Compressed Natural Gas As An Alternate Auto Fuel And It's Handling Systems

A Project Report submitted in partial fulfillment of the requirements for the Degree of

MASTER OF TECHNOLOGY

In

GAS ENGINEERING

(Academic Session 2003-05)

By

Nitin Kumar Baniwal

Under the Supervision of

Dr. Himmat Singh

COLLEGE OF ENGINEERING STUDIES

UNIVERSITY OF PETROLEUM & ENERGY STUDIES

DEHRADUN [U.A.] 248007

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CERTIFICATE

This is to certify that the Project Report on *"Compressed Natural Gas as an Alternate Auto Fuel & it's Handling Systems"* submitted to University of Petroleum & Energy Studies, Dehradun, by **Mr. Nitin Kumar Baniwal,** in partial fulfillment of the requirement for the award of Degree of Master of Technology in Gas Engineering (Academic Session 2003-05) is a bonafide work carried out by him under my supervision and guidance. This work has not been submitted anywhere else for any other degree or diploma.

Date: 22. 5. 2005

Dr.Himmat Singh

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Executive summary

Compressed Natural Gas (CNG) is being used internationally as an auto fuel. Natural gas is in most cases a less costly and cleaner-burning fuel than other fuels. The use of CNG results in reduced amount of petroleum consumption, fewer air pollutants and greenhouse gas emissions in applications. Standards for CNG and emission norms/ tail pipe emissions is also a major concern of this project to accommodate the requirements of NGV engine and vehicle applications, a number of international standards have been established like SAE J1616 and ISO 15403. To make the better understanding of natural gas conversion into CNG, we need to first understand the entire process of compression of natural gas, compression stations i.e. mother station, online station, daughter station and the system of transport and storage of compressed natural gas at high pressure and distribution of that natural gas at high pressure (HP), medium pressure and low pressure (suction pressures ranging from about 340 to about 3600 psig and discharge pressures ranging from about 340 to about 4500 psig).

Delivery system of natural gas by the means of movable transport in which gas is filled onto multiple pressure vessels from a pipeline to a compressed natural gas (CNG) re-fueling station. At the re-fueling station, the multiple pressure vessels will be connected to an un-loading conduit leading to the storage facilities. The natural gas is un-loaded by means of pressure differential until pressures are made equal, after that pressurized hydraulic fluid is pumped into the annulus between the bladder and the steel walls of the pressure vessel which will squeeze the remaining gas out of the bladder to storage. Then the transport is disconnected from the un-loading facilities and returned to the pipeline for re-filling with natural gas.

This report also covers the system and method of refueling of a powered vehicle storage with CNG, which employs a compressor system operable at suction pressures ranging from about 340 to about 3600 psig and discharge pressures ranging from about 340 to about 4500 psig along with a tank to store CNG temporarily at an intermediate storage pressure of from about 340 to about 4500 psig, preferably from about 1700 to about 2700 psig, apparatus for selectively filling vehicle storage tanks with CNG from an inlet source, from the compressor discharge and from the intermediate storage tanks, and apparatus for selectively supplying CNG to the compressor inlet at either the available line pressure or the intermediate storage pressure.

Chapter – 1

INTRODUCTION

Compressed Natural Gas

Unlike other hydrocarbon fuels (e.g. petrol, diesel and LPG, natural gas consists predominantly of a molecule naturally found in the environment-methane. As a road fuel, it is available as Compressed Natural Gas (CNG) - stored at high pressure and ambient temperature, or as Liquefied Natural Gas (LNG) - stored at lower pressure and low temperature. Natural gas is generally comprised of methane found in most parts of the world. Natural gas could be transported through pipeline or as liquefied natural gas (LNG) by vessels. Compressed Natural Gas (CNG) can be utilized as fuel in combustion engines. Presently, one million vehicles are using CNG as fuel throughout the world. The contents of natural gas vary depending on gas production field. Impurities include heavy hydrocarbons, nitrogen, carbon dioxide, oxygen and hydrogen sulfide. In vehicles, compressed natural gas should be stored in a large and heavy cylinder at a pressure of 220 atmospheres. However, considering a storage capacity and calorific value of CNG having 8.8 thousand joules (In comparison gasoline is 32 thousand joules) travel distance of the vehicle is limited. Additionally, due to limited number of CNG stations, the design of vehicle fuel system should as well consider utilization of gasoline.

The source of natural gas - The remains of plants and creatures that have been driven to lower layers of lakes and ancient oceans during million of years are gradually analyzed and converted to organic elements and as a result of earth's pressure and internal heat converted to gas and oil and is stored in underground storages in a depth of 3000 to 4000 meters and in a pressure of few hundred atmospheres.

Treating and preparation of gas for consumption - During production of natural gas, there are impurities such as sand and gravel, sour water and acid gases which are treated in treating plants to becomes available for consumption. The treated gas is delivered to cities and consumption centers through high-pressure pipelines.

Characteristics of Natural Gas - Natural gas is odorless, colorless and lighter than air. In order to detect gas leaks, odorants are injected to natural gas in the City Gate Stations to secure consumer safety. The calorific value of one cubic meter of natural gas is approximately equivalent to one liter of kerosene.

Effective factors for complete combustion and optimum utilization of natural gas - Providing enough air for complete combustion of gas, each cubic meter requires some 10 cubic meters of air for combustion and a more blue color flame indicates ample supply of air for combustion. - Application of gas filter in gas appliances and their proper cleaning - Application of flow regulating utensils in gas appliances - Selection of proper capacity (diameter) for chimneys - Insulation of water heater storage tanks and heat exchange storage tanks in household units and insulation of expansion tanks on roof tops - The largest energy loss in buildings occurs as heat loss through the windows. Therefore application of appropriate housing materials and double-layered windows are very effective in reducing energy consumption.

The typical composition and physical Properties of CNG (i.e. Compressed Natural Gas) are as follows:

Typical Composition

Methane:	88%
Ethane:	5%
Propane:	1%
CO2:	5%
Others:	1%
Total:	**100%**

Physical Properties

Non-toxic – Natural gas being lead/sulphur free, its use substantially reduces harmful engine emissions. When natural gas burns completely, it gives out carbon dioxide and water vapour - the very components we give out while breathing!

Lighter than air – Natural gas being lighter than air, will rise above ground level and disperse in the atmosphere, in the case of a leakage.

Selected Properties of Presently Available Fuels

Physical State	Gasoline Liquid	Liquified Petroleum Gas	Compressed Natural Gas	Methanol Liquid	Ethanol Liquid
Net Energy Content BTU/lb	18,700 19,100	19,800	21,300[a]	8,600	11,500
Octane Number Range (R + M) ÷ 2	87 - 93	104[b]	120[b]	99	100
Sulfur Content (W + %)	0.02 - 0.045	Neg[c]	Neg[c]	None	None

Table - 1

a - Pure Methane.

b - Octane ratings above 100 are correlated with given concentration of tetraethyl lead in 150-octane.

c - Natural sulfur content very low but measurable.

Source: Steering A New Course: Transportation, Energy, and the Environment, pages 75, 76.

Measuring a fuel's relative potential energy can easily be done by defining that fuel's Btu content. A Btu is defined as the amount of heat necessary to raise one (1) pound of water, one (1) degree Fahrenheit.

Refueling System of CNG Vehicles

Refueling a CNG vehicle is simple, clean and convenient. CNG refueling stations can be built anywhere there is a gas supply, subject of course to planning approval. With compressed natural gas, it is possible to take advantage of two types of refueling operation.

Fast Fill - At a fast fill refueling station, gas is compressed to a maximum of 250 bar and stored in three banks of buffer storage cylinders. While being refueled, a vehicle is connected to each bank in sequence to maximize the refueling pressure. Refueling times similar to diesel and petrol can be achieved.

Timed Fill - 'timed fill' refueling appliances are available which will compress gas from domestic mains pressure directly into a vehicle tank. These units unit will fill one or two light duty vehicles overnight and are used in situations where only one fill per day is required and the vehicles are parked up overnight. This refueling method can also be used for fleets, where a single compressor is sized to suit the refueling requirement.

Types of CNG Stations

Basically there are four types of CNG stations have been developed to produce and boosting the natural gas. These are as follows:

Mother Station: Mother stations are connected to the pipeline and have high compression capacity. These stations supply CNG to both vehicles and daughter stations (through mobile cascades). Typically they have the facility of filling all types of vehicles – buses/autos/cars. The Mother station requires heavy investment towards compressor, dispensers, cascades, pipelines, tubing etc.

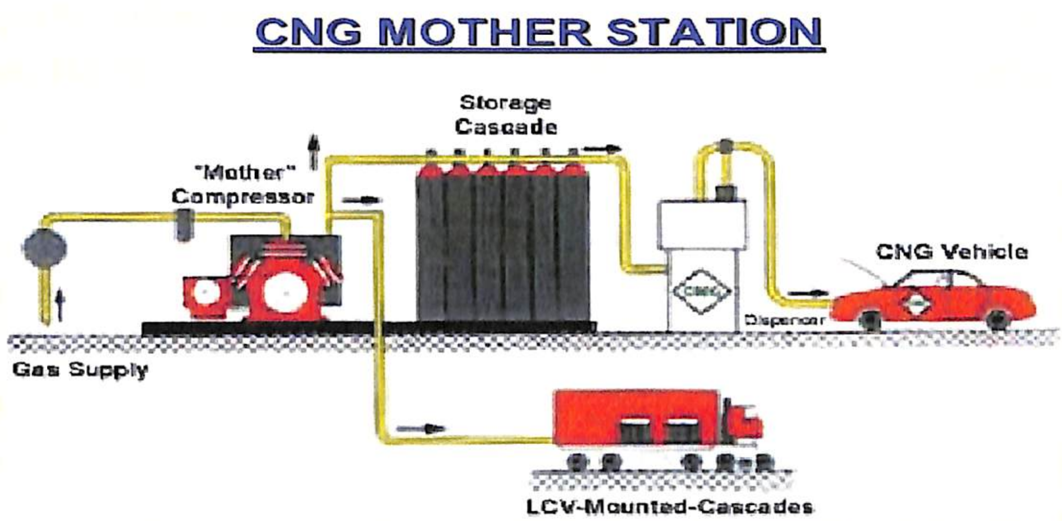


Figure - 1

Online Station: CNG vehicle storage cylinders need to be filled at a pressure of 200 bars. "On line Stations" are equipped with a compressor of relatively small capacity, which compresses low pressure pipeline gas to the pressure of 250 bar for dispensing CNG to the vehicle cylinder. The investment in an online station is midway between daughter station and mother station.

Daughter Station: The "Daughter Stations" dispense CNG using mobile cascades. These mobile cascades at daughter stations are replaced when pressure falls and pressure depleted mobile cascade is refilled at the "Mother Station". The investment in a daughter station is least among all types of CNG stations. There is reduction in storage pressure at daughter stations with each successive filling. Once the storage pressure drops, the refueling time increases, while the quantity of CNG dispensed to vehicle also decreases.

Daughter-Booster Station: Installing a booster compressor can eliminate drawbacks of daughter stations. The mobile cascade can be connected to the dispensing system through a booster. Daughter booster (compressor) is designed to take variable suction pressure and discharge at constant pressure of 200 bars to the vehicle being filled with CNG. The investment in daughter booster station is slightly higher than that of daughter station.

Typical Daughter Booster Station

Mega CNG stations have been conceptualized to cater to a large fleet of vehicles, particularly the buses. The objective is to provide comfortable filling experience to the consumers when they come to the station for refueling. Mega CNG stations are constructed on much larger plot of land than that of conventional CNG stations, as a result of which more number of Compressors and Dispensers can be installed and more number of vehicles can be simultaneously refueled at such stations.

Dispenser Systems and Fuel Metering

- The performance, reliability and range of costs for CNG dispenser and metering technologies vary depending on the manufacturer, the intended application, the level of electronics sophistication, and other factors. Technologies are gradually being improved but more work needs to be done to reduce costs. Dispensers are second only to gas compression equipment as the most expensive part of a CNG fueling station.

- Gas flow meters account for much of the total dispenser cost. Efforts are underway to improve and standardize fuel metering, with better compensation for the heat of compression to ensure complete fills. GRI has recently developed and licensed a fast-fill algorithm to address complete filling of vehicle cylinders. Private companies are also attempting to improve cylinder filling (e.g., Pinnacle's dispenser that compensates through measurement of interior CNG tank temperature during fast filling).

- CNG dispensers intended for public–access stations must meet challenging and expensive Weights and Measures (W&M) regulations, including National Type Evaluation Program

(NTEP) certification that may impose requirements not fully germane to gaseous fuels. Government agencies with vested interests in expansion of the CNG infrastructure should consider working with the dispenser industry and W&M officials to investigate this further.

- Most fast-fill station users who were surveyed were concerned about the cost of CNG dispensers, but found dispenser performance (fill times and completeness) and reliability to be acceptable.

- Reliable, cost-effective dispensers are best procured by carefully assessing the intended application and vehicle fill requirements, and then working with reputable, knowledgeable installer/packagers to choose the best make and model. Availability and cost of critical replacement parts such as computer boards should be established up front. Tubing diameter of at least ½ inch should be required. Users who may want to modify the dispenser's software program should check in advance if the software is proprietary.

The Advantages of Compressed Natural Gas

The Environmentally Clean Advantage

- Compressed natural gas is the cleanest burning fuel operating today. This means less vehicle maintenance and longer engine life.
- CNG vehicles produce the fewest emissions of any motor fuel.
- Dedicated Natural Gas Vehicles (NGV) has little or no emissions during fueling. In gasoline vehicles, fueling emissions account for at least 50% of a vehicle's total hydrocarbon emissions.
- CNG produces significantly less pollutants than gasoline.

The Maintenance Advantage

- Some fleet operators have reduced maintenance costs by as much as 40% by converting their vehicles to CNG.
- Intervals between tune-ups for natural gas vehicles are extended 30,000 to 50,000 miles.
- Intervals between oil changes for natural gas vehicles are dramatically extended--anywhere from 10,000 to 25,000 additional miles depending on how the vehicle is used.
- Natural gas does not react to metals the way gasoline does, so pipes and mufflers last much longer.

The Performance Advantage

- Natural gas gives the same mileage as gasoline in a converted vehicle.
- Dedicated CNG engines are superior in performance to gasoline engines.
- CNG has an octane rating of 130 and has a slight efficiency advantage over gasoline.
- Because CNG is already in a gaseous state, NGVs have superior starting and drive ability, even under severe hot and cold weather conditions.
- NGVs experience less knocking and no vapor locking.
- Natural gas is cheaper per equivalent gallon than gasoline (an average of 15% to 50% less than gasoline).

In Delhi, there has been a large debate over the comparative merits of ULSD and CNG: the reason being there has been a misunderstanding as to what exactly is ULSD. Diesel that has 50 parts per million (ppm) sulphur content alone can be called ULSD. All the misunderstanding was caused by the Ministry of Petroleum and Natural Gas (MOPNG) officials going on press referring to diesel with 500 ppm sulphur as ULSD. The officials were in trouble as they were not in a position to meet the deadline set by Supreme Court. As a result, the impression they gave to the public was that of a conspiracy according to which the 500 ppm diesel, that is currently available in Delhi was being proclaimed as a clean fuel. The confusion apart, there has been tremendous debate, which was initiated by the investigation of Environment Protection and Control Authority (EPCA) as per the guidelines of the apex court. Also known as the Bhurelal committee by its chairman, the committee was asked to file a report on whether 10 ppm sulphur diesel can be considered clean fuel and what other fuels could be considered clean fuels, which were not harmful to the environment "or otherwise not injurious to public health." The investigation of the committee saw representations by various parties, which were preceded by in depth analysis of the benefits of both the fuels by various scientific research organizations. While some of them concentrated only on the scientific side, some others also analyzed the social and politico-economical impacts of such a mandate. For a better understanding of the fuel scenario in Delhi and to understand the background of the 1 BhureLal Committee report ruling mandating CNG, it would be helpful to take a look at the arguments posed for and against both the fuels.

Summary of Arguments For and Against CNG

There are roughly 12 arguments that exist for and against the advocacy of CNG as a better fuel against other environment-friendly fuels. This is a brief summary of those lengthy debates.

Argument 1: CNG vehicles emit more ultra fine particles than diesel.

For

Dinesh Mohan of Indian Institute of Technology, Delhi cites a European study that has revealed that CNG emits finer particles than diesel which have greater propensity to enter the lungs thereby making the CNG option that much more dangerous (Business Standard, May 21, 2001). A study done by the US-based Harvard Centre for Risk Analysis contends that CNG vehicles emit more ultra fine particles (also called nanoparticles) than diesel vehicles.

Against

Across the world, scientific studies have established that particulate matter from diesel exhaust is extremely toxic. It comprises tiny particles coated with extremely toxic chemicals called PAH, some of which are known to be the most potent carcinogens. Compared with diesel vehicles, CNG vehicles emit negligible amount of particles.

Conclusion

The graph below shows that CNG buses emit more ultra fine particles than diesel buses.

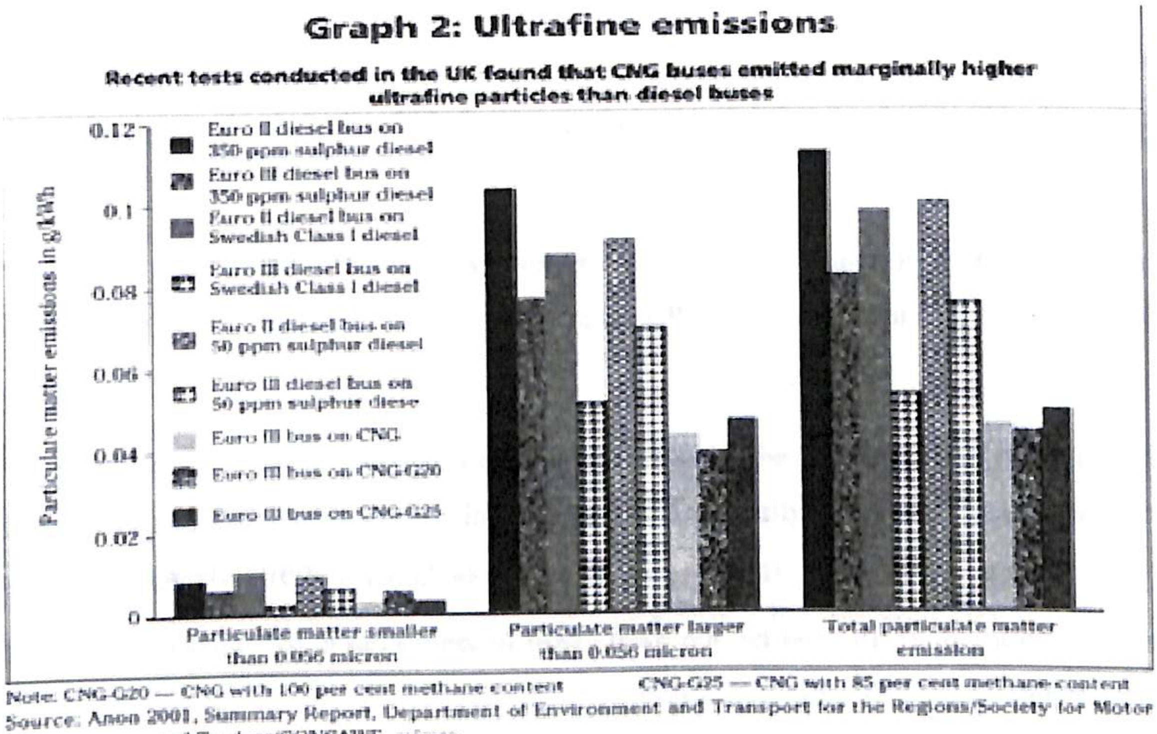


Figure - 2

Argument 2: CNG causes cancer

There has been widespread propaganda that CNG is carcinogenic and advocates of CNG condemn and deny this vehemently. Narendra Nath, Industry minister of Delhi, said that the people he met at the explosion site told him that, CNG is carcinogenic (The Indian Express, April 7, 2001).

Against

Conventional diesel is 100 times more, Euro II diesel 30 times more, Euro III diesel 20 times more and Euro IV diesel ten times more carcinogenic than CNG. Emissions from the cleanest diesel vehicles, equipped with particulate filters and running on best quality diesel fuel are still four times more carcinogenic than CNG.

Argument 3: It is dangerous to attempt a conversion of such massive proportions

For

"There is no city in the world that has even one-tenth of the number of 10,000 buses targeted in Delhi, using CNG," said R K Pachauri, Director, TERI in the Hindustan Times, April 8, 2001.

Against

Public transport in Delhi was asked to move to CNG in the perspective of the extremely high levels of toxic pollutants in the city in the ambient air. No city in the world has been found with particulate matter pollution as high as that of Delhi.

But another reason why a large fleet of buses have not yet been made the target of mandatory alternative fuel regulations in European and US cities is because of lesser number of buses in those cities, lesser intensity of bus use and comparatively lesser relative contribution of buses to air pollution.

Argument 4: CNG will inhibit introduction of better engine technology in the future.

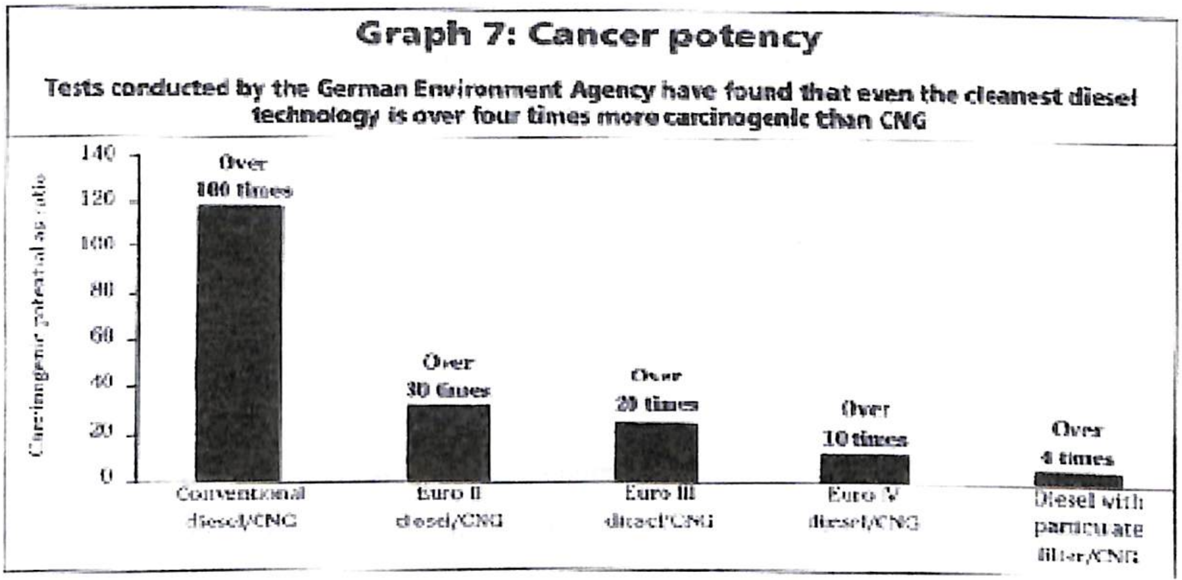


Figure - 3

For

The trouble with a complete switch is that Delhi would be saddled with today's technology for years instead of phased modernization, which can be ensured by phasing out a proportion of vehicles every year.22 Business Standard, May 21, 2001.

Against

Moving to CNG will not only help us to get emission results comparable to Euro IV norms, it will also straightaway reduce cancer risk from diesel vehicles significantly. Since CNG is a cleaner fuel, it is possible to meet much tighter standards within a short time frame and make a quantum leap.

It is unfortunate that though CNG technology can help to meet much tighter emissions standards, existing emissions regulations for CNG vehicles are extremely flawed. The present emission regulations for CNG vehicles do not recognize that CNG is an inherently clean fuel. Therefore, it has not been possible to get the best out of the CNG strategy.

Argument 5: CNG prices should be hiked to recover the costs of investment

For

Both Ram Naik and A K Dey, Managing Director of Indraprastha Gas Limited have issued statements to the press that CNG prices would have to be hiked to recover the cost of investment. On July 26, 2001, The Times of India reported Ram Naik saying that the cost of CNG would be substantially higher than diesel when the requirement would be met through liquefied natural gas (LNG) imports. IGL has made large investments for setting up CNG stations and is incurring loss in Delhi. Shortly after taking over office, A K Dey had made a presentation before the union minister of petroleum and natural gas, Ram Naik, wherein he had advocated an increase in the price of compressed natural gas (July 23, 2001, The Statesman.).

Against

IGL is making profit from the very first year of its operation and only recently an excise duty has been slapped on it to raise revenue. The annual report of IGL shows that the company has been making profit right from the first year. It is showing profits even after taking depreciation and payment of taxes into account. IGL showed a profit of about Rs 35 lac in the year 2000 and has shown a profit of more than Rs one crore in 2001.

The Calendar of Events

On July 28, 1998, in an unprecedented development, the Supreme Court (SC) ruled that the total passenger bus fleet of Delhi be increased from the then figure of about 6,000 to 10,000 by April 1, 2001 and the entire city bus fleet be converted to CNG. The objective was to expand the city's public transport system and also to control pollution. To deal with pollution from petrol-driven vehicles, the SC ordered the exclusive sale of unleaded and low benzene petrol and advanced improved Euro II vehicular standards by almost five years.

By August 2001, Delhi had the largest fleet of CNG buses in the world. There were 2,394 buses, over 27,000 autos and 14,000 other vehicles running on CNG. When the deadline for converting the entire public passenger transport fleet to CNG expired, all parties concerned approached the SC to air their grievances—schools, private bus operators and auto drivers' unions. The Court, in its order of March 26, gave a conditional extension to commercial transporters to run diesel vehicles till September 30, 2001. The extension was given on the condition that the operators would obtain special permits issued by the Delhi administration on the basis that the operators had placed orders to replace their diesel vehicle with CNG. The Court directed the Environment Pollution (Prevention and Control) Authority (EPCA)— known as the Bhure Lal committee, after its chairperson, Bhure Lal—to file a report on whether ten ppm sulphur diesel can be considered clean fuel and which other fuels could be considered "clean," that which were not harmful to the environment "or otherwise not injurious to public health." Delhi chief minister, Sheila Dikshit and union minister of petroleum and natural gas, Ram Naik, met and decided that that they cannot run the city's transport on one fuel, as any accident in the pipeline will bring the entire transport in Delhi to a standstill. They decided to ask EPCA to recommend that diesel with 0.05 percent sulphur is world standard clean fuel and should be accepted in place of CNG.

May: Private CNG buses hit the roads

There were reports of clashes between diesel and CNG bus staff as they both competed for passengers on the roads. As more and more CNG buses hit the roads, queues began to grow at filling stations. Indraprastha Gas Limited (IGL) officials kept saying that the problem will be solved soon.

June: The Delhi government said that the non-availability of gas could lead to another transport crisis. It filed an affidavit in the court saying the September 30 deadline cannot be met, as MPNG (Ministry of Petroleum and Natural Gas) is not supplying adequate CNG. IGL promised to install booster compressors at its daughter stations (stations without any compressors) and convert them to daughter-boosters (stations with compressors) By September, which would reduce lines.

July: Media reports of heart-rending stories of how nights are spent at CNG stations in the sweltering heat were by now common. Drivers do not see their children, do not sleep, do not bathe. Lines stretch for 2-3 km and there is still no action. "I think I will leave my photo at home for my family to remember me. The court can pass orders. But what about us," a bus driver was quoted saying.

August 5: Five people are injured as a TELCO CNG bus catches fire. Safety norms for CNG vehicles became the hot topic. Next day in the Parliament, members say CNG technology is not safe or viable. Naik tells Parliament that it will take 4-5 years to increase CNG supply beyond the existing capacity to meet Delhi's vehicle needs. "No more gas is available physically."

August 16: Dinesh Mohan, Henry Ford professor at IIT-Delhi, releases a study. He says pollution levels will go up if the SC order is implemented. "Contrary to popular perception CNG will not reduce pollution. It will lead to more carbon monoxide (CO), hydrocarbons and nitrogen oxides (NOx) emissions as compared to 500 ppm Sulphur diesel."

August 17: Affidavits are filed in court. Delhi government wants the Court to allow low sulphur diesel, but it qualifies that this is only till CNG supply becomes adequate. Wants the September 30 deadline to be extended. Union government seeks a ban on conversion of private vehicles to CNG. It requests the court that Euro II compliant diesel buses be allowed in Delhi. "Now CNG and diesel options are almost comparable, both having their own merits, with CNG buses having marginal advantage in respect to particulate matter emissions," says the Oil and Gas ministry.

The Court holds firm, rejects all affidavits, but is annoyed at the long queues and inadequate supply. "We have been repeatedly told that supply is adequate and that IGL is prepared to meet future demands. Even today we are informed that there is no shortage of CNG to meet the present demand as also the future demand to implement the orders. The Court says, "there appears to be mishandling of the CNG supply issue." The next hearing was scheduled for September 21 by which time the Court said, "We hope we shall be informed that proper remedial steps have been taken and there are no queues of autos and buses and other vehicles waiting to get CNG at the filling stations." But the hope did not last much. Even today, the plight of the drivers continues. And as if this was not enough, the impact of ignoring the economics of mass conversion is inevitably coming to the forefront.

Chapter – 3

Existing CNG Gas Quality Standards

The general purpose pipeline gas quality standards do not necessarily serve the needs of engines and vehicles, which operate within much wider ranges of pressure and temperature than conventional gas burning appliances. To accommodate the requirements of NGV engine and vehicle application, a number of international standards have been established, i.e. SAE Jl616 and ISO 15403.

3.1 SAE J1616

Water content: The local dewpoint temperature of the fuel should be 5.6 ^{0}C below the monthly lowest dry-bulb temperature at the maximum operating cylinder pressure. The margin of 5.6 ^{0}C is intended to prevent hydrate blockage due to pressure reduction at various stages in the vehicle fuel system.

Carbon dioxide: Given that the corrosive environment is controlled via the limited water concentration, no limits are required on the concentration of CO_2 for this purpose. Rather, a limit of 3.0% CO_2 by volume is recommended to help maintain stoichiometry.

Sulphur compounds: The total content of sulphur compounds, including odorants, should be limited to 8-30 ppm by mass to avoid excessive exhaust catalyst poisoning.

Methanol: No methanol shall be added to natural gas at the CNG refueling station. µµMethanol can cause corrosion of natural gas cylinders and deterioration of fuel system components.

Oxygen: Given that the corrosive environment is controlled by the limited water concentration, no limits are required on the concentration of oxygen for the control of corrosion. On the other hand, the oxygen level must not produce a mixture within the Flammability limits of natural gas.

Particulate and foreign matter concentration should be minimized to avoid contamination, clogging and erosion of fuel system components. CNG fuel delivered to the vehicle should have particulate matter content equal to or less than 5 micron in size.

Oil content: Additional data are required to determine acceptable lubricating oil levels as well as standardized test procedures for quantifying lubricating oil content. Lubricated compressor oil levels should be monitored and coalescing filters may be installed downstream of the compressor discharge to control oil.

Hydrocarbon dewpoint temperature: The composition of natural gas should be such that the original gaseous storage volume will form less than 1 % of a liquid condensate at the lowest ambient temperatures and gas storage pressure between 5.5 and 8.3 MPa, at which maximum condensation occurs, depending on gas composition.

Natural gas odorant: Natural gas introduced into any CNG refuelling station or vehicle shall have a distinctive odour strong enough for its presence to be detected down to a concentration in air of not over 1/5 of the lower flammability limit. This is approximately 1 % gas-in-air volume.

Wobbe Index: Variability in the Wobbe Index affects most significantly engines that are not equipped with closed loop controls. A Wobbe Index range of 48.5-52.9 MJ/m3 is recommended, although a range of 44.7-46.6 MJ/m3 has also been found acceptable for use on current equipment in high altitude areas. The recommended range, typical of most U.S. natural gas, would allow maximum variation from nominal air-fuel ratio of about $^{+}$-3.7%, which is comparable to the range in variation in petrol density.

Knock rating: No specific recommendations are given on the MON rating of natural gas. It is noted that work by King (1992) and Kubesh (1992) shows a close correlation between the reactive hydrogen-carbon ratio and MON antiknock performance.

3.2 ISO 15403

Water content: The water dewpoint of the fuel at the refuelling station outlet shall be sufficiently below the lowest ambient temperature in which refuelling stations and vehicles will operate.

Hydrocarbon content: The composition of natural gas shall be such that at any pressure, less than 1 % of a liquid condensate is formed at the lowest ambient temperature and under the worst gas storage pressure conditions. Maximum condensation occurs at between 2.5 MPa and 4.5 MPa.

Sulphur compounds: The total sulphur content may have an adverse impact on exhaust after treatment equipment and should be taken into account. Given that the corrosive environment is controlled by the lack of liquid water, no special limitation is required on the concentration of hydrogen sulphide.

Carbon dioxide and oxygen: Given that the corrosive environment is controlled by the lack of liquid water, no special limits are required on the concentration of carbon dioxide and oxygen.

Methanol: No methanol shall be added at the CNG refuelling station.

Particulate material: The CNG fuel delivered shall be technically free from dust. The possible oil content of natural gas shall have no effect on the safe operation of the vehicle.

Odour: Natural gas delivered to any natural gas vehicle should be odorized similar to a level found in the local gas distribution system.

Wobbe Index: Although it is acknowledged that variations in the Wobbe Index can significantly affect engines without closed loop, adaptive fuelling controls, no limits or ranges are specified.

Knock rating: No generally accepted standard test procedure is available. No knock rating values are specified.

3.3 Engine Manufacturer's Recommended Gas Quality

Component	Tolerance	CAT Dual-Fuel	Cummins	Deere	Detroit	Mack
Hydrocarbons						
Methane	Minimum	88.0%	90%		88%	85%
Ethane	Maximum	6.0%	4%		6%	11%
C3+	Maximum	3.0%				
Propane	Maximum		1.7%	5%	1.7%	9%
C4+	Maximum		0.7%		0.3%	
C6+	Maximum	0.2%				
Butane	Maximum			1%		5%
C2+ C3+C4						11%
Inerts (N2, CO2)	Rangel Max	1.5-4.5%	3.0% total			2%N2 3%CO2
Oxygen	Maximum	1.0%	0.5%			
Hydrogen	Maximum	0.1%	0.1%		0.1%	
CO	Maximum	0.1%	0.1%			
Sulfur	Maximum		0.001% by mass		22 ppm by mass	
Methanol	Maximum				0%	
CO2 + N2 + O2	Maximum				4.5%	

Table 2 - Recommended Gas Composition Ranges by Some Natural Gas Engine Manufacturers (SAE, 2001 and Detroit Diesel Corporation, 1998)

To ensure that their engines will work satisfactorily and durably in the end-use application, normally engine manufacturers require information on the composition of the natural gas in the location of use. They also issue recommended fuel specifications to guide intending users (see Tables 2 and 3).

Property	Tolerance	CAT Dual-Fuel	Cummins	Deere	Detroit	Mack
Wobbe Index. (MJ/m3)	Range		48.46 - 51.33		47.7-51.0	
Octane Rating (MON)	Minimum			118	115	
Methane Number MN	Minimum		80 (std. engines) 65 for Plus Technology	33.74 MJ/m3		
Lower Heating Value	Minimum		43.7 MJ/kg for Plus Technology engines			
Higher Heating Value			36.3 MJ/m-' (standard engines)			

Table 3 - Recommended Gas Combustion Properties by Some Natural Gas Engine Manufacturers (SAE, 2001, Cummins, 2001 and Detroit Diesel Corporation, 1998)

3.4 Emission Standards for New Vehicles

The various measures taken by government to mitigate emissions from transport sector are as follows:

Stringent emission norms

Mass emission standards for new vehicles were first introduced in India in 1991. Stringent emission norms along with fuel quality specifications were laid down in 1996 and 2000. Euro I norms are applicable from 1 April 2000 and Euro II norms will be applicable all over India from 1 April 2005. However, in the case of the National Capital Region (NCR), the norms were brought forward to 1 June 1999 and 1 April 2000 for Euro I (Bharat Stage I) and Euro II (Bharat Stage II), respectively (CPCB, 1999; SIAM, 1999)

Roadmap for Introduction of new Vehicular Emission Norms for New Vehicles
(Except 2 & 3 Wheelers)

	For 11 Major Polluted Cities	For The Rest of the country
Bharat Stage - II	1 April, 2003	1 April, 2005
Euro - III	1 April, 2005	1 April, 2010
Euro - IV	1 April, 2010	

Bharat State II norms have already been introduced in Delhi, Mumbai, Kolkata & Chennai in the year 2000 & 2001

Source : Auto Fuel Policy, Govt. of India, October-2003

Table -4

Cleaner fuel quality

To conform to the stringent emission norms, it is imperative that both fuel specification and engine technologies go hand in hand. Fuel quality specifications have been laid down by the Bureau of

Indian Standards (BIS) for gasoline and diesel for the period 2000–2005 and beyond 2005 for the country.

Given the increased usage of diesel in India it has become necessary to reduce the sulphur content of diesel. The directive by the Supreme Court, the Ministry of Petroleum and Natural Gas requires the supply of diesel with 0.05 per cent (500 ppm) sulphur content in the entire NCR from July 2001. In Mumbai and Calcutta, all vehicles are required to use 0.05 per cent sulphur in diesel from October 2000 and October 2002, respectively. Unleaded gasoline was introduced in April 1995 in the four metro cities of Delhi, Mumbai, Calcutta and Chennai. Lead has been phased out in the entire country since 1 February 2000. Similarly the benzene content is to be reduced and now, unleaded petrol with 1 per cent benzene and 0.05 per cent sulphur content is being supplied in the NCR. It will also be extended further to other parts of the country. The use of LPG as fuel for automobiles has also been permitted.

Inspection and maintenance (I&M)

The most important step towards emission control for the large in-use fleet of vehicles is the formulation of an inspection and maintenance system. It is possible to reduce 30–40 per cent pollution loads generated by vehicles through proper periodical inspections and maintenance of vehicles (CPCB, 2000). I&M measures for in-use vehicles are an essential complement to emission standards for new vehicles. In India, the existing mechanism of I&M is inadequate. Thus, there is a great need to establish effective periodic I&M programmes.

Other Stringent Measures in Certain Areas

On 1st April 1999, the specifications for 2T oil became effective. In order to prevent the use of 2T oil in excess of the required quantity, premixed 2T oil dispensers have been installed in all gasoline stations of Delhi (CPCB, 1999). Traffic management measures such as restriction on movement of goods vehicles during peak traffic hours have been enforced. Other measures include bans on commercial vehicles more than 15 years old, phase out of high polluting vehicles, replacement of all pre-1990 autos and taxis with new vehicles sing clean fuels; and the removal of eight-year old buses from the roads unless they use compressed natural gas (CNG) or other clean fuel. It is also planned that all buses/autos/taxis in Delhi are to switch over to CNG instead of diesel by 30 September 2001 (CPCB, 1999). By the end July 2001, 1,600 buses, 25,000 autos and 10,000 cars including 1,100 taxis were operating on CNG in Delhi. Also, Indraprastha Gas Ltd. (IGL) has provided 71 CNG stations in Delhi with plans to increase the number of stations to 90 by March 2002. (EPCA, 2001). However, the current infrastructure for CNG distribution for vehicles in Delhi is proving to be a constraint due to lack of compression capacity at the gas refueling stations, and poor distribution of refueling stations across the city. Likewise, in Mumbai, the CNG distribution infrastructure needs improvement.

Role of the judiciary

In recent years, the judiciary has played a prominent role in environmental protection. A number of judgments relating to stringent vehicle emission norms, fuel quality, introduction of cleaner fuels, phasing-out of older vehicles, and shifting of hazardous industries have provided a great deal of momentum in the efforts to improve air quality. The Environment Pollution (Prevention & Control) Authority for the National Capital region (EPCA) has been monitoring the implementation of action points outlined in the White paper on Pollution in Delhi with an action plan and priority measures approved by the Supreme Court. The status of action on the issues arising out of the Court's directions in July 1998 and March 2001 are given in Table 4.8.

Chapter – 4

Effects of Natural Gas Composition Variations on the Operation, Performance and Exhaust Emissions of Natural Gas -Powered Vehicles

Normally Occurring Quality of Commercial Natural Gas

Contaminant Levels

The contractual limits specified by commercial contracts and the limits specified by standards are just that - limits. In reality the normally occurring levels of non-hydrocarbon levels tend to be quite well below the limits. Table 5 gives a comparison in the case of sulphur compounds in natural gas in New South Wales, Australia (AGL, 1995).

Similarly, the contract limit for water content in pipelines in many countries are specified at some 112 mg/m^3 while the normally occurring water content can be much lower, at some 65 mg/m^3 or lower.

Based on an example of natural gas density of 0.755 kg/m^3, the typical total sulphur concentration of 7 mg/m^3 is equivalent to 9.24 ppm. This is still lower than the sulphur content of diesel fuel. For example, the sulphur content of "low sulphur" diesel is 500 ppm and "ultralow sulphur" diesel, 10 - 50 ppm.

Sulphur Compound	Contract Limit a Source (mg/m3)	Typical Level at Odorant Injection Location (mg/m3)	Typical Level in Downstream D System (mg/m3)
Mercaptan sulphur	4.6	1.5	1.5
Hydrogen sulphide	5.7	2.5	2.5
Odorants *	-	6.0	3
Odorants *	35.0	10.0	7

Table-5 Sulphur Concentration Levels in NSW Natural Gas (AGL, 1995 and Tas, 2002)

*The odorants (TBM and THT) are added only at the gas utility custody transfer point, not during transmission. As the commercial contracts and specifications do not normally specify the individual hydrocarbon constituent limits, to predict potential performance characteristics of natural gas engines one has to examine the actual variations in the hydrocarbon composition.

Composition variation

In the early 1990s, with the need to specify an acceptable gas quality standard for the safe operation of on-board CNG storage systems and the acceptable operation of CNG engines and vehicles, a major survey of the variation of the quality of natural gas was carried out in a study funded by the then Gas Research Institute. The results of this study (Liss and Thrasher, 1992) were summarised in the SAE CNG fuel quality standard J1616, and showed a degree of gas composition variation across the geographic spread of the US.

Later surveys also established the degree of variations between supply sources within large geographic areas such as Europe and Australia. Variations in the composition of gas delivered by pipelines can be caused by:

(a) Variations in the proportion of the contribution from various sources at a given supply Location; and
(b) Time variations within a given supply source.

These variations involve mainly the composition of the hydrocarbon mix and are not regulated by the general purpose pipeline gas standards beyond keeping within the limits of the heating value and the Wobbe Index.

Spot surveys of natural gas composition at an Australian location taken at 30-minute intervals for two 16-day periods in the (Southern) summer and winter of 2000 have shown the following variations:

- Methane: 86.91-92.05%
- Ethane: 4.61-9.80%
- Propane: 0.075-0.997%
- n-butane: 0.001-0.020%
- i-butane: 0.001-0.012%
- Wobbe Index: 48.73 - 49.9MJ/m^3.

The variations in the average daily Wobbe Index and Motor Octane Number (MON) were calculated from composition data for Argentina and Malaysia in 2001 and 2002 and are given in Table 6. The MON calculation method is given by Kubesh (1992).

Property	Argentina		Malaysia		
	Daily average		Daily average		Monthly average
	June 2001	January 2002	June 2001	December 2001	June-Dec. 2001
Wobbe Index					
Minimum	49.58	49.43	45.23	42.08	42.08
Average	49.73	49.82	48.00	48.49	48.35
Maximum	49.95	50.29	50.42	49.77	50.42
Range	0.7%	1.7%	10.8%	15.8%	17.3%
MON					
Minimum	127.3	132.7	124.0	127.3	123.8
Average	127.7	135.2	129.6	129.8	129.3
Maximum	128.3	136.9	135.4	132.0	135.4
Range	0.80%	3.1%	8.8%	3.6%	9.0%

Table 6 - Wobbe Index (MJ/m) and MON variations, and their range as a percentage of the average, in Argentinean and Malaysian natural gas.

Adding to the normal composition variations is the practice in many countries of adding propane/butane/air mixtures into normal natural gas for peak shaving, thus lowering the Motor Octane rating of the fuel during those periods.

Effects of Natural Gas Quality on Engine and Vehicles

Water content

The use of natural gas with high water content can result in the formation of liquid water, ice particles or hydrates at low operating temperatures and high pressure. Such formations can interfere with consistently smooth flow of fuel into the engine and cause problems such as poor drivability or even engine stoppage.

A range of gas dryer products is available on the market. There are no major technical issues beyond the correct selection and operation of the dryer systems. It should be noted that certain drying media have an affinity for compressor oil and gas odorants, and they should be suitably selected so that the required oil and odorant contents of the natural gas fuels are maintained.

As water is removed from gas during the liquefaction process, water is not an issue in LNG vehicle operation.

Heavier Hydrocarbons

Some gas utilities may add propane/air mixtures to natural gas during peak demand periods. Propane has a low vapour pressure and if present in significant quantities it will form a liquid phase at elevated pressures and low temperatures. Fuel variability due to re-vaporisation of this liquid condensate at reduced storage cylinder pressure can lead to difficulty in controlling the air-fuel ratio.
In addition, the significant presence of the heavier hydrocarbons in the gas mixture lowers its knock rating and can lead to potential engine damage.

Compressor Carryover Oil

Substantial amounts of oil can be added to the gas during compression, which can subsequently condense and interfere with the operation of CNG engine components such as gas pressure regulators. On the other hand, a minimum level of carryover oil is required for durable gas injector operation. Various injector manufacturers recommend different minimum oil levels.

Oil in the gas at the compressor outlet is commonly removed by coalescing filters, however, they are insufficient in many cases, as up to 50% of the carryover oil exists in vapour form in the warm (or hot) compressor outlet gas. Additional measures will need to be considered, for example, by additional cooling of the discharge gas or by using synthetic oil or mineral oil or a combination of mineral oil and a suitable adsorption filter downstream of the coalescing filter (Czachorski et al, 1995).

At this time there is no established, generally accepted carryover oil level as well as consistent, standardized methods of determining the oil level in gas.
LNG has an opposite problem as lubricants are removed in the liquefaction process.

Sulphur Compounds

Sulphur compounds in natural gas are in the form of mercaptans, hydrogen sulphide, and odorants. The first two are naturally occurring at source (gas fields) and have already been reduced by treatment at the gas processing plant.

The sulphur-based odorants (tetrahydrothiophene, THT, and tertiary butylmercaptan, TBM), at concentrations as low as 10-15 mg sulphur/m^3 of natural gas, can have a very detrimental effect on the conversion efficiency of oxidation catalysts used on lean bum natural gas engines (Nylund and Lawson, 2000).In the US, typical contract terms and industry practice limit total sulphur to 8 - 30 ppm on a mass basis; although extensive surveys have indicated that the average sulphur content of all samples is around 10 ppm.

Typically, 80% of the sulphur, i.e. 8ppm is from the odorant (Liss and Thrasher, 1992).

In Europe, the natural gas coming from the Siberian gas fields Urengoi and Jamburg contains less than 1.5 ppm S. In Finland it is 9 ppm (Riikonen, 1993, as reported by Nylund et al, 2002). This corresponds well to the US example.

At these levels, natural gas sulphur content is well below that of low sulphur (500 ppm) and ultralow sulphur (10 - 50 ppm) diesel. However, as will be seen in the following, it may be necessary to lower it further to ensure oxidation catalyst durability.

Some of the most detailed reported work on the effect of sulphur on oxidation catalysts for methane in lean bum natural gas engine exhaust is that of Lampert et al (1996), McCormick et al (1996) and Lampert and Farrauto (1997). They have found that:

- NGV exhaust contains sulphur derived from the gas and engine lubricating oil (see Table 5 for typical values).

- Sulphur in NGV exhaust strongly inhibits methane oxidation over palladium catalysts- at as little as 1 ppm (by mass) of sulphur in sulphur oxides present in the exhaust of a lean burn natural gas engine.

- Sulphur poisoning deactivates methane activity to a greater extent than the alkanes (ethane and propane), which comprise the non-methane hydrocarbon (NMHC) components of NGV exhaust. Thus, as the catalyst ages, total hydrocarbon (THC) emissions may increase above THC regulation levels even if the NMHC emissions remain below the regulatory NHMC limits.

- Currently, emission standards for NMHC, CO, and engine oil-derived particulates in lean bum NGV exhaust can be met with palladium or platinum containing catalysts supported on monoliths.

	Maximum 8 Level (ppm)	Average 8 Level (pp
In input CNG	30 (or 22.65 mgS/m^3 gas) *	12 (or 9.06 mg S/m^3 g
In exhaust at idl	2.6	1.6
* CNG contribution	1.7	0.7
* Engine oil contributi	0.9	0.9
In exhaust at cruise:	1.3	0.6
* CNG contribution	1.2	0.5
* Engine oil contributi	0.1	0.1

Table 7 - Estimates of sulphur (8) in lean burn NGV exhaust (Lampert and Farrauto, 1997). Sulphur concentration in the oil is 0.4% by mass.

Based on an example of natural gas density of O.755 kg/m^3, i.e. each mass ppm of sulphur is equivalent to 0.755 mg S/m^3 gas.

In the example of Table 7, the sulphur level in the lean burn NGV exhaust exceeds 1 ppm at idle, but is well below 1 ppm at cruise condition, with the natural gas-derived sulphur contributions in the exhaust at 0.7 and 0.5 ppm at idle and cruise respectively. The contribution of engine oil is larger than that of CNG during idling, i. e. the more critical phase of operation.

Sulphur content in gas can be minimized by more accurate injection of odorants (just sufficient for leak detection), and further reducing hydrogen sulphide and mercaptans at the gas fields.

As even very low levels of sulphur can still cause catalyst deterioration over time, it is essential that methods and hardware be developed to minimize the effects of exhaust sulphur on the exhaust catalyst system. In fact, this very issue is currently under investigation by the diesel engine and diesel exhaust after treatment industry (EP A, 2002), using approaches such as:

- Developing more sulphur- tolerant after treatment materials and systems.
- Reducing the sulphur level of engine oils (by changing oil formulations).

As sulphur compounds - including odorants - are removed by the gas liquefaction process, sulphur poisoning of the exhaust catalyst will not be an issue for LNG vehicles. On the other hand, the lack of odorant in liquefied natural gas means that some cost-effective means of leakage detection would have to be added to the LNG for use on vehicles.

Fuel Composition and Air-fuel Ratio Control

Typical emissions trends as a function of the air-fuel ratio are shown in Figure 1. It is essential to maintain the desired equivalence ratio of the engine under all operating conditions in order to minimize emissions and maximize efficiency. Changes in the gas composition which affect the equivalence ratio will affect engine performance and emissions, whether it be stoichiometric or lean-bum combustion.

The composition variations are the result of adjustments carried out either at the producer level (gas fields) or local level (at peak demand times) in an effort to maintain key parameters such as the Wobbe Index. As NGV usage continues to form a minor portion of the total gas usage, it is doubtful that producer and utility operation will be amenable to change in response to the requirements of the NGV market only.

Attempting to remove the heavier hydrocarbons at NGV compression and refuelling stations is impractical as it would:

- Require additional equipment, operation and cost.
- Further upset the essential fuel parameters such as the Wobbe Index.
- Lose valuable heating value, which is the reason the heavier hydrocarbon adjustments are made in the first place.

The more practical solution at this time appears to be further development/deployment of vehicle fuel control systems that can tolerate changes in the heavier hydrocarbon contents in the intended vehicle market.

Fuel Composition and Knock Resistance of the Fuel

The most comprehensive work in recent times on the knock resistance rating of natural gas fuel appears to be that of Kubesh (1992).

Of all hydrocarbon compounds used as motor fuel, methane has the highest knock resistance. The higher the carbon content of the compound, the lower is its knock rating. Thus, gas composition has a definite effect on the knock rating of the natural gas.

In Kubesh's work it was established that the MON for available natural gases in the USA ranged between 115 and 130+. The MON ranges of Argentina and Malaysia are respectively 127-137 and 124-135 (see Table 6).

To ensure that gas engines will operate without knock in service, engine manufacturers specify minimum knock resistance properties of the fuel. For heavy-duty gas engines (see Table 3) the manufacturers specify minimum fuel MON or methane number (MN). For example, Deere and Detroit require minimum MON of 118 and 115 respectively. Very encouragingly, Cummins has been able, though improved control systems, to reduce the minimum MN from 80 for its standard engines to 65 for its Plus Technology engines.

Chapter – 5

Current status of CNG in Indian scenario – a study of the major cities in India

5.1 Energy Demand and Environmental Emissions

Energy Demand

Delhi

There is a significant growth in transport energy demand. However, assumptions on MRTS, curbs the energy demand for motorized transport to some extent. It grows by 2.3 times during 1997-2020. Annual growth rate is worked out to be 4.4% against the assumed economic growth rate of 5.6%. Total energy demand from transport services in 1998 is 42.2 million GJ and it increases to 137.4 million GJ by 2020. Energy intensity for passenger transport falls over the years due to assumptions of penetration of more energy efficient CNG and battery operated vehicles. However, energy intensity for freight transport increases during the same period, due to increase in share of LCV in total freight transport, which is relatively energy inefficient. Passenger transport dominates the energy demand. However, its share falls from 84% to 81% by 2020. As far as individual fuel is concerned, natural gas demand of about 1 billion cubic meters by the year 2020 suggests the need for an elaborate CNG supply network. Replacement of diesel driven passenger vehicles like bus, taxis etc. by CNG driven vehicles, leads to fall in demand for diesel. In the later periods, only goods vehicles demand for it. Because of higher share of personalized model of transport, growth in gasoline demand is 2.35 times the present consumption.

Mumbai

In Mumbai, a 3-fold increase is expected during 1998-2020. Annual growth rates are worked out to be 4.4% and 5.1% respectively for Delhi and Mumbai, as against assumed economic growth rates of 5.6% and 6.6% respectively. The total energy demand from transport services in 1998 is 19.1 million GJ and it increases to 60.3 million GJ in 2020. Like the case in Delhi, the energy intensity of passenger transport falls over the planning horizon due to penetration of more energy efficient CNG and battery operated vehicles. Passenger transport dominates the energy demand. However, its share falls from 94% to 92% by 2020. Natural gas demand of about 1 billion cubic meters by the year 2020 suggests the need for an elaborate CNG supply network. Replacement of diesel driven passenger vehicles like bus, taxis etc. by CNG driven vehicles, leads to fall in demand for diesel.

5.2 Environmental Emissions

Emissions

Delhi recorded the highest level of pollution loading of CO, HC, NOx, SO2, TSP and Pb relative to the other cities. CO emission factor of gasoline vehicles are higher compared to diesel. Annual emission of CO in Delhi was 177740 tonnes (t) in 1995/96, which was 28% higher than in 1990/91 and in the next fifteen years, it would increase by 16%. Annual CO emissions in the other three cities are almost three and a half times less than that of Delhi in 1995/96. With very poor combustion efficiencies in two-stroke scooters, motorcycles and auto rickshaws, they nearly contributed in 1995/96 nearly 55%, 44%, 50% and 67% of total CO emissions in Delhi, Calcutta, Mumbai and Bangalore respectively. Contribution by two wheelers would further go up to 58%, 64%, 62% and 85% during 2010/11. With the country's liberalization policy, the penetration of new technology cars started in 1995, which is coupled with the introduction of catalytic converter in cars from April 1, 1995 in Delhi, Calcutta and Mumbai. These have resulted in drop in share of CO emissions from cars between 1995/96 to 2010/11. Share of CO emissions is likely to decrease from 39% to 27% in Delhi, 53% to 33% in Calcutta, 32% to 17% in Mumbai and 22% to 8% in Bangalore during the fifteen year period.

Except in Bangalore, all other cities are likely to have increasing share of CO contribution by bus. Emission factor of HC from gasoline vehicles are higher compared to diesel. Annual emission of HC in Delhi was 71450t, which is 30% higher than the present level and is expected to increase further to 17% by 2010/11. Like CO emission, HC emission in the three other cities is also three and a half times less than that of Delhi in 1995/96. With almost 20- 40% of the fuel supplied to two stroke engines are exhausted without being combusted, would lead to over 80% contribution of HC emission by scooters, motorcycles and auto rickshaws in Delhi during 1995/96. The corresponding values for Calcutta, Mumbai and Bangalore are 71%, 76% and 86% respectively. By 2010/11, two stroke engine driven vehicles will contribute 84%, 85%, 85% and 95% HC emission in Delhi, Calcutta, Mumbai and Bangalore respectively.

Diesel driven vehicles emit more NOx compared to gasoline. Emission rate of NOx is estimated to be the highest (83000 t in 1995/96) in Calcutta and would continue to remain around the same level in the coming years. However in Delhi, annual NOx emission is 43930t, which is 32% higher compared to the 1990/91 level and would increase by 70% by 2010/11. Similarly, in Mumbai the 1995/96 emission loading was 21550t, which is 18% more, compared to 1990/91 and 69% by 2010/11. In Bangalore, the emission level is 13160t during 1995/96 which is 72% higher compared to the 1990/91 level but this would decline to 63% by 2010/11. Buses contribute nearly 65%, 33%, 83% and 79% of NOx emission in Delhi, Calcutta, Mumbai and Bangalore respectively.

Contribution of SO2 emission is higher in diesel vehicles compare to gasoline. Highest emission (5180t) of SO2 is observed in Delhi during 1995/96, followed by Mumbai 3100t, Calcutta 1550t and Bangalore 1840t respectively. With respect to the 1990/91 loading, SO2 emission in Delhi, Mumbai, Calcutta and Bangalore in 1995/96 was 35%, 28%, 8%, and 72% more. These would increase further to 116%, 86%, 45% and 114% respectively by 2010/11. Diesel vehicles emit significant TSP compared to the gasoline ones. Delhi recorded the highest level of emission loading in 1995/96 (9440t). This is 34% higher compared to the 1990/91 level and it is further going to increase to 51% by 2010/11. Mumbai and Bangalore had the same TSP level of 3050t in 1995/96. The rate of increase of TSP emission in Bangalore would be very significant (around 135%) compared to Mumbai by 2010/11. Buses would contribute as high as 45% emission of TSP in Mumbai. While around one third of the TSP share would be contributed by buses in Delhi and Bangalore. In the case of Calcutta, only around 9% of the emission share is currently contributed by buses and is expected to decline marginally to 8% by 2010/11.Pb is only emitted by gasoline vehicles. Delhi recorded the highest loading (102t) of Pb in 1995/96, which is 30% higher compared to 1990/91 but would decrease after 2000/01 steadily with the gradual lead phase out program introduced in the country. Annual Pb emission in 1995/96 in Calcutta, Mumbai and Bangalore was 31t, 26t and 25t respectively and would decline steadily with lead phase out program.

Ambient Air Quality in Seven Major Cities During 2002

STATE / CITY	SO_2		NO_2		RSPM		SPM	
AREA CLASS	I	R	I	R	I	R	I	R
Andhra Pradesh								
Hyderabad	L	L	L	M	M	H	M	H
Delhi								
Delhi	L	L	L	M	C	C	H	C
Gujarat								
Ahmedabad	L	L	M	M	C	C	M	C
Karnataka								
Bangalore	L	L	L	M	M	H	L	H
Maharashtra								
Mumbai	L	L	L	L	M	H	M	C
Tamilnadu								
Chennai	M	L	L	L	M	M	M	M
West Bengal								
Kolkata	L	L	H	H	H	C	M	C

T.O.I. 10-7-2002

Twelve 'dirty' cities targeted

Times News Network

New Delhi: The Centre has asked the states to prepare pollution control plans for nearly a dozen 'dirty' cities by August 20. Plans for a second group of cities will be readied by October-end.

As for Delhi, the petroleum ministry says the CNG queues will continue, at least till November. The Central Pollution Control Board (CPCB) estimates that between 50 and 70 per cent of the air pollution in most cities is caused by vehicles.

As state environment secretaries and pollution control board officials met here for the second day on Tuesday, it was clear that a number of fundamental issues remain to be tackled before cities like Chennai and Bangalore can switch over in a big way to fuels like LPG.

These relate to supply, distribution, pricing, presence of stan-dardised kits, retro-fitment, safety, possibility of domestic cylinders sneaking in as replaceable cylinders and coordination between Union ministries and states for much of this.

Delhi, said petroleum ministry joint secretary Shivraj Singh, is getting natural gas in abundance after cuts in private industry allocations. "We see some problems up to November," he said, given the shortage of compressors and ongoing work on a pipeline.

Overall, his ministry's presentation indicated, there is not enough LPG and the gap will increase, with the only import source being West Asia. Other fuels also need to be looked at, it said, reiterating that the entire public transport fleet of any city should not be run on a single alternative fuel. In most cities, it was said, CNG and LPG as automotive fuels may need subsidies if these are to remain competitive.

The meeting decided that action plans for Kolkata, Ahmedabad, Pune and Kanpur, described as more polluted than Delhi, would be ready by August 20. So will plans for cities like Lucknow, Agra, Faridabad, Varanasi and Patna.

By the end of the exercise, plans have to be ready for Chennai, Bangalore, Hyderabad, Mumbai and towns like Indore, Jaipur, Kochi, Bhopal, Ludhiana, Surat, Nagpur, Nashik and [illegible]. In all, 27 cities are to be covered.

The CPCB, which has prepared a draft, says that action plans will have to deal with air pollution as a whole—vehicular and industrial pollution, cleaner fuels and pollution from diesel generating sets.

5.3 TAILPIPE EMISSIONS AND AIR QUALITY

Most alternative fuel vehicles tend to emit fewer tailpipe emissions when compared with an equivalent gasoline vehicle. When direct emissions testing were conducted (Battelle Memorial Institute, 1995 as cited by CEC, 1999), CNG earned the lowest ozone forming potential and carbon monoxide emissions of the four fuels tested: CNG, LPG (propane), M85, and reformulated gasoline (the base fuel). The exhaust system of CNG vehicles requires few modifications to produce low emission levels in comparison with a gasoline engine. While tailpipe emissions of gasoline vehicles have improved substantially over the past few years (and some have reached super ultra-low emissions (SULEV) certification), they require complex emissions control systems or a hybrid-electric drive train to achieve this in comparison with a natural gas vehicle. It must be noted, however, that auto manufacturers are capable of improving emissions of their gasoline vehicles. However, they typically only design their vehicles to meet emissions requirements, not to exceed them. Therefore, the fact that CNG vehicles have superior tailpipe emissions to most equivalent gasoline vehicles is more a cost-saving measure in the design of gasoline vehicles than an inability to improve their emissions. However, CNG vehicles appear to be a more cost-effective means of producing very low emissions vehicles. Several studies have analyzed the cost of improving air quality by comparing a number of alternative fuel vehicles. These studies generally consider the cost of the fueling system and CNG technology versus the amount of reduction in tailpipe emissions.

One study (Harrington, Walls and McConnell as cited by Walls, 1996) revealed natural gas vehicles meet the EPA's cutoff point for cost-effectiveness of under $10,000 per ton of hydrocarbons (HC) reduced. In comparison, the cost per ton of HC reduction in methanol vehicles was estimated at $33,000 to $60,000 (Krupnick and Walls, 1992 as cited by Walls, 1996). With regard to electric vehicles, it was concluded that due to the high production cost and disadvantages of ownership, battery-electric vehicles (which are currently the only vehicles capable of meeting California's zero-emission vehicle [ZEV] mandate) are an excessively expensive method of achieving tailpipe emissions goals, and can be met more cheaply with other low-emission fuels and vehicles (Rubin, 1994).

Due to the nature of their fueling system, dedicated natural gas vehicles produce little or no evaporative emissions during fueling and use as opposed to a gasoline vehicle which requires special modifications to achieve this goal. Dedicated CNG vehicles present substantial tailpipe emissions benefits over other alternative fuel and gasoline vehicles and from a cost-effectiveness perspective are viable solutions to reducing emissions from the light-duty vehicle segment, assuming auto manufacturers are unwilling to invest more money in further reducing gasoline vehicle emissions.

COMPARATIVE EMISSIONS FROM DIFFERENT FUELS

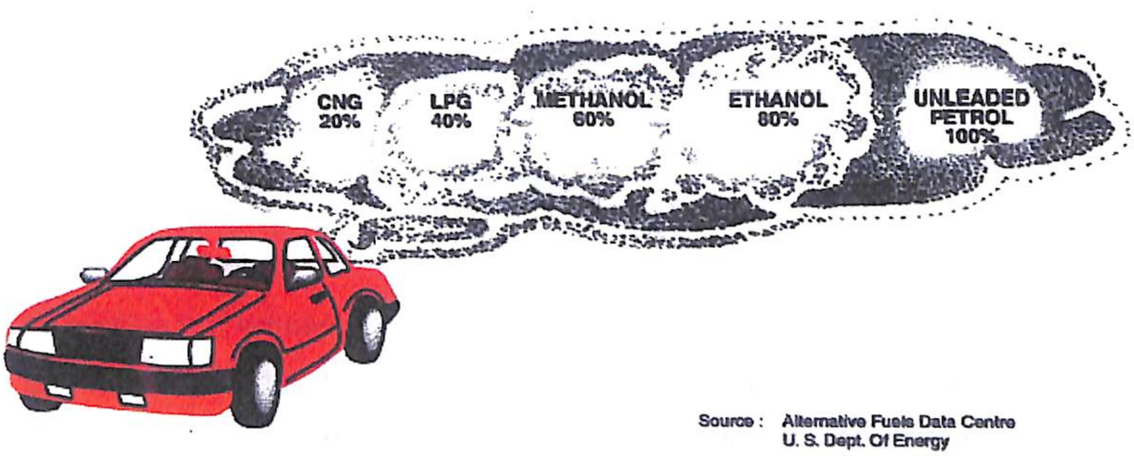


Figure - 4

5.4 GLOBAL CLIMATE CHANGE

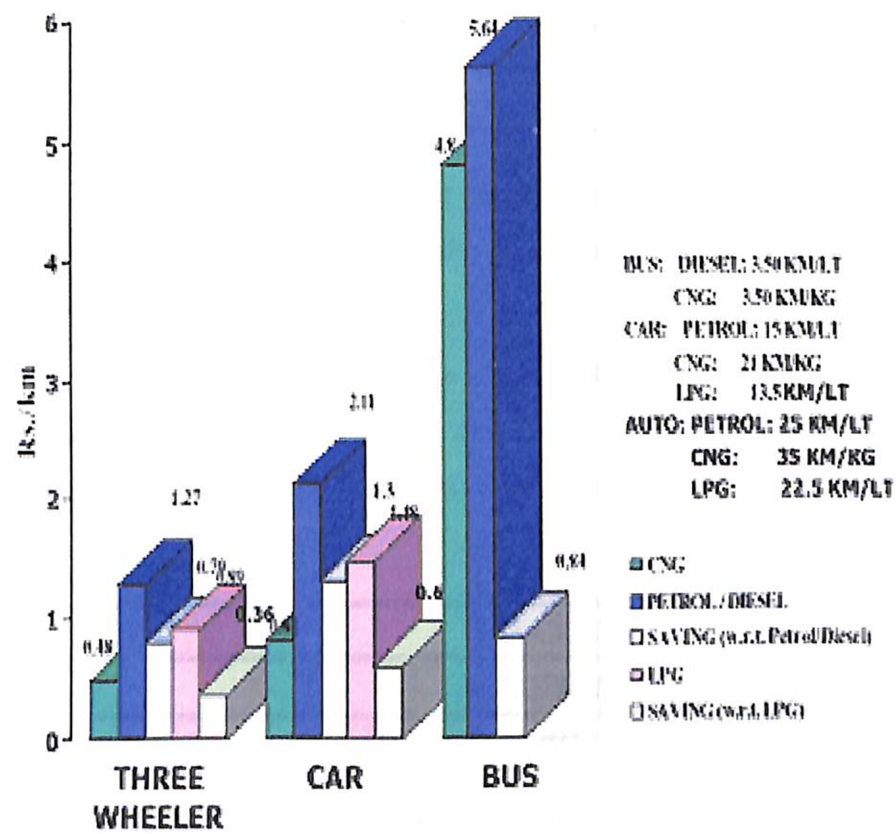
A growing concern with the American transportation sector is the potential impact carbon dioxide (CO2) emissions can have on global climate change. Carbon dioxide is a greenhouse gas (GHG) and the rising concentration of GHGs is expected to increase the average surface temperature of the earth and affect global climate, sea levels, water resources, agriculture, and ecosystems (CEC, 2000). Regional changes in climate can create favorable conditions for pathogens, and expand the life cycle of pests and enhance the spread of disease (CEC, 2000).

The Intergovernmental Panel on Climate Change (IPCC) in 1997 stated "the balance of evidence...suggests a discernible human influence on global climate (as cited by Laird, 2001)." The United States transportation sector emits large amounts of carbon dioxide into the atmosphere. In 1999, total US carbon dioxide emissions equaled 5,598.7 million metric tons and the transportation sector accounted for one-third of those emissions (DOE, 1999). Of that one-third, 98 percent were a result of petroleum products for transportation (DOE, 1999). California's vehicle fleet represents roughly 15 percent of the nation's total. It is understandable why the State of California, though officially not as concerned with global climate change as air quality, would nevertheless have interest in reducing the amount of carbon dioxide it produces. As a secondary benefit, vehicles which provide CO2 reductions may also provide energy security benefits.

Alternative fuel vehicles are considered to have carbon dioxide emissions advantages over gasoline vehicles because they generally contain less carbon than gasoline. Natural gas vehicles produce roughly 20 percent fewer carbon dioxide emissions than an equivalent gasoline vehicle (CEC, 1998) even after accounting for the input energy to compress natural gas (CEC, 1998). However, natural gas has a higher methane content (another greenhouse gas) so this could affect CNG fuel's advantage somewhat. Therefore, while CNG vehicles are not likely to offer the sole solution to reducing carbon dioxide emissions and subsequent potential effect on climate change, they do have significant advantages over traditional gasoline fueled vehicles, all other factors equal.

5.5 Economics of CNG

The growth of CNG vehicles in the year 2002 was primarily because of economic advantage of CNG with regard to petrol / diesel. The economics of running the CNG vehicles vis-à-vis its operation on petrol / diesel has been worked out at the current price of fuel. The results are reproduced in the form of the following bar graph, figure -5.



CNG : 16.83 Rs/Kg PETROL : 33.70 Rs/Lt. DIESEL : 20.73 Rs/Lt.

LPG: 20.04 Rs/Lt

Figure - 5

5.6 Indian Refueling Infrastructure

Cities where City Gas Distribution Projects being planned:

As per the directive of the Hon'ble Supreme Court of India dated April 5, 2002, in order to control heavy air pollution due to vehicular traffic, the following cities in India have been identified for developing infrastructure for distribution of alternative fuel:

Kanpur	Varanasi
Agra	Jodhpur
Faridabad Patna	Jharia

However, the study of air pollution indicated that the pollution in the cities of Jodhpur and Jharia is mainly due to dust pollution than vehicular emissions. Also, there are no trunk gas pipeline in the vicinity of Patna and Varanasi.

Subsequently, in August 2003, Hon'ble Supreme Court of India has issued a directive to the Union of India and the state governments to draw plans to introduce clean fuels in 11 cities apart from the existing cities of Delhi and Mumbai. These are:

Kolkata	Surat
Chennai	Lucknow
Bangalore	Kanpur
Hyderabad	Agra
Ahmedabad	Pune
Sholapur	

Under its Project Blue Sky, GAIL has already drawn plans to implement city gas projects in the five cities of Kanpur, Lucknow, Agra, Bareilly and Pune in phases at an estimated investment of Rs. 554 crores (equivalent to 118 Million USD).

CNG STATIONS IN INDIAAS ON JANUARY 1, 2004

Station Type	Delhi	Maha.	Gujarat				Grand Total
	IGL	MGL	Vadodara GAIL	Surat GGCL/ GSPC	Ankleshwar GGCL	Total	
Mother	56	3	1	1	0	2	61
Online	25	46	0	2	0	2	73
Daughter Booster	30	15	0	0	0	0	45
Daughter	6	0	1	0	1	2	8
TOTAL	**117**	**64**	**2**	**3**	**1**	**6**	**187**

Table -8

Item	Delhi	Mumbai	Gujarat				Grand Total
	IGL	MGL	Vadodara GAIL	Surat GGCL / GSPC	Ankleshwar GGCL	Total	
No. of vehicles							
Cars	15876	47870	450	663	123	1236	64982
Autos	56846	61497	16	429	0	445	118788
RTV/LCV	5164	7	0	0	0	0	5171
Buses	10075	47	0	0	0	0	10122
TOTAL	**87961**	**109421**	**466**	**1092**	**123**	**1681**	**199063**
Average Consumption						-	-
TPD	760.00	382.30	0.57	3.00	0.30	-	-
MMSCMD	**1.18050**	**0.54280**	**0.00073**	**0.00300**	**0.00030**	-	-

Table -9 Vehicle population and average consumption in different cities

The total no. of CNG stations planned to be operational by the end of financial year 2003 – 2004 would be as follows:-

1) Delhi: 120

2) Mumbai, Maharashtra: 88

3) Gujarat: 6

Difficulties for Developing CNG Infrastructure

The following difficulties are faced in developing CNG infrastructure:

- Limited natural gas allocation leading to delay in management decisions on expenditure commitment.
- Uncertainty about conversion of vehicles & CNG demand.
- Lack of indigenous technology.
- Capital intensive project - a mother station cost would be 5-6 times the cost of a petrol pump & pipeline need to be in place.
- Infrastructural constraints (Electricity, land etc.).
- Delay in getting permissions from statutory authorities.
- Objection from local people, encroachment.
- Low storage capacity of on board cylinders, thus requiring

Factors Influencing the Success of CNG Project

- Government commitment to the program
- Sustainable economic advantage over liquid fuels
- Appropriate CNG technologies
- Appropriate program management
- OEM support
- Safety of CNG vehicles and CNG economic are key factors that determine the success of CNG program

Environment and Climate Protection

In India a new Auto Fuel Policy has been adopted in October'03 and the policy gives a roadmap for achieving various vehicular emission norms over a period of time and the corresponding fuel quality up gradation requirements. While it does not recommend any particular fuel or technology for achieving the desired emission norms, it suggests, taking into account security of supplies and existing logistics, perspectives, that liquid fuels should remain as main auto fuel through out the country and that the use of CNG/LPG be encouraged. The report also recommends measures for improving the present mechanism of checking pollution form in used vehicles.

The roadmap for vehicular ignition norm for new vehicles would be as follows:

Coverage	Cars, LCVs & Heavy Duty Diesel vehicles	2/3 Wheelers
Entire Country	Bharat Stage II: 1.4.2005 Euro III Equivalent: 1.4.2010	Bharat StageII:1.4.2005 Bharat Stage III: Preferably from 1.4.2008 but not later than 1.4.2010
11 Major cities (Delhi/NCR, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur & Agra	Bharat StageII:1.4.2003 Euro III Equivalent: 1.4.2005 Euro IV Equivalent: 1.4.2010	

Lessons Learnt in Implementing CNG Program

IGL in a short span of five years has installed 117 CNG stations in NCT of Delhi in spite of various hurdles faced during implementation of the program. The following lessons have been learnt in implementing the CNG infrastructure development program:

- Study of geographical spread of CNG vehicles movement is a must to analyze the peak demand at individual CNG stations.
- Pipeline distribution infrastructure needs to be in place.

- Dedicated/adequate mobile cascade filling arrangement continuous supply of gas to daughter stations.
- Involvement of local government/transport authorities.
- Genuine cylinder kits and spare parts be used for CNG vehicles to avoid accidents.
- Suitable codes/standards are to be in placed for CNG kit fitment, testing etc.
- Safety and performance standards should be in place, monitored and enforced.
- CNG stations need to be built in large open space to allow multi vehicle and multi point dispensing.
- Development of CNG infrastructure needs to be in line with growth of CNG vehicles.
- Long term advance planning needs to be carried out.
- Development of CNG station is time and d capital consuming activity.

CNG IN INDIA

	NO OF STATIONS	NO OF VEHICLES
DELHI	117	85000
MUMBAI	66	110000
VADODARA	03	200
SURAT	02	2000
ANKLESHWAR	01	150
TOTAL	189	200000

Table -10

CNG - WORLD WIDE

	NO OF STATIONS	NO OF VEHICLES
USA	1250	1300000
ARGENTINA	952	710000
ITALY	355	370000
PAKISTAN	600	600000
NEW ZEALAND	190	43230
INDIA	189	200000
RUSSIA	187	205000
BRAZIL	131	120000
CANADA	120	87500

WORLD WIDE 3.5 MILLIONS CNG VEHICLES

Table - 11

5.7 Indian Transport sector

Growth and composition of registered vehicles

With over 2.4 million registered vehicles in Delhi as on 30th March 1995, the city has the major vehicle population in the country even though it position third in the list of mega cities in the country after Mumbai and Calcutta. It is interesting to note that the vehicle population of Mumbai (0.67 million), Calcutta (0.56 million) and Bangalore (0.8 million) taken together accounts for 2.03 million vehicles which is even less than the vehicle population of Delhi alone during 1994/95.

The annual registration of motor vehicles in the four cities went up at an average growth rate of 11.2% in Delhi, 7% Calcutta, 4.5% in Mumbai and 11.1% in Bangalore between 1984/85 and 1990/91. But, these growth rates declined between 1990/91 and 1994/95 to 7.8%, 4.2%, 1.5% and 8.4% in Delhi, Calcutta, Mumbai and Bangalore respectively. In absence of a convenient and well connected public mass transport system in the four cities, the growth of personal modes like scooters, motorcycles and cars have grown rapidly. The auto rickshaw as the intermediate public transport system has also grown very rapidly in late 1980s mainly in Calcutta and Bangalore. In 1994/95, the share of scooters and motorcycles together accounted for 75% of the total registered vehicles in Bangalore, 70% in Delhi, while in Calcutta and Mumbai its share accounted for 44% and 42% respectively. During the same period, the share of car and jeep taken together was 37% in Calcutta, 35% in Mumbai, 25% in Delhi and 14% in Bangalore. This means that the share of personalized modes in the four cities was highest in Delhi at 95% and least in Mumbai at 77% during 1994/95. Unfortunately, the share of public mass transport (that of a bus) has been declining in Delhi and Bangalore with its current share only around 1%, while in Calcutta and Mumbai, its share has been increasing with current share being 2.4% and 1.8% respectively. As far as goods vehicles are concerned their share has been declining in the total fleet size in each of the four cities. In 1994/95, its share was 5.14% in Delhi, 8.29% in Calcutta, 6.18% in Mumbai and 4.8% in Bangalore respectively.

Vehicle projections with attrition factor

Without altered policies and assuming an attrition factor (or vintage value) of 15 years for a scooter and motorcycle, 20 years for an auto rickshaw, 25 years for a car, taxi and jeep, and 10 years for a bus, it is estimated that Delhi is expected to have 2.4 million passenger vehicles plying on Delhi roads in 2000/01 and 2.8 million in 2010/11. The corresponding figures for Calcutta are 0.44 million and 0.53 million, Mumbai 0.42 million and 0.73 million; Bangalore 0.65 million and 0.97 million respectively. In other words, number of motorized passenger vehicles - with assumed attrition factor for different types of modes - is expected to increase by 40% in Delhi, 19% in Calcutta, 77% in Mumbai and 49% in Bangalore between 1995/96 and 2010/11.

Percentage increase in vehicle population (1985-2001)	
Ahmedabad	490
Vadodara	472
Surat	782
Mumbai	335
Delhi	422

Source: Mashelkar Committee Report, 2002 on Auto fuels.

Table - 12

Category-wise population of different vehicles in Ahmedabad, Surat & Vadodara as in April, 2002.

City	Autos/ Tempos	Cars/ Cabs	Buses	Goods Carriages	Tractors/ Others
Ahmedabad	68064	168833	22106	46138	67137
Surat	38275	76456	1399	41529	14969
Vadodara	22025	59623	1478	36144	31177
·	128364	304912	24983	123811	113283

Source : Mashelkar Committee Report.

Table - 13

Chapter – 6

Development of L-CNG Refueling System

Development of L-CNG Refueling System

The L-CNG refueling system is the refueling plant that fills CNG made from LNG for NGVs, having an advantage over the traditional CNG refueling systems. The purpose of development, a basic structure, the problem of development, the plan of the experiment and the results are as follows.

GENERAL DESCRIPTION

6.1 Differences between L-CNG Refueling System and Conventional Refueling System

Conventional CNG refueling systems, which have been widely used, basically takes out the gas from the gas supply pipes of city gas companies and increases its pressure using the compressor to refuel the compressed gas to the NGV.

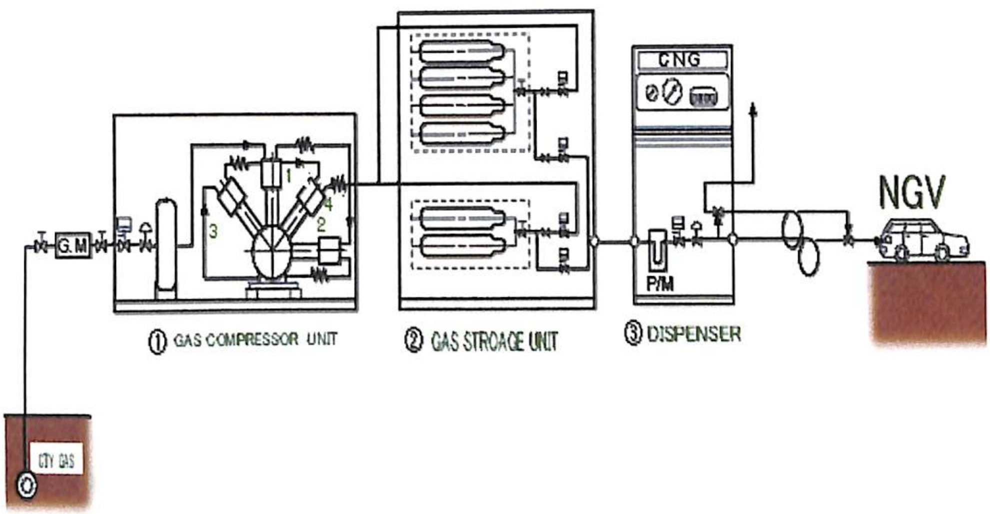


Figure 6 Example of conventional filling method

The main feature of this newly developed L-CNG refueling system is that it receives the LNG from the LNG lorry to the cooled LNG tank, increases the pressure of the LNG using the LNG pump, evaporates the gas using the vaporizer, stores the gas vapor into the gas storage unit, and charges and supplies the gas to the NGV (See the following Fig.).

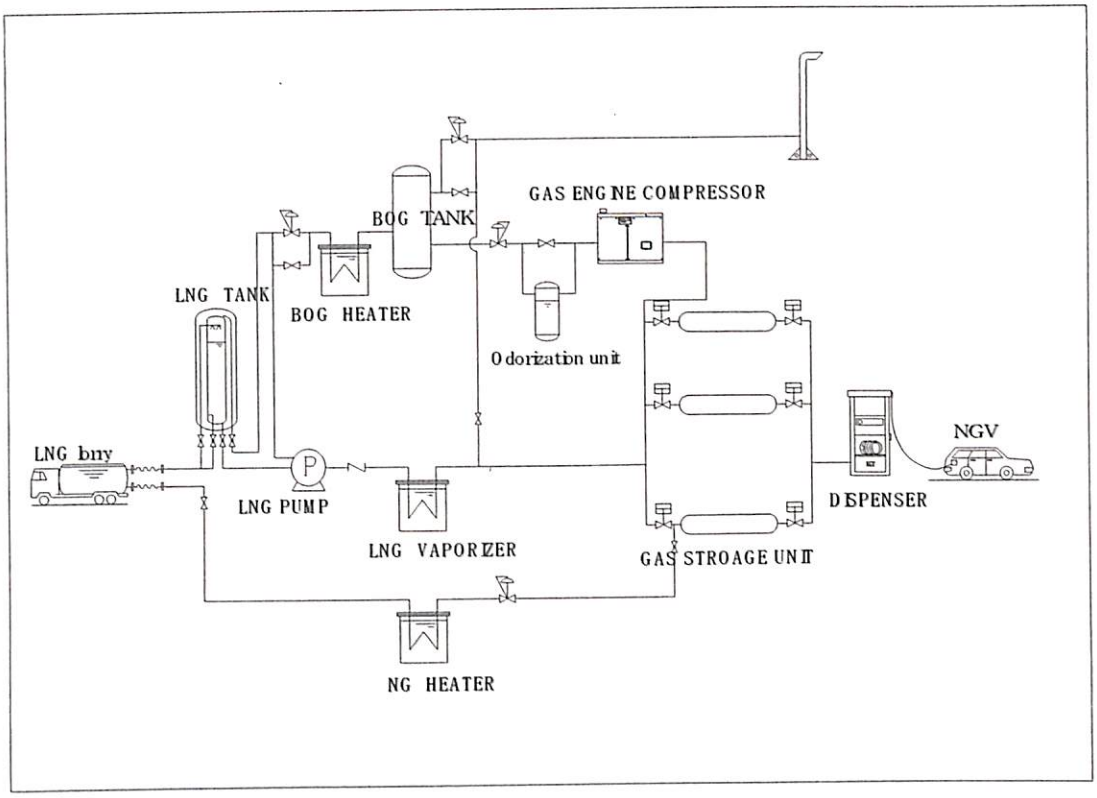


Figure 7. L-CNG REFUELING SYSTEM

6.2 Advantages of the Newly Developed L-CNG Refueling System when Compared to Conventional System

The following describes the advantages of the L-CNG refueling system when compared to the conventional refueling system.

(1) NGV refueling stations can be constructed in an area beyond city gas company supply areas.

Presently in Japan, the city gas pipes have been spread only in urban areas. Therefore, NGV refueling stations can be constructed only in limited areas. To solve this problem, refueling stations using the mother-daughter system are also used, but this system has not been widespread due to high operation costs. Therefore, the spread of the NGV is limited to business vehicles, such as city round buses and/or garbage collection cars that perform the routine work in urban areas. Thus, NGVs do not easily spread to the transportation vehicles among cities, which are originally expected to improve and reduce the exhaust gas.

Additionally, it is also not expected to maintain the infrastructure, such as construction of city gas pipes to refueling stations due to limited demands.

This newly developed L-CNG refueling system can be installed in LNG lorry delivery areas regardless of city gas pipes. Therefore, it is thought that the application of NGV is extended widely.

(2) LNG pump is used to produce the compressed natural gas (CNG), ensuring high efficiency.

In the conventional NGV refueling systems, the compressor is used to produce the CNG. Of course, it is possible to install a sufficient gas storage unit even using the compressor. If long-time continuous operation can be performed, highly efficient operation can be performed even using a small compressor.

However, when checking the current circumstances, particularly, those in Japan, the compressor cannot be operated efficiently due to legal limitations about gas storage units. Therefore, to make the refueling system applicable to refueling of the NGV, which needs to be performed within a short-time, it may be required to construct a refueling station where a large compressor with high-voltage receiving equipment is installed.

For example, a 250 $Nm^3/hr.$-class compressor normally requires power capacity of approximately 75 - 95KW. On the other hand, however, it must be carefully observed that the energy, which has been used for the compressor, is not used to travel the vehicles. We have no objection to that the use of natural gas to fuel vehicles preserves the global environment, but we have an objection to large amounts of electric power being consumed to charge the natural gas since other energy is consumed to generate the electric power.

That is, as the NGV is spread widely, large electric energy is consumed. As a result, a dilemma arises that this does not preserve the global environment effectively. Therefore, it is absolutely necessary to reduce as much energy used for refueling of the natural gas vehicle (gas refueling work) as possible.

From this viewpoint, use of L-CNG makes it possible to perform the gas refueling work more efficiently. For example, when using the LNG pump, a power source of about 7.5 KW is only needed. Additionally, energy is also required to evaporate the LNG. However, the atmospheric temperature and the BOG described later, gas, which cannot be used for refueling, are used as fuel for the boiler. Therefore, it is thought that this energy to evaporate the LNG is almost disregarded.

(3) Future possibility – composite utilization of energy and refueling of LNG vehicles.

A system that we think to manufacture at this time is a refueling system, in which the hot-water vaporizer is combined with the LNG pump.

We did not especially select the air temperature type vaporizer having low running costs, in order to efficiently use the boil off gas (BOG) that is generated as the LNG is stored and received.

Additionally, the refueling system can be combined with other cogeneration systems and utilize the cold heat. Therefore, the application of this system can be extended and the system has large promise since it uses the energy, which is normally disposed of. Moreover, if LNG vehicles become popular, the refueling system is made applicable to such vehicles with small modifications. It is said that this point also becomes the great advantages.

6.3 Disadvantages of L-CNG Refueling System when Compared to Conventional Refueling Systems

On the contrary, the following points are considered as disadvantages when constructing the L-CNG refueling system.

(1) Problems about initial construction cost and installation space.

When compared to the conventional NGV refueling systems, the L-CNG refueling system needs specific units and devices designed only for LNG, such as the LNG tank, LNG pump, and LNG vaporizer.

Therefore, it is thought that the initial construction cost may increase by 30% to 50% when compared to that of the conventional system. Additionally, since an installation space for such units and devices are needed, the necessary land area also becomes larger than that of the conventional compressor system.

(2) Problems about production of boil off gas and weathering

It has already been described that the boil off gas (BOG) is produced as the LNG is received and stored. The BOG is a gas, the main component of which is methane. The BOG is produced as the light contents of LNG are evaporated by the heat input to the LNG tank and/or piping.

In plants using the LNG for fuel equipment for factories and city gas LNG plants, the supply pressure is only approximately 0.2 to 0.3MPa. Therefore, the BOG can be mixed in the supply gas without any problems.

However, the application of the L-CNG refueling station is intended only for refueling to NGV. Therefore, it is difficult to process the low-pressure gas, which has been evaporated once. Since the main component is methane gas, which is global warming gas, it must not be exhausted to the atmosphere.

Additionally, as the BOG is produced, the weathering problem must be investigated that the LNG component in the LNG tank is concentrated to heavy contents. It is thought that this problem may easily occur in the refueling station where a large LNG tank is installed and only few vehicles are charged every day. If this occurs, the gas may not become applicable to the fuel for the NGV as the concentration of the heavy content becomes high.

In addition to the above problems, there are several problems, which have not been solved, such as fog generation due to use of air temperature type vaporizer or cool-down and quick restart methods of the LNG pump.

When we started to develop this refueling system, we aimed at solving such problems and along with the promotion of the practical uses of the L-CNG refueling system.

6.4 STRUCTURE OF L-CNG SYSTEM

In the L-CNG system, several units and devices are used, which have not been used in the conventional refueling system as described previously. The following describes these units and devices.

LNG Tank

It is necessary to install a LNG tank to store the LNG. Generally, vertically or horizontally placing cylindrical tank, which is called "CE (cold evaporator)", is used.

To prevent the heat input from the outside, the LNG tank has a double-metallic shell structure consisting of an inner tank (LNG tank) and an outer tank (cold insulation tank). The clearance between the inner and outer tanks is filled with the heat insulation material (pearlite). Additionally, this clearance is kept in a vacuum status at high level to improve the heat insulation effect.

LNG Tank (horizontal)

LNG Tank (vertical)

LNG Pump

A LNG pump is installed to increase the LNG pressure from 0.2 - 0.3 MPa (G) to 25 MPa (G).

When selecting a LNG pump and installing it, the following points have been considered.

(1) A plunger type LNG pump is used by taking the required pressure and flow rate into consideration.

(2) To prevent any pulsation trouble, a pressure control tank (accumulator) is installed on the discharge side.

(3) When considering the quick restart, it is preferable to use a submerge type pump, which is installed inside the LNG tank. However, when considering the maintenance work, use of submerge type pump becomes difficult from a technical viewpoint. Therefore, a vertical plunger pump is used, in which the pump main body is stored in the small heat insulation casing. This casing has the vacuum heat insulation structure, the same as CE. The heat/cold insulated pipes are connected to the upper and lower portions. Each portion is connected to the bottom part and gas phase part of the LNG tank. Therefore, the inside of the pump casing is always filled with LNG.

(4) The pump is installed as close to the LNG tank as possible and has a structure, in which the BOG produced at the inlet is escaped to the LNG tank.

LNG Pump

LNG Vaporizer

A LNG vaporizer is installed to evaporate the boosted LNG. At this time, either an air temperature vaporizer that uses the air temperature or a hot water type vaporizer that supplies the heat source from other parts through the hot water is selected.

Features of Air Temperature Type Vaporizer

The following describes the features of the air temperature type vaporizer.

(1) Since the atmospheric temperature is used as heat source, additional heat source unit and hot water piping are not required, ensuring the simple structure. The installation space can also be reduced when compared to the hot water type vaporizer.

(2) Since the atmospheric temperature may affect the vaporizer operation, the temperature of the produced CNG does not always become constant. Normally, the temperature of the produced CNG becomes a level 10°C lower than the atmospheric temperature.

(3) If this vaporizer is operated continuously, frost or ice may stick to the fin tube surface of the vaporizer, causing the evaporation performance to lower. Additionally, fog may be produced depending on the atmospheric temperature and humidity. It is already known that this fog may cause the system to malfunction if any entry-monitoring sensor is installed. Additionally, the fog may hinder the view of vehicles if the fog stays on the road.

Features of Hot Water Type Vaporizer

The following describes the features of the hot water type vaporizer.

(1) This vaporizer uses the hot water as a medium and needs other heat sources. Therefore, several units, such as hot water boiler and hot water circulation pump are required in addition to the vaporizer. However, it is possible to use the heat delivered from other units as the heat source. In this development, it has been determined to use a hot water boiler that uses the heat from other units as fuel for the BOG process described previously.

(2) Since only the set temperature of the hot water affects the gas temperature, change of complicated control parameters are not needed. Additionally, since the temperature of the produced gas is stable, it is possible to avoid the natural pressure increases in the gas

storage unit.

(3) Even though the vaporizer is operated continuously, the performance is not lowered. Additionally, fog is not produced. Since it is not necessary to consider the ventilation system when installing this vaporizer, the vaporizer can also be stored in the pit of the refueling station.

BOG Tank

A BOG tank is needed, which is used to store the BOG from the LNG tank and pump. However, when the produced BOG is diffused at adequate intervals, this tank is not required absolutely. Since the precondition of this development plan is producing BOG as much as possible, the BOG tank needs to be installed.

Hot Water Type Vaporizer

BOG Tank

Units and Devices Common to those of Conventional Refueling Stations using Compressors

The downstream side of the LNG vaporizer is basically the same as that of the refueling system using the compressor. Therefore, common units and devices can be used.

Gas Storage Unit

Dispense

Others

The BOG of the BOG tank is used as the heat source for the vaporizer as described above. As for the process other than this method, a system is used that increases the pressure using the compressor and collects the gas to the gas storage unit. This compressor is intended to process the BOG and is not intended to increase the pressure at normal working level. Therefore, a compressor having a large capacity is not required. In this system, a small engine compressor is used.

This compressor is manufactured by modifying the small engine-type charger that is developed by Yamaha and our company jointly. The BOG is used as the fuel and the BOG is compressed to feed it to the gas storage unit. Therefore, the BOG may be processed efficiently.

Odorization Unit

According to the legal regulations in Japan, the fuel gas to be charged to the NGV must be odorized appropriately. Therefore, an odorization unit is installed.

In the conventional refueling system using the compressor, the city gas, a raw material, already has the odor. Therefore, it is not necessary to odorize the city gas. However, since the LNG is colorless and odorless, it is necessary to install an odorization unit. The odorant uses THT (tetrahydrothiophene), the same as that used for the city gas.

The freezing point of this material is -96.1°C and the material coagulates inside the LNG. To prevent any problems from occurring in the LNG pump, mixing the odorant in the LNG must be avoided.

Since no documents could be found describing whether or not the odorant has sufficient volatilizing performance and mixing capability for the high-pressure CNG, we have developed the verification tests. The details are described in the clause, Test Items.

Small Engine Compressor

Odorization Unit

LNG Receiving Equipment

In addition to the LNG tank, various equipment units are installed to receive the LNG from the LNG lorry.

Lorry Receiving Hose

Lorry-Pressurization Evaporator

This evaporator is designed to evaporate the fluid in the LNG tank to pressurize the gas phase of the lorry and to unload the LNG to the LNG tank. Since this system uses the gas in the gas storage unit with the decreased gas-pressure, this lorry-pressurization evaporator is not needed.

Chapter – 7

Design methodology & Handling systems used in CNG Facilities

7.1 Sample Specification Reciprocating Compressor Package for Compressed Natural Gas Fueling Station

Application Information

Gas: Utility grade natural gas

Number of units:

Flow at design point: SCFM

Specific gravity:

Design suction pressure: PSIG

Minimum suction pressure: PSIG

Maximum suction pressure: PSIG

Discharge pressure: PSIG

Suction temperature: °F

Design ambient: °F

Interstage temperature: °F

Site elevation: Feet

Area classification: Class I, group D, division 2

Gas supplied to the compressor shall be clean and dry. Dry gas for compressor specification purposes is defined as the moisture content being low enough that water will not condense during the compression and cooling processes. Adequate suction filtration to remove condensates and particulates shall be provided or specified by purchaser to be included in the seller's scope of supply.

Design suction pressure is the reference point at which the compressor and cooler shall be designed to achieve the specified flow. If at maximum suction pressure, power consumption exceeds rating of driver required for the design pressure conditions, purchaser shall advise if a larger driver is to be supplied or if pressure regulators are acceptable to limit power consumption.

The following national standards shall be followed:

- AMSE/ANSI B31.3
- ASME unfired vessel code
- NFPA 52
- NFPA 70
- OSHA Part 29

Compressor package specification shall be as follows:

Compressor shall be of the horizontal opposed reciprocating piston design and include crosshead guides as supplied by Knox Western or equal. Compressors with trunk type (automotive type) cylinders that also serve as the crossheads shall not be acceptable. Compressor shall be designed for natural gas service. No converted air compressors shall be acceptable.

Compressor shall have low linear piston speed. At maximum compressor speed (RPM), the piston speed shall be less than 758 feet per minute. As the rate of piston ring wear is directly related to linear speed, the compressor will have longer ring life than a machine with a higher linear piston speed. This means longer wear and less down time than units with higher piston speeds.

The compressor shall be a true balanced-opposed design and have a fully machined crankshaft to provide optimum balance and vibration free operation. This reduces the foundation requirements and your installation expenses.

The frame shall be pressure lubricated including crosshead guide, wrist pin bushings, connecting rod bearings and (spray) main bearing. This type of lubrication is much more constant than splash lubrication and results in longer compressor life and lower maintenance costs.

The compressor shall be equipped with double acting or tandem, single acting cylinders as needed to meet the configuration requirements of the application. The maximum allowable working pressure shall be at least 10% over the maximum operating pressure of the application. Maximum discharge pressure shall be less than 4500 PSIG with the maximum working pressure being 5000 PSIG. Cylinder shall be hydro tested at two times the maximum allowable working pressure. Design temperature of the cylinder shall be 350°F with maximum operating temperature being 300°F.

As the process is sensitive to liquid carry-over from the compressor, reduction of lubricating oils is very important. The cylinders on these compressors shall be, as minimum requirement, mini (or minimum) lubricated cylinder as defined as having no injected oil. The only lubrication is that which migrates through the pressure packing along the piston rod from the crankcase. By using reinforced TFE piston and rider rings, no oil is required to be forced in the cylinder. This eliminates the requirement of recovering and disposing of the cylinder lubricant from the gas stream.

If oil free compression is required, true non-lubricated cylinders with a long, single compartment distance piece may be specified. No part of the piston rod shall alternately enter the crankcase and the gas cylinder pressure packing.

The cylinders on the compressor shall be non-cooled cylinders. Non-cooled cylinders employ large surface areas to conduct the heat of compression into the ambient air, plus further cooling is accomplished by the cool inlet gas entering the cylinder through large passageways within the cylinder casting. These cylinders have the advantage of simple construction, free from the stresses induced by local cooling and eliminate the requirement of a closed loop cooling water system. Gas cooling is accomplished by a forced air cooler.

Compressor valves shall be of the plate design. They shall be a simple guard and seat assembly type valve. Valves may be either the individual plate type or a ported plate type.

The compressor package shall be designed to be placed outdoors without an enclosure when operating in a normal operating range. Compressor enclosures shall only be required when continued operation in subfreezing ambient is expected, or when noise abatement, ascetics or safety and security are concerns.

Capacity control on the compressors shall be achieved by an automatic discharge to suction bypass control. A pressure transducer monitors the discharge pressure and opens a valve on the bypass line accordingly to direct the flow back to the suction side. The advantage of this type of control system is that it automatically controls variable flow over the full range of pressure and flow conditions. An adequately sized suction receiver shall be included in the compressor package. The suction separator may be incorporated in the receiver. Capacity control by suction valve unloading shall not be acceptable.

The bare compressor shall be tested for a minimum four hours by the manufacturer to ensure proper fit up. The packager shall test the complete package on natural gas for a minimum of four hours to ensure proper function of the compressor package.

The compressor shall be driven by either a TEFC electric motor or natural gas fueled engine as determined by the purchaser. The driver may be coupled with compressor with V belt drive on applications of 150 horsepower or less. Guards for belts and couplings that comply with OSHA regulations shall be supplied. Driver shall be suitable for the hazardous location as described above.

Forced air intercoolers and after coolers shall be supplied. Coolers shall be of the fit fan type and be designed to cool the gas within 20 degrees of the design ambient temperature.

Suction and interstage separators with drain controls, as required, shall be included. Interstage piping shall be supplied with relief valves at the suction side of the compressor and at the discharge of each stage. Piping with nominal diameter of one inch or less may be bright-annealed stainless steel tubing with high pressure, stainless steel fittings. Welded piping shall comply with ASME B 31.3.

Control panel, minimum instrumentation, alarms and shutdowns shall be supplied as follows:

- High discharge temperature at each stage
- Low suction pressure
- High discharge pressure at each stage
- Compressor vibration
- Low compressor oil pressure
- Emergency shutdown
- Interfaces as required for station management system

The compressor controls may be included in a local panel or incorporated in the station management control system.

Gas supplied to the compressor shall be clean and dry. Dry gas for compressor specification purposes is defined as the moisture content being low enough that water will not condense during the compression and cooling process. Adequate suction filtration to remove condensates and particulates shall be provided or specified to be included in the package scope of supply by purchaser.

The following documentation shall be submitted as minimum:

- 3 sets, blueprints, complete general arrangement and piping and instrumentation drawings
- 3 sets, blueprints, final drawings
- As built recommended spare parts and special tools list

Start up and training by the compressor manufacturer's factory service engineer for each package shall be available as an additional item.

7.2 System and Method for Compressing Natural Gas

A system and method to refuel vehicle storage tanks with compressed natural gas (CNG) utilize a single stage compressor operable at suction pressures ranging from about 330 to about 3600 psig and discharge pressures ranging from about 330 to about 4500 psig.

The use of compressed natural gas ("CNG") as an alternative fuel for powered vehicles is well known. Natural gas is less costly in most cases and cleaner fuel than gasoline. One disadvantage of compressed natural gas as a powered vehicle fuel is the required volume to store the quantity of gas needed to provide a range of travel comparable to that experienced with gasoline. In order to store a adequate volume of natural gas to provide a reasonable range of travel, it has been thought desirable to compress the natural gas to a pressure of about 3000 to 3600 psi or higher.

As the vehicle tank pressures required to store adequate natural gas to provide a reasonable range of travel are relatively high when compared to available consumer line pressures, the refueling of vehicle storage tanks presents yet another problem. Refilling vehicle storage tanks with CNG within a time period comparable to that required to refill conventional vehicle fuel tanks with gasoline can necessitate the use of large, costly, multistage compressors. Alternatively, home or on-board CNG refueling systems have been developed that can deliver the compressed gas at the required pressure, but such systems are characterized by very low flow rates, necessitating long periods for refueling.

Among the various systems for refueling vehicle storage tanks that have previously been disclosed, one conventional system uses a large, multistage compressor to compress the natural gas to about 4000 psi or greater and then holds the CNG in large volume intermediate storage tanks at that pressure. During refueling, the CNG is allowed to flow into the vehicle storage tanks until the vehicle tank pressure is about 3000 psi. After refueling, the intermediate storage is replenished with sufficient gas to again raise the storage pressure to about 4000 psi. This system is inefficient because of the repetitive need to charge storage tanks to about 4000 psi.

Another system, disclosed in U.S. Pat. No. 4,646,940 utilizes a differential pressure measuring apparatus in controlling CNG refueling. The patent discloses preferentially refueling the CNG tanks of a vehicle first from low pressure, then intermediate pressure, and finally, high pressure storage tanks. A reference cylinder at 2750 psi is used to cut off the refueling operation.

U.S. Pat. No. 4,501,253 discloses a low volume (approximately one cubic foot per minute) on-board automotive methane compressor for refilling vehicle storage tanks by compressing the gas from available line pressure to about 2000 to 3000 psi.

U.S. Pat. Nos. 4,515,516 and 5,169,295 disclose systems in which liquid pressure is used to boost CNG pressures in storage/refueling process. U.S. Pat. No. 4,515,516 discloses a home use natural gas refueling system in which a liquid is used to boost the gas from line pressure to greater than 2000 psi. The system utilizes a variable rate pump which pumps the compression fluid at a high rate for low pressures and a low rate for high pressures. (An illustrative flow rate is about one gallon per minute of compression fluid above 600 psi.)

U.S. Pat. No. 5,169,295 discloses a higher volume liquid-based compression system that can be mounted on a car, truck, boat, train or plane, but is preferably mounted on a tractor trailer truck with the hydraulic pumps connected to the tractor engine by a transfer case. The maximum pressure of the liquid supplied from the liquid supply means is less than the minimum pressure of the gas from the gas-supplying conduit. In the preferred embodiment the supply pump has an maximum output pressure of about 350 psig, and the maximum pressure of the gas-supplying conduit may range from about 400 to about 2900 psig.

Other previously disclosed CNG refueling systems utilize adsorbent-filled cylinders to reduce the tank pressure needed to store a predetermined amount of natural gas. Such systems are disclosed, for example, in U.S. Pat. Nos. 4,522,159; 4,531,558; and 4,749,384.

Summary of Method

According to the current invention, a CNG refueling system and method are provided that will enable motor vehicle storage tanks to be refueled quickly and efficiently through the use of a single stage compressor that is operable over a wide range of suction pressures in combination with means for temporarily storing the CNG at a preferred intermediate storage pressure of from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig (based on a storage temperature of about 70 DEG F.) and means for selectively supplying gas to the compressor at the intermediate storage pressure. Because the most efficient storage pressure for natural gas at 70 DEG F. ranges from about 1700 to about 2700 psig, within this pressure range the greatest volume of gas can be withdrawn from storage with the smallest attendant reduction in storage vessel pressure. By selectively controlling the inlet gas supply to the compressor between an external (relatively low pressure) supply line and intermediate storage vessels, thereby taking advantage of the higher density of gas drawn from the intermediate storage vessels, one can achieve an increase in compressor capacity without increasing horsepower or energy consumption. Where the desired maximum vehicle tank pressure exceeds about 3000 psig, refueling rates can be increased and horsepower requirements reduced by first delivering CNG to the vehicle storage tanks simultaneously from the compressor and from the intermediate storage tanks until the vehicle tank pressure equalizes with the intermediate storage pressure, and then by "topping off" the tanks with CNG supplied to the compressor from intermediate storage at pressures ranging between 1700 and 2700 psig. Whereas a 20 horsepower compressor may, for example, compress about 97 cfm natural gas from a suction pressure of about 800 psig to a discharge pressure of about 3000 psig, the same 20 horsepower compressor may compress about 345 cfm natural gas from a suction pressure of about 2500 psig to a discharge pressure of about 3000 psig. This increased CNG delivery rate at higher pressures enables a user to fill vehicle storage tanks quickly and efficiently to pressures greater than 3000 psig.

According to one embodiment of the invention, a CNG vehicle refueling system is provided that comprises: Means for selectively delivering natural gas received from an external source directly to a motor vehicle storage tank at the available line pressure; means for simultaneously delivering part of the natural gas received from the external source directly to the motor vehicle storage tank and for compressing part of the natural gas received from the external source and delivering the CNG to intermediate storage at a pressure higher than the available line pressure; means for simultaneously delivering CNG to the vehicle storage tank from the compressor discharge and from intermediate storage; means for selectively delivering CNG from the intermediate storage to the suction side of the compressor for further compression; means for delivering the further compressed natural gas into the motor vehicle storage tank; and means for selectively refilling the intermediate storage with natural gas compressed from available line pressure after the vehicle storage tank is filled.

According to another preferred embodiment of the invention, the subject refueling system comprises a single stage compressor operable over a range of suction pressures extending, for example, from about 330 to about 3600 psig with a discharge pressure of up to about 4500 psig, in combination with means for temporarily storing the compressed gas in intermediate storage at a pressure ranging between about 330 and about 3600 psig (preferably between about 1700 and about 2700 psig, and most preferably between about 2300 and about 2400 psig), and means for selectively controlling the supply of gas to the suction side of the compressor from either a relatively low pressure source such as a natural gas transmission line or from the intermediate storage.

According to another embodiment of the invention, a motor vehicle refueling system is provided that comprises in combination: A single stage compressor connectable to a source supplying natural gas at a pressure ranging from about 330 to about 1000 psig that is operable at suction pressures ranging from about 330 to about 3600 psig and at discharge pressures ranging from about 330 to about 4500 psig; intermediate storage means for temporarily storing CNG at intermediate storage pressures ranging from about 330 to about 3600 psig, preferably from about 1700 to about 2700 psig, and most preferably from about 300 to about 2400 psig; means for supplying natural gas received from the external source directly to a motor vehicle storage means at a supply pressure ranging from about 330 to about 1000 psig; means for simultaneously supplying CNG to the vehicle storage means from the intermediate storage means and from the compressor until the pressure in the vehicle storage means equalizes with the intermediate storage pressure; means for further compressing CNG supplied from the intermediate storage means up to the maximum intended fill pressure for the vehicle storage means, preferably from about 3000 to as high as about 4500 psig, to complete filling the vehicle storage means; and means for

compressing natural gas from the source pressure up to the desired intermediate storage pressure to refill the intermediate storage means after the refueling the vehicle storage means.

According to another embodiment of the invention, a method for refilling vehicle storage tanks with CNG is provided that comprises the step of using CNG supplied from intermediate storage at a pressure ranging from about 330 to about 3600 psig, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig, as the feed to a compressor that is capable of further pressurizing the CNG to a discharge pressure as high as the intended maximum fill pressure of the vehicle storage tanks, ranging up to about 4500 psig, and most preferably from about 3000 to about 3600 psig. By using CNG temporarily stored at a pressure ranging from about 1700 to about 2700 psig to supply a refueling compressor, one can "top off" vehicle storage tanks quickly and more efficiently than has been achieved through the use of prior art methods.

According to another embodiment of the invention, a method for refueling vehicle storage tanks with CNG is provided that comprises the steps of: Supplying natural gas at a pressure ranging from about 330 to about 1000 psig to a single stage compressor that is operable at suction pressures ranging from about 330 to about 3600 psig with attendant discharge pressures ranging from about 330 to about 4500 psig; compressing and temporarily storing CNG at intermediate storage pressures ranging from about 330 to about 3600 psig, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig; compressing CNG from the supply pressure (about 330 to about 1000 psig) to the vehicle storage tank pressure and discharging the CNG to the vehicle storage tanks while simultaneously supplying CNG to the vehicle storage tanks from the intermediate storage tanks and while allowing the vehicle storage tank pressure to equalize with the intermediate storage tank pressure; when the vehicle storage tank pressure has equalized with the intermediate storage tank pressure, supplying CNG to the compressor from the intermediate storage tanks and further compressing the CNG up to the intended full vehicle storage tank pressure, preferably from about 3000 to about 4500 psig, and most preferably from about 3000 to about 3600 psig, until the vehicle storage tanks are filled; and thereafter refilling the intermediate storage tanks with CNG supplied to the compressor at about 330 to about 1000 psig until such time as the intermediate storage tanks are again filled to a predetermined pressure ranging from about 330 to about 3600 psig, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig.

According to one preferred embodiment of the method of the invention, when the vehicle storage tank pressure is below the available line pressure (preferably from about 330 to about 1000 psig) at which natural gas is supplied to the compressor suction at the start of refueling, the vehicle storage tank pressure is allowed to equalize with the available line pressure prior to supplying CNG to the vehicle storage tanks either from the compressor or from the intermediate storage tanks. While in this mode of operation, if the pressure in the intermediate storage tanks is below a predetermined desirable level such as, for example, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig, the compressor can be used to refill the intermediate storage tanks to the predetermined desirable pressure level while the vehicle storage tank pressure is equalizing with the available line pressure. As used herein, the term "available line pressure" is used to include any source (other than the storage tanks of the vehicle being refueled) of natural gas at a pressure ranging from about 330 to about 1000 psig. Where the actual available line pressure is lower than about 330 psig, the use of a booster pump or other similarly satisfactory means may be required in order to raise the line pressure to a level of at least about 330 psig.

7.3 TRANSPORT, STORAGE AND DISTRIBUTION OF COMPRESSED NATURAL GAS

System concern with transport and storage of compressed natural gas (CNG) at high pressure (HP) and distribution of natural gas at high pressure (HP), medium pressure (MP) and low pressure (LP), which system is distinguished in that the layout thereof is such that during fluid transportation to or between units of the system or internally between tanks of the separate units a closed loop can be formed in which gas at specific pressure is

transported from one or more tanks to one or more other tanks while liquid at the same pressure as the gas or at marginally higher pressure is transported from said one or more other tanks to said one or more first tanks, the volume of said one or more first tanks being approximately equal to the volume of said one or more other tanks.

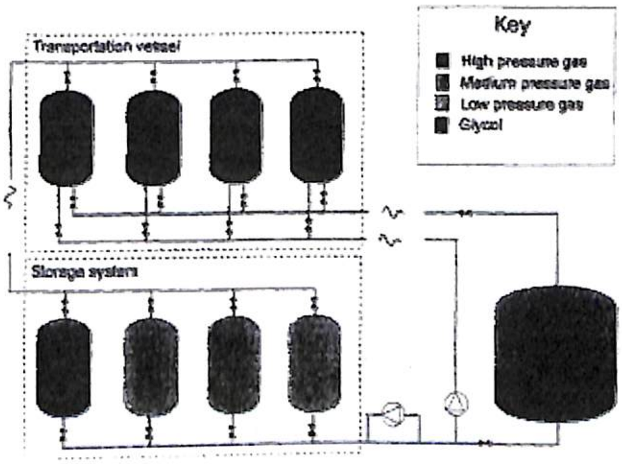


Figure - 8

Storage and transporting of compressed natural gas has a substantial potential worldwide and it can be advantageously compared with LNG and pipelines for the appropriate combinations of distance from the gas source and gas consumption.

Traditionally, storing of natural gas in large amounts has been restricted to underground installations at near atmospheric pressure. Underground storing of natural gas at elevated pressure requires reinforcement of the walls of the underground installation. The pressure limit is 40 bar g for storing natural gas in underground installations.

To store CNG at higher pressure steel containers are required, and so far this technology has been restricted to relatively smaller volumes, like tanks on Lorries and trains.

Filling of a pressure container for transportation of natural gas from a gas source at high pressure (e. g. a HP gas pipeline) is associated with a low initial temperature because the gas must be choked before reaching the empty container, which involves a substantial pressure difference. If the pressure of the gas source is very high, the initial temperature may drop to e.g.-100 C which will result in the formation of gas hydrates and ice like structure unless the gas has been dried. The very low temperature may cause great material related problems for the construction. Further, very high gas speeds and choked flow in the tube system will occur, and the time for filling the tank can be very long.

However, if different pressure levels or different temperature levels are available at the gas terminal, the transport container may be loaded directly without significant temperature problems. One example is high temperature gas downstream export compressors.

Unloading from a pressure container is also associated with low temperatures. The receiving container will be subjected to expansion effects with associated low temperature during unloading of the transport container. A still more serious problem is the extremely low temperature which is obtained in the transport container per se due to expansion of gas in the container at near adiabatic conditions. The thermodynamic effect which occurs when gas in a container expands is different from the mechanism upon choking, and calculations show that the temperature of the gas and in the container upon unloading may sinkto-150 C

In Patent Publication US 4446804 a process for transportation of oil and gas at high pressure in tanks on board a ship is disclosed, whereby loading and unloading are carried out using a suitable liquid under pressure, for instance water, in the separate tanks. The loading comprises filling a tank or group of tanks containing liquid under pressure with oil and gas while the pressurized liquid is simultaneously displaced to the next tank or group of tanks to be filled, whereupon the next tank/group of tanks is filled with the load while liquid under pressure is further displaced to a third tank/group of tanks and so on. The unloading comprises removing the load from one tank or group of tanks by introducing a liquid under pressure into the tank/group of tanks, unload the load in the next tank/group of tanks through the transfer of liquid under pressure from the first tank/group of tanks to the next one and so on, whereby the ratio between oil and gas in the mixture is kept as constant as possible during the entire unloading operation by adjusting the unloading of gas from the different tanks or groups of tanks.

According to US 4446804 it is considered most advantageous to operate at a pressure of about 100 bar. The known process concerns according to the patent claims only mixtures of oil and gas, however, in the specification it is mentioned that the process also may be used for gas alone (column1, lines 64-66). There is no special mention of the increasing problems met upon transportation and handling of gas without oil. Liquids are nearly incompressible and, accordingly, do not contribute to the introductorily mentioned problems when loading and unloading gas at high pressure, which problems, accordingly, are biggest when handling only gas.

Further, in the patent publication US 4446804 other liquids than water have not been mentioned for pressure equalization and displacement during loading and unloading of oil and gas. Neither is anything particularly mentioned regarding certain ways of coupling tanks together beyond what appears from that which is mentioned above. The water for pressure equalization and displacement according to US 4446804 may be provided from a separate tank or from a source of produced water. Consequently, in patent publication US 4446804 there are no indications to a person of skill in the art regarding other ways of working the process of said invention than those which have been mentioned above. With respect to the pressure for working the invention according to US 4446804, it is not excluded to use higher pressure, however, it is considered economically most favorable to work the invention at a reduced pressure of about 100 bar (column 1, line 66-column 1, line 3).

Summary of Method

With the present invention a system is provided for transport and storage of compressed natural gas (CNG) at high pressure (HP) and distribution of said natural gas at high pressure (HP), medium pressure (MP) and low pressure (LP), which system comprises : i) transport units having one or several tanks for loading and transport of HP CNG and equipment for loading, internal transportation in the transport unit and unloading HP CNG and liquid at high pressure, ii) a storage unit having one or several tanks for storing of HP CNG and equipment for loading, internal transportation in the storage unit and unloading HP CNG and liquid at high pressure, and a storage tank for liquid which may be delivered at HP, MP and LP, and iii) a distribution unit comprising one or more tanks for HP CNG, one or more tanks for MP CNG and one or more tanks for LP CNG, which tanks are connected for distribution to consumers of HP CNG, MP CNG and LP CNG respectively, and equipment for loading HP CNG and internal transportation in the distribution unit of HP CNG, MP CNG and LP CNG and liquid, and equipment for fluid communication between the storage tank for liquid and possible tanks for CNG in further pressure ranges and with equipment for fluid communication. The system according to the present invention is distinguished in that its lay out is such that during fluid communication to or between units of the system or internally between tanks of the separate units a closed loop may be formed wherein gas at specific pressure is transported from one or more first tanks to one or more second tanks while liquid at the same pressure as the gas or marginally higher pressure is transported from said one or more other tanks to said one or more first tanks, the volume in said one or more first tanks being approximately equal to the volume of said one or more other tanks.

The present invention also concerns a process using the system according to the invention, distinguished by forming a closed loop at fluid communication to or between units of the system or internally between tanks of one unit, in which loop gas at specific pressure is transported from one or more first tanks to one or more other tanks while liquid at the same pressure as the gas or at marginally higher pressure is transported from said one or more other tanks to said one or more first tanks, whereby the volume in said one or more first tanks is approximately equal to, most preferably exactly equal to, the volume in said one or more other tanks.

By means of the present invention it is made possible to load or unload large amounts of CNG at high pressure in short time without encountering problems caused by very low temperatures connected with expanding gas. The gas is transported and stored typically at above 200 bar g.

The concept according to the invention with a closed loop for fluid communication between tanks is conducive to relatively minor demands with respect to pumping of liquid under pressure. For said pumping it is rather only the friction pressure loss which must be overcome.

7.4 CNG Refueling System

CNG utilizes reticulated natural gas that is delivered to the fleet owner's depot by a network of underground pipelines – the same pipelines that deliver natural gas to residential, commercial and industrial premises. The natural gas is compressed on site and, if necessary, small quantities of CNG are stored in 'cascade storage' cylinders on site to enable high flow dispensing to the vehicle (see graphic over). In many cases, the cascade storage is omitted and the CNG is dispensed directly into the vehicle cylinders at a much slower flow. Each situation has its advantages and disadvantages and both are explained in these Guidelines.

Fleet operators have been used to using bulk stored liquid fuels where large tankers deliver the liquid fuels into large storage tanks located on the fleet operator's site. When refueling vehicles with liquid fuels, the necessary quantity of fuel is dispensed into the vehicles when needed. Natural gas is delivered by pipeline and it is not practical, efficient or even necessary to compress and store CNG in large volumes. In most circumstances, in order to minimize costs and maximize savings when considering CNG, it may be necessary to reconsider the refueling procedures that are currently being used.

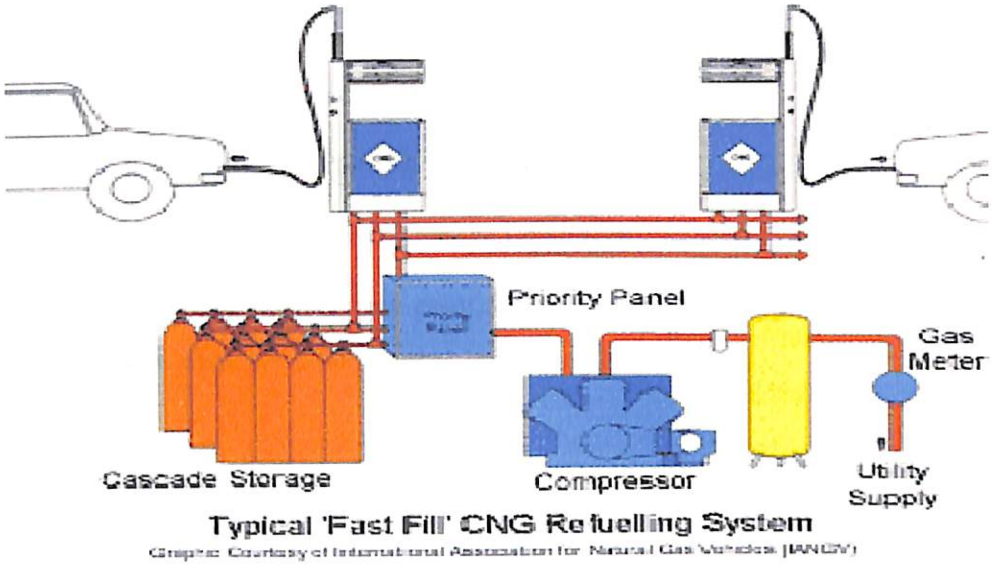


Figure - 9

It is most probable that changing the fleet management procedures will result in lower capital cost for the installed CNG compression equipment and thereby offer more efficient operations which, in turn, greatly increase the savings that can be achieved in the fleet operating costs when running on CNG.

Another important issue that needs careful attention when determining the refueling requirements is the need to provide 100% compression redundancy – (i.e. backup equipment necessary to enable compression to continue in the event of compressor malfunction or servicing requirements). Whilst redundancy may be deemed as necessary, there are ways of potentially satisfying the fleet operator's concerns. These and other significant practical issues, including establishing refueling equipment that can grow with the needs of the fleet, are addressed further within these Guidelines.

All of the possible benefits discussed in these Guidelines are cumulative benefits and wherever possible, each of the benefits should be determined and included. To assist in determining the infrastructure requirements, Appendix A shows the various factors and details that should be addressed. Once these factors have been determined, these details should assist the fleet owner in providing the correct information to the equipment suppliers.

Various financing options for CNG refueling equipment include:

- Direct purchase from the equipment supplier
- Leasing the equipment from the equipment supplier
- Leasing the equipment from a finance institution
- Packaged supply from a gas provider or equipment supplier where a delivered compressed price per cubic metre1 (m3) is offered.

Example 1

Consider a fleet of 12 trucks using approximately 120 m^3 CNG (equivalent to approximately 120 liters of diesel) each per day. If it were required to refuel all of these 12 vehicles over one hour period each day (fast fill) then the CNG system would be required to dispense 1440 m^3 in this one hour period. If the same fleet were to refuel overnight by a slow fill system this would then equate to 1440 m^3 over 12 hours or 120 m^3/hour for the compressor requirements as very little storage would be required.

A further benefit that can be obtained is the savings in electricity costs by using slow fill. In the fast fill situation, the CNG has to be compressed to 25 MPa storage pressure whereas the slow filling requires the compressor to only deliver 16.5 MPa fill pressure at 15^0 C or the equivalent pressure at a different ambient temperature. Fast fill systems allow the vehicle to be filled to 20 MPa as during the fast refueling process, the transfer of the CNG to the vehicle storage causes the temperature of the gas to rise. On cooling down to 15^0 C, the stabilized gas pressure would then be approximately 16.5 MPa.

Example 1 shows that considering fast, slow or a combination of fast/slow refueling can substantially reduce the size of the plant required and therefore the cost involved. Careful consideration needs to be given to the fleet management and refueling procedures in order to optimize the financial benefits that will be achievable by the fleet owner.

In addition, CNG compressors, like any hard working machinery, are better operated for many hours per day rather than numerous start/stop operations over a short period. The overall maintenance of these compressors should be less when they are run hot over many hours to that of short start/stop operation

Fleet Management

The ease of dispensing liquid fuels that are stored in bulk on site, has led to the expectation that fleet vehicles need to be refueled with CNG in a similar manner. In some cases, this may be an operational requirement however, many fleets can benefit from making adjustments to existing refueling routines. It is possible to deliver CNG at any flow rate required however; this may come at a severe cost penalty. The higher capital cost of installing larger compressors and costly storage vessels to provide refueling for approximately one hour per day of refueling (such as in the case of garbage fleets which generally return to base and refuel at the same time), is not the most cost effective solution and it can cause the economics of the study to not be viable.

Most depots based, heavy vehicle fleets generally have the vehicles parked in the yard for at least 12 – 14 hours overnight. One consideration to be looked at is the use of slow refueling where these vehicles can be fuelled at one time together, unattended, during this overnight period. For fast refueling of vehicles, the longer the period of refueling time that can be accepted the lower the required capacity of the compressor(s) and storage and therefore, the capital cost.

Extending the total refueling times on site will result in:

- Lower capital costs
- Better load factors for natural gas and compression electricity - therefore the possibility for better gas and electricity prices
- Lower maintenance costs

In some cases, the savings generated by extending refueling times have justified the hiring of part time staff to take care of the refueling process. Instead of the drivers refueling the vehicles at the end of a shift, the vehicles are left in the care of the refueling staff that fills the vehicles up according to a predetermined schedule.

Equipment Requirements

The previous section on Fleet Management highlighted the benefits of changing refueling procedures to optimize the potential savings. If slow refueling were to be used and there was also a need to top up or refuel vehicles throughout the day, suitable storage could be added to allow sufficient stored CNG to provide this quick fill capacity. If the majority of vehicles were being refueled overnight then it leaves the capacity of the installed compressors available throughout the day to fill site storage and meet the need for limited fast fill. Storage requirements need to be determined wisely as the use of oversized storage will add further cost unnecessarily.

The compressor selection criteria are important as the selection of a compressor too large will not give as much versatility and, if there is a need for redundancy, the reserve capacity may **also** be too large.

Refer again to Example 1 which demonstrated that for a one hour refueling time required a compressor(s) of approximately 1200 m3/hour plus storage and the slow fill for 12 hours required compressor(s) of 120 m/hour.

If the compressor, for either application, were to be a single compressor then to provide suitable redundancy, in times when the compressor was down for repairs or maintenance, would require a compressor of similar size as standby (assuming there is no other viable temporary supply of CNG). Over sizing compressors to provide for redundancy will cause unnecessary capital cost and therefore, the project will not provide the best economic solutions. A selection of two or more smaller compressors will give a very flexible configuration and will allow one compressor to be off line, albeit with reduced capacity, without having to shut down completely.

In the slow fill example where 120 m3/hour of compression was required, the use of 3 x 40 m3/hour compressors would allow the refueling station to operate at 67% capacity for repair and maintenance periods without the need to provide expensive built-in redundancy. Using modular development with compressors and CNG storage also allows flexibility with expansion should the fleet or fuel requirements increase. Extra storage and/or compressors can readily be added when required.

Note: if access to public CNG refueling sites or other depot based sites is available then back up equipment may in fact not be necessary as the alternate supply would meet this requirement.

Metering

Metering requirements will vary, depending on the fleet management procedures required. While accurate metering equipment is available, CNG electronic metering dispensers are more expensive than liquid fuel measurement equipment. Consideration needs to be given as to whether each vehicle needs individual fuel records or whether more general measuring will suffice. Control of liquid fuels, by individually metering the fuel to each vehicle, has historically been a means of monitoring pilfering either by siphoning fuel from the vehicle fuel tanks or separately dispensing through the pump to other containers. CNG is less likely to be pilfered as it is difficult to handle in portable containers and the fuel cannot be siphoned off.

CNG compressor stations are generally fitted with an input supply meter provided by the gas provider and this measurement can be used as the basis for apportioning CNG across the fleet. If slow filling is to be used, it will not be possible to economically individually meter fuel usage to each vehicle.

Reasonable indication of dispensed fuel can also be made by registering the vehicle fuel pressure prior to refueling and, by using a simple chart, determining the estimated usage.

Gas Supply

It is very important that all aspects of the required natural gas supply are discussed with the proposed gas provider. Check the availability of high-pressure gas mains within the area to determine the highest gas pressure that could be made available. Higher gas pressures will assist in reducing both the capital and operating costs of the compression equipment. The higher-pressure gas may reduce the compressor configuration by one or two stages thereby reducing the capital cost. The expected load factor on the gas networks will also provide the ability to obtain better gas prices. Referring to

Example 1, the fast fill scenario anticipated taking 1440 m3 of natural gas in one hour and the slow fill to take 120 m3 each hour for a 12 hour period. This reduction in load factor will significantly reduce the capacity required in the network system for the same delivered load.

This improved load factor means less capital equipment reserved in the gas network to provide this expected load. There may also be financial benefits by determining with the gas provider if a gas main extension could be constructed from a high-pressure network in order to receive higher gas pressures on the site for the compressors.

CNG refueling system for multiple vehicles

The use of compressed natural gas ("CNG") as an alternative fuel for motor vehicles is well known. Natural gas is in most cases a less costly and cleaner-burning fuel than gasoline. One disadvantage of natural gas as a motor vehicle fuel is the volume required to store the quantity of gas needed to provide a range of travel comparable to that experienced with gasoline. In order to store a sufficient volume of natural gas to provide a reasonable range of travel, it has been thought desirable to compress the natural gas to a pressure of about 3000 to 3600 psi or higher.

Because the vehicle tank pressures needed to store sufficient natural gas to provide a reasonable range of travel are relatively high when compared to available consumer line pressures, the refueling of vehicle storage tanks presents yet another problem. Refilling vehicle storage tanks with CNG within a time period comparable to that required to refill conventional vehicle fuel tanks with gasoline can necessitate the use of large, expensive, multistage compressors. Alternatively, home or on-board CNG refueling systems have been developed that can deliver the compressed gas at the required pressure, but such systems are characterized by very low flow rates, necessitating long periods (such as overnight) for refueling.Among the various systems for refueling vehicle storage tanks that have previously been disclosed, one conventional system uses a large, multistage compressor to compress the

natural gas to about 4000 psi or greater and then holds the CNG in large volume intermediate storage tanks at that pressure. During refueling, the CNG is allowed to flow into the vehicle storage tanks until the vehicle tank pressure is about 3000 psi. After refueling, the intermediate storage is replenished with sufficient gas to again raise the storage pressure to about 4000 psi. This system is inefficient because of the repetitive need to charge storage tanks to about 4000 psi.

Another system, disclosed in U.S. Pat. No. 4,646,940 utilizes a differential pressure measuring apparatus in controlling CNG refueling. The patent discloses preferentially refueling the CNG tanks of a vehicle first from low pressure, then intermediate pressure, and finally, high pressure storage tanks. A reference cylinder at 2750 psi is used to cut off the refueling operation.

U.S. Pat. No. 4,501,253 discloses a low volume (approximately one cubic foot per minute) on-board automotive methane compressor for refilling vehicle storage tanks by compressing the gas from available line pressure to about 2000 to 3000 psi.

U.S. Pat. No. 4,515,516 and 5,169,295 disclose systems in which liquid pressure is used to boost CNG pressures in storage/refueling process. U.S. Pat. No. 4,515,516 discloses a home use natural gas refueling system in which a liquid is used to boost the gas from line pressure to greater than 2000 psi. The system utilizes a variable rate pump which pumps the compression fluid at a high rate for low pressures and a low rate for high pressures. (An illustrative flow rate is about one gallon per minute of compression fluid above 600 psi.)

U.S. Pat. No. 5,169,295 discloses a higher volume liquid-based compression system that can be mounted on a car, truck, boat, train or plane, but is preferably mounted on a tractor trailer truck with the hydraulic pumps connected to the tractor engine by a transfer case. The maximum pressure of the liquid supplied from the liquid supply means is less than the minimum pressure of the gas from the gas-supplying conduit. In the preferred embodiment the supply pump has an maximum output pressure of about 350 psig, and the maximum pressure of the gas-supplying conduit may range from about 400 to about 2900 psig. Illustrative pumping rates for the compression liquid range up to about 200 gpm.

Other previously disclosed CNG refueling systems utilize adsorbent-filled cylinders to reduce the tank pressure needed to store a predetermined amount of natural gas. Such systems are disclosed, for example, in U.S. Pat. No. 4,522,159; 4, 53 1,558; and 4,749,384.

Refueling Method

According to the present invention, a CNG refueling system and method are provided that will enable motor vehicle storage tanks to be refueled quickly and efficiently through the use of a compressor system that is operable over a wide range of suction pressures in combination with means for temporarily storing the CNG at a preferred intermediate storage pressure of from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig (based on a storage temperature of about 70 DEG F.) and means for selectively supplying gas to the compressor system at the intermediate storage pressure. Because the most efficient storage pressure for natural gas at 70 DEG F. ranges from about 1700 to about 2700 psig, within this pressure range the greatest volume of gas can be withdrawn from storage with the smallest attendant reduction in storage vessel pressure. By selectively controlling the inlet gas supply to the compressor system between an external (relatively low pressure) supply line and intermediate storage vessels, thereby taking advantage of the higher density of gas drawn from the intermediate storage vessels, one can achieve an increase in compressor capacity without increasing horsepower or energy consumption. Where the desired maximum vehicle tank pressure exceeds about 3000 psig, refueling rates can be increased and horsepower requirements reduced by first delivering CNG to the vehicle storage tanks simultaneously from the compressor and from the intermediate storage tanks until the vehicle tank pressure equalizes with the intermediate storage pressure, and then by "topping off" the tanks with CNG supplied to the compressor from intermediate storage at pressures ranging between 1700 and 2700 psig. Whereas a 20 horsepower compressor may, for example, compress about 97 cfm natural gas from a suction pressure of about 800 psig to a discharge pressure of about 3000 psig, the same 20 horsepower compressor may compress about 345 cfm natural gas from a suction pressure of about 2500 psig to a discharge pressure of about 3000 psig. This increased CNG delivery rate at higher pressures enables a user to fill vehicle storage tanks quickly and efficiently to pressures greater than 3000 psig.

According to one embodiment of the invention, a CNG vehicle refueling system is provided that comprises: Means for selectively delivering natural gas received from an external source directly to a motor vehicle storage tank at the available line pressure; means for simultaneously delivering part of the natural gas received from the external source directly to the motor vehicle storage tank and for compressing part of the natural gas received from the external source and delivering the CNG to intermediate storage at a pressure higher than the available line pressure; means for simultaneously delivering CNG to the vehicle storage tank from the compressor discharge and from intermediate storage; means for selectively delivering CNG from the intermediate storage to the suction side of the compressor for further compression; means for delivering the further-compressed natural gas into the motor vehicle storage tank; and means for selectively refilling the intermediate storage with natural gas compressed from available line pressure after the vehicle storage tank is filled.

According to another preferred embodiment of the invention, the subject refueling system comprises a single stage compressor operable over a range of suction pressures extending, for example, from about 330 to about 3600 psig with a discharge pressure of up to about 4500 psig, in combination with means for temporarily storing the compressed gas in intermediate storage at a pressure ranging between about 330 and about 3600 psig (preferably between about 1700 and about 2700 psig, and most preferably between about 2300 and about 2400 psig), and means for selectively controlling the supply of gas to the suction side of the compressor from either a relatively low pressure source such as a natural gas transmission line or from the intermediate storage.

According to another embodiment of the invention, a motor vehicle refueling system is provided that comprises in combination: A single stage compressor connectable to a source supplying natural gas at a pressure ranging from about 330 to about 1000 psig that is operable at suction pressures ranging from about 330 to about 3600 psig and at discharge pressures ranging from about 330 to about 4500 psig; intermediate storage means for temporarily storing CNG at intermediate storage pressures ranging from about 330 to about

3600 psig, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig; means for supplying natural gas received from the external source directly to a motor vehicle storage means at a supply pressure ranging from about 330 to about 1000 psig; means for simultaneously supplying CNG to the vehicle storage means from the intermediate storage means and from the compressor until the pressure in the vehicle storage means equalizes with the intermediate storage pressure; means for further compressing CNG supplied from the intermediate storage means up to the maximum intended fill pressure for the vehicle storage means, preferably from about 3000 to as high as about 4500 psig, to complete filling the vehicle storage means; and means for compressing natural gas from the source pressure up to the desired intermediate storage pressure to refill the intermediate storage means after the refueling the vehicle storage means.

According to another embodiment of the invention, a method for refilling vehicle storage tanks with CNG is provided that comprises the step of using CNG supplied from intermediate storage at a pressure ranging from about 330 to about 3600 psig, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig, as the feed to a compressor that is capable of further pressurizing the CNG to a discharge pressure as high as the intended maximum fill pressure of the vehicle storage tanks, ranging up to about 4500 psig, and most preferably from about 3000 to about 3600 psig. By using CNG temporarily stored at a pressure ranging from about 1700 to about 2700 psig to supply a refueling compressor, one can "top off" vehicle storage tanks quickly and more efficiently than has been achieved through the use of prior art methods.

According to another embodiment of the invention, a method for refueling vehicle storage tanks with CNG is provided that comprises the steps of: Supplying natural gas at a pressure ranging from about 330 to about 1000 psig to a single stage compressor that is operable at suction pressures ranging from about 330 to about 3600 psig with attendant discharge pressures ranging from about 330 to about 4500 psig; compressing and temporarily storing CNG at intermediate storage pressures ranging from about 330 to about 3600 psig, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig; compressing CNG from the supply pressure (about 330 to about 1000 psig) to the vehicle storage tank pressure and discharging the CNG to the vehicle storage tanks while simultaneously supplying CNG to the vehicle storage tanks from the intermediate storage tanks and while allowing the vehicle storage tank pressure to equalize with the intermediate storage tank pressure; when the vehicle storage tank pressure has equalized with the intermediate storage tank pressure, supplying CNG to the compressor from the intermediate storage tanks and further compressing the CNG up to the intended full vehicle storage tank pressure, preferably from about 3000 to about 4500 psig, and most preferably from about 3000 to about 3600 psig, until the vehicle storage tanks are filled; and thereafter refilling the intermediate storage tanks with CNG supplied to the compressor at about 330 to about 1000 psig until such time as the intermediate storage tanks are again filled to a predetermined pressure ranging from about 330 to about 3600 psig, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig.

According to one preferred embodiment of the method of the invention, when the vehicle storage tank pressure is below the available line pressure (preferably from about 330 to about 1000 psig) at which natural gas is supplied to the compressor suction at the start of refueling, the vehicle storage tank pressure is allowed to equalize with the available line pressure prior to supplying CNG to the vehicle storage tanks either from the compressor or from the intermediate storage tanks. While in this mode of operation, if the pressure in the intermediate storage tanks is below a predetermined desirable level such as, for example, preferably from about 1700 to about 2700 psig, and most preferably from about 2300 to about 2400 psig, the compressor can be used to refill the intermediate storage tanks to the predetermined desirable pressure level while the vehicle storage tank pressure is equalizing with the available line pressure. As used herein, the term "available line pressure" is used to include any source (other than the storage tanks of the vehicle being refueled) of natural gas at a pressure ranging from about 330 to about 1000 psig. Where the actual available line pressure is lower than about 330 psig, the use of a booster pump or other similarly satisfactory means may be required in order to raise the line pressure to a level of at least about 330 psig.

According to another preferred embodiment of the invention, a CNG refueling system for a plurality of motor vehicles each having CNG storage means is provided, the system comprising compressor means operable over suction pressures ranging from about 330 to about 3600 psig and discharge pressures ranging from about 330 psig to about 4500 psig; at least one intermediate storage tank for storing CNG at pressures ranging from about 330 to about 3600 psig; means for selectively delivering natural gas received from an external source to the compressor means; means for selectively delivering CNG discharged from the compressor means into the intermediate storage tank until the pressure in the intermediate storage tank reaches a predetermined maximum level not greater than about 3600 psig; means for selectively controlling the delivery of CNG to the CNG storage means of each vehicle; means for selectively delivering CNG to each selected vehicle CNG storage means from the intermediate storage tank or from the compressor means; and means for selectively supplying CNG to the compressor means from the intermediate storage tank until the pressure in each selected vehicle CNG storage means reaches a maximum intended vehicle storage fill pressure. According to a particularly preferred embodiment of the invention, means are provided in the foregoing system for selectively and simultaneously delivering CNG to each selected vehicle storage means from the intermediate storage tank and from the compressor means. According to yet another embodiment of the invention, means are provided in the foregoing system for selectively delivering natural gas received from the external source directly into the selected vehicle storage means until pressure in the selected vehicle storage means equalizes with the pressure of the external source.

According to another embodiment of the invention, a method is disclosed for selectively refilling a plurality of vehicle CNG storage means from an initial pressure to an intended fill pressure with compressed natural gas, the method comprising the steps of providing a source of natural gas at a supply pressure ranging from about 330 to about 1000 psig; providing an intermediate storage tank; selectively delivering natural gas from the source to a compressor means that is operable at suction pressures ranging from about 330 to about 3600 psig with attendant discharge pressures ranging up to about 4500 psig; compressing the natural gas and selectively storing the compressed natural gas discharged from the compressor means in the intermediate storage tank until an intermediate storage pressure ranging up to about 3600 psig is reached; selectively delivering compressed natural gas to each selected vehicle CNG storage means from the intermediate storage tank or from the compressor means until the vehicle CNG storage means pressure equalizes with the intermediate storage tank pressure; selectively delivering compressed natural gas to the compressor from the intermediate storage tank and further compressing the natural gas; and selectively delivering the further compressed natural gas from the compressor to the selected vehicle CNG storage means until the selected vehicle CNG storage pressure reaches the intended fill pressure. According to another preferred embodiment of the invention, compressed natural gas is simultaneously delivered to each selected vehicle CNG storage means from both the intermediate storage tank and from the compressor means until the vehicle CNG storage means pressure equalizes with the intermediate storage tank pressure. According to another preferred embodiment of the invention, natural gas is selectively delivered from the source to the vehicle CNG storage means until the vehicle CNG storage means pressure equalizes with the supply pressure.

Chapter – 8

Conclusion

Deterioration in the quality of urban air was the major problem faced by the country during 1990s.Finally on July 28, 1998, in an unprecedented development, the Supreme Court (SC) ruled that the total passenger bus fleet of Delhi be increased from the then figure of about 6,000 to 10,000 by April 1, 2001 and the entire city bus fleet be converted to CNG. The objective was to expand the city's public transport system and also to control pollution. The factors accounting for the decision were many advantages which were highlighted as a result of a number of debates in the country for and against the alternate fuel. The major advantages associated with the fuel are

Compressed natural gas is the cleanest burning fuel operating today which means means less vehicle maintenance and longer engine life. Moreover CNG vehicles produce the fewest emissions of any motor fuel. On comparing with other fuels it is found that CNG produces significantly less pollutants than gasoline and tailpipe emissions from gasoline operated cars release carbon dioxide, which contributes to global warming which is greatly reduced with natural gas.

In terms of maintenance also CNG has comparative advantages_Surveys indicate that NGVs are as safe as or safer than those powered by other fuels. For e.g. a 1992 AGA survey of more than 8,000 vehicles found that with more than 278 million miles traveled, NGV injury rates per vehicle mile traveled were 34% lower than the rate for gasoline vehicles.

If we look in terms of performance of a CNG driven vehicle it is found that dedicated CNG engines are superior in performance to gasoline engines, CNG has an octane rating of 130 and has a slight efficiency advantage over gasoline. Because CNG is already in a gaseous state, NGVs have superior starting and drive ability, even under severe hot and cold weather conditions. Moreover NGVs experience less knocking and no vapor locking.

In terms economics it is reflected from the studies that the growth of CNG vehicles in the year 2002 was primarily because of economic advantage of CNG with regard to petrol / diesel. The economics of running the CNG vehicles vis-à-vis its operation on petrol / diesel has been worked out at the current price of fuel and it is found that CNG is the most economic fuel.

An insight into the current status of CNG in Indian scenario – a study of the major cities in India reflects that there is a significant growth in transport energy demand. Annual growth rate is worked out to be 4.4% against the assumed economic growth rate of 5.6%. Total energy demand from transport services in 1998 is 42.2 million GJ and it increases to 137.4 million GJ by 2020. This shows how much importance CNG foresees in the future.

Under its Project Blue Sky, GAIL has already drawn plans to implement city gas projects in the five cities of Kanpur, Lucknow, Agra, Bareilly and Pune in phases at an estimated investment of Rs. 554 crores (equivalent to 118 Million USD).

Storage and transporting of compressed natural gas has a substantial potential worldwide and it can be advantageously compared with LNG and pipelines for the appropriate combinations of distance from the gas source and gas consumption.

It is most probable that changing the fleet management procedures will result in lower capital cost for the installed CNG compression equipment and thereby offer more efficient operations which, in turn, greatly increase the savings that can be achieved in the fleet operating costs when running on CNG.

Another important issue that needs careful attention when determining the refueling requirements is the need to provide 100% compression redundancy – (i.e. backup equipment necessary to enable compression to continue in the event of compressor malfunction or servicing requirements).

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