fibres is always elastic, therefore, stress ratios and strain ratios are equal.
- b) High elongation strain gauges are required.
- c) Strain gauges should be orientated in the direction of the fibres on which they are mounted (i.e. with hoop fibre on the outside of the cylinder, mount gauges in the hoop direction).

d) **Method 1** (applies to cylinders that do not use high tension winding)

- 1) Prior to autofrettage, apply strain gauges and calibrate.

- 2) Measure strains at autofrettage, at zero pressure after autofrettage and at working and minimum burst pressure.
- 3) Confirm that the strain at burst pressure divided by the strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at operating pressure is compared with the rupture strain of cylinders reinforced with a single fibre type.

e) **Method 2** (applies to all cylinders)

- 1) At zero pressure after winding and autofrettage, apply strain gauges and calibrate.
- 2) Measure strains at zero, working and minimum burst pressures.
- 3) At zero pressure, after strain measurements have been taken at the working and minimum burst pressures, and with strain gauges monitored, cut the cylinder section apart so that the region containing the strain gauge is approximately 125 mm long. Remove the liner without damaging the composite. Measure the strains after the liner is removed.
- 4) Adjust the strain readings at zero, operating, and minimum burst pressures by the amount of strain measured at zero pressure with and without the liner.
- 5) Confirm that the strain at burst pressure divided by strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at operating pressure is compared with the rupture strain of cylinders reinforced with a single fibre type.

**Manufacturer's instructions for handling, use and inspection of cylinders**

**General**

The primary function of the manufacturer's instructions is to provide guidance to the cylinder purchaser, distributor, installer and user for the safe use of the cylinder over its intended service life.

**Distribution**

The manufacturer should advise the purchaser to supply these instructions to all parties involved in the distribution, handling, installation and use of the cylinders.

The document may be reproduced to provide sufficient copies for this purpose; however, it should be marked to provide reference to the cylinders being delivered.

### **Reference to existing codes, standards and regulations**

Specific instructions may be stated by reference to national or recognized codes, standards and regulations.

### **Cylinder handling**

Handling procedures should be described which would ensure that the cylinders will not suffer unacceptable damage or contamination during handling.

### **Installation**

Installation instructions should be provided which would ensure that the cylinders do not suffer unacceptable damage during installation and during normal operation over the intended service life.

Where the mounting is specified by the manufacturer, the instructions should, where relevant, contain details such as mounting design, the use of resilient gasket materials, the correct tightening torques and avoidance of direct exposure of the cylinder to the environment, chemicals and mechanical contacts. Cylinder locations and mountings should comply with recognized installation standards.

Where the mounting is not specified by the manufacturer, the manufacturer should draw the purchaser's attention to possible long-term impacts of the vehicle mounting system, e.g., vehicle body movements and cylinder expansion/contraction under the pressure and temperature conditions of service.

Where applicable, the purchaser's attention should be drawn to the need to provide installations such that liquids or solids cannot be collected to cause cylinder material damage.

The correct pressure relieve device to be fitted should be specified.

Cylinder valves, pressure relief devices and connections should be protected against breakage in a collision. If this protection is mounted on the cylinder, the design and method of attachment



should be approved by the cylinder manufacturer. Factors to be considered include the ability of the cylinder to support any transferred impact loads and the effect of localized strains on cylinder stresses and fatigue life.

### **Use of cylinders**

The manufacturer should draw the purchaser's attention to the intended service conditions specified in this International Standard, in particular the cylinder's permissible number of pressure cycles, its life in years, the gas quality limits and the permissible maximum pressures.

### **In-service inspection**

The manufacturer should clearly specify the user's obligation to observe the required cylinder inspection requirements (e.g. reinspection interval, by authorized personnel). This information should be in agreement with the design approval requirements, and should cover the following aspects.

#### **a) Periodic requalification**

Inspection and/or testing is required to be performed in accordance with the relevant regulations of the country(ies) where the cylinders are used.

Recommendations for periodic requalification by visual inspection or testing during the service life should be provided by the cylinder manufacturer on the basis of use under service conditions specified herein. Each cylinder should be visually inspected at least every 36 months, and at the time of any re-installation, for external damage and deterioration, including under the support straps. The visual inspection should be performed by a competent agency approved or recognized by the regulatory authority, in accordance with the manufacturer's specifications.

Cylinders without labels or stamps containing mandatory information, or with labels or stamps containing mandatory information that is illegible in any way should be removed from service. If the cylinder can be positively identified by manufacturer and serial number a replacement label or stamping may be applied, allowing the cylinder to remain in service.

#### **b) Cylinders involved in collisions**

Cylinders which have been involved in a vehicle collision should be re-inspected by an authorized inspection agency. Cylinders which have not experienced any impact damage from the collision

may be returned to service, otherwise the cylinder should be returned to the manufacturer for evaluation.

c) Cylinders involved in fires

Cylinders which have been subject to the action of fire should be re-inspected by an authorized inspection agency, or condemned and removed from service.

➤ **NGV2**

The ANSI NGV2 standard (4) requires several other tests in addition to the pressure cycling, hydrostatic burst pressure test, and bonfire test required by FMVSS 304. These additional tests include drop testing with various cylinder orientations, bullet penetration tests to demonstrate that the cylinder will not fragment, and environmental exposure tests. The latter include temperature extreme exposures and corrosive liquid exposures. Newhouse et al. (6) and Trudgeon (7) have provided summaries of these tests and minimum acceptable results.

➤ **NGV and CNG Fuel System and Component Tests**

The National Highway Traffic Safety Administration (NHTSA) requires U.S. NGVsto be crash tested in accord with FMVSS 303 to verify that vehicle fuel system leakages in crashes do not exceed specified limits equivalent to those for gasoline fueled vehicles. ANSI standard PRD1 specifies minimum requirements for PRDs, while ANSI NGV3.1 specifies requirements for other fuel system components. Chapter 4 of NFPA 52-2006 (9) specifies NFPA requirements for NGV fuel system pressurized components, including requirements for ten particular components to be listed or approved. CGA C-6.4 (10) provides information and procedures for the periodic visual examination and inspection of natural gas (and hydrogen) vehicle fuel containers which are certified to meet the ANSI NGV2 standard.

## *Indian context*

### **XVIII. SIAM letter to CCOE relating to approval for using Type IV cylinders in CNG, HCNG & H2 vehicles in India**

**SIAM**

**Society of Indian Automobile Manufacturers**

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TD-01:909

19 January 2012

Shri T R Thomas  
Chief Controller of Explosives,  
A Block CGO Complex 5<sup>th</sup> floor Seminary Hills,  
Nagpur,  
Maharashtra-440006

**Sub: Type IV composite cylinders for CNG/Hydrogen/HCNG Applications**

Dear Shri Thomas,

This is in reference to the subject on approval of Type IV Composite cylinder technology for on board use of CNG/Hydrogen/HCNG in vehicles by CCOE.

We understand from our members and their cylinder manufacturers/suppliers that Type-IV cylinders are not permitted in India for CNG, H2 and / or HCNG applications.

In this connection we would like to draw your attention to the following:

SIAM recognizes the need for upgrade of the technology in terms of light weighting and adopting well proven technologies such as composite cylinders (Type IV) which is prevailing in the other countries. This topic was also in discussion in MED 16 (BIS Technical Committee for the gas cylinders) and a document MED16 (0815)C was finalized for composite cylinders which is under printing. Internationally, Type IV cylinders are in use for more than 20 years and are well governed by testing procedures included in ECE R110 and ISO 11439. Type-IV gas cylinders provide substantial weight reduction and hence reduction in carbon emissions when used on vehicles. The Indian Gas cylinder rules, 1981 was revised in 2004 to include definition of all-composite cylinders.

Given the above facts on safety and proven track record of all-composite cylinders, we would request your approval for using Type-IV cylinders in CNG, HCNG & H2 vehicles in India.

In case additional clarifications are required, we would be happy to discuss the same and provide any clarifications required.

Looking forward to your favourable consideration.

With regards,

Yours sincerely,



K.K. Gandhi  
Executive Director (Tech) - SIAM



## **XIX. Composite Cylinders for On-Board Storage of Compressed Natural gas (CNG) as a Fuel for Automotive Vehicle – Specification**

On January 12, the Bureau of Indian Standards (BIS) in New Delhi published a newly approved standard: *Composite Cylinders for On-Board Storage of Compressed Natural gas (CNG) as a Fuel for Automotive Vehicle – Specification (IS 15935: 2011)*. The Standard was adopted after the draft finalized by the Gas Cylinders Sectional Committee had been approved by the mechanical Engineering Division Council.

Cylinders for the on-board storage of fuel for natural gas vehicle (NGV) service are required to be light-weight, at the same time maintaining or improving the level of safety currently existing for other pressure vessels.

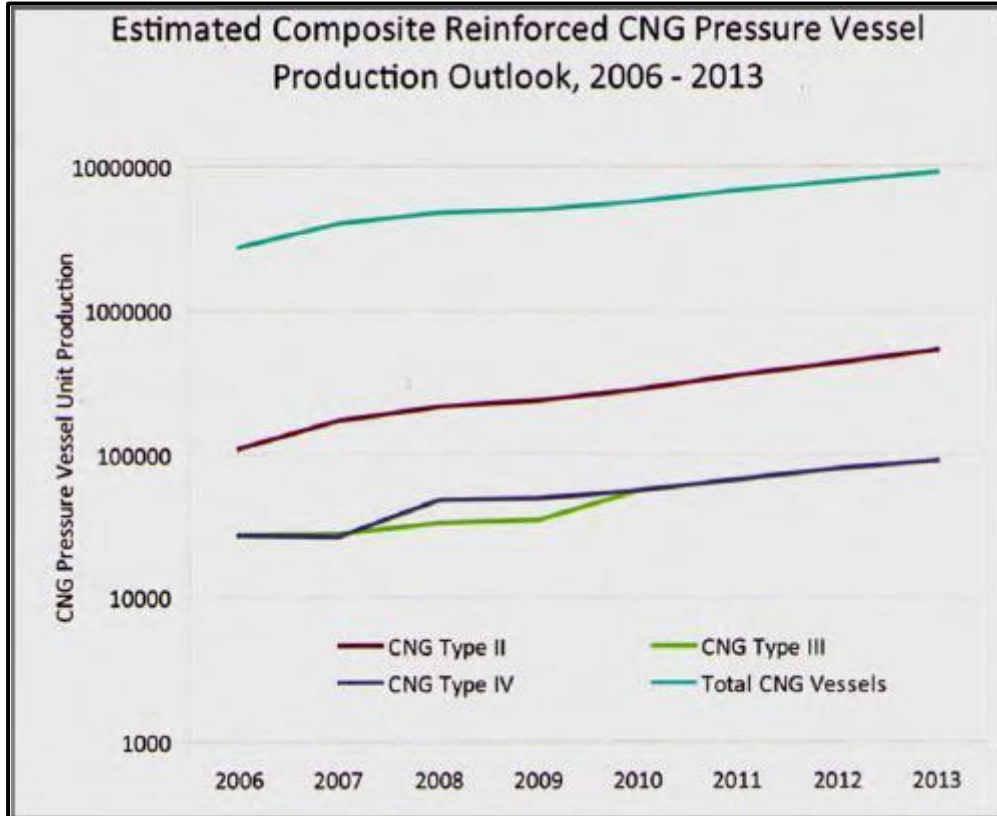
The Standard specifies minimum requirements for serially produced light-weight, composite refillable gas cylinders intended for on-board storage of high pressure compressed natural gas (CNG) as a fuel for automotive vehicles. It covers the following types:

- CNG 2: metal lined hoop wrapped composite cylinders
- CNG 3: metal lined full wrapped composite cylinders
- CNG 4: non-metal lined full wrapped composite cylinders

BIS acknowledges that “considerable assistance has been taken from” a number of ISO standards in drawing up this Standard.

Importantly, it notes cylinders manufactured according to its Standard will operate safely “if used in accordance with specified service conditions for the specified finite service life only. The expiry date is marked on each cylinder and it is the responsibility of the owner and user to ensure that cylinders are periodically tested as per norms laid down by statutory authorities”.

*Figure 19: Estimated Production of Composite Reinforced CNG Cylinders*



## XX. Conclusion

- Type IV cylinders are in use for more than 20 years in developed countries.
- They are well governed by testing procedures included in ECE R 110, ISO 11439 and FMVSS 304.
- Type IV gas cylinders provide substantial weight reduction and hence reduction in carbon emissions when used on vehicles.
- Type IV cylinders are significantly lower in cost than Type III cylinders. In comparison with steel tanks, a ROI of Type 4 cylinder is about 4 years.
- Subject on Type IV Composite cylinder technology was also discussed in MED 16 (BIS Technical Committee for the gas cylinders) and the finalized Indian standard IS 15935: 2011 was already released.
- Considering the benefits stated above and also complying with safety requirements of International regulations, Type IV cylinders must be permitted in India for CNG, H2 and / or HCNG applications.
- All provisions in the CMVR or Gas cylinder rules may be amended, considering the benefit country would derive out of Type IV cylinders usage.
- Lower weight of cylinders would enable packaging of cylinder in the roof, which is a relatively safest option for passenger vehicles application