

자동차연료로서 CNG의 경제성 분석

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Benefit Analysis of CNG as an Automobile Fuel

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요 약

전 세계적으로 급성장하고 있는 자동차연료로 압축천연가스(CNG)의 사용이 일반화되고 있다. 1996년도에 100만 대이던 CNG자동차가 2006년도에는 5배가 증가하였으며, 지금도 계속 증가하고 있는 추세이다. CNG연료는 가솔린 및 디젤연료에 비하여 효율적이고 완전연소에 가까워 청정연료로서 적합하다. 또한 배출가스로서 일산화탄소, 탄화수소 및 질소산화물 등이 다른 연료에 비하여 유리하며, 경제적인 면에서도 투자가치가 있다. 본 연구에서는 천연가스자동차의 환경적인 특성과 효율적이고 경제적인 면에서 고찰하고자 한다.

주제어: 압축천연가스, 압축천연가스자동차, 휘발성 유기화합물, 배출가스

Abstract: The adoption of compressed natural gas (CNG) as a vehicle fuel is a common phenomenon as it is accelerating worldwide. Increasing number of CNG driven vehicles around the world has jumped up from one million in 1996 to five million in 2006. CNG as a vehicle fuel is very popular to the end users because of its clean-burning properties and cost effective solution compared to other alternative fuels like diesel and gasoline. The use of CNG as a fuel reduces vehicular emission that is consisted of carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), carbon dioxide (CO₂) etc. This research highlights the characteristics of CNG vehicles, CNG arrangement in the vehicles, CNG fueling procedures and most importantly the environmental and economic factors that are highly considered as cost effective solution for the flexibility of using CNG in the automobiles.

Key words: Compressed natural gas (CNG), Compressed natural gas vehicles (CNGVs), Volatile organic compounds (VOCs), Emission

1. Introduction

Natural gas is found in large underground fields much like crude oil. However, due to its gaseous state overland transport of natural gas is not feasible. Rather, extensive underground

pipelines were developed to carry it from the wellhead to customers thousands of miles away. CNG is basically methane (CH₄) from fossil sources and is stored in special fuel tanks under pressure (typically between 13.78 and 24.13 MPa) for vehicle transportation. This ensures enough fuel for an acceptable

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driving range in specially designed or modified vehicles. CNG does not have energy density of liquefied fuel and it offers sufficient range for light or heavy vehicles. CNG produces less CO₂ than gasoline, similar to or slightly less than diesel and generally produces fewer amounts of air quality emissions than diesel but only slightly less than gasoline. Since 1960 CNG has become a vehicle fuel alternative to oil based gasoline and diesel fuel.

2. Major Concerns of CNG

2.1. CNG Technology

CNG can be used in Otto-cycle (gasoline) and modified diesel cycle engines. Lean-burn Otto-cycle engines can achieve higher thermal efficiencies when compared with stoichiometric. Otto-cycle engines at the expense of higher oxides of nitrogen and hydrocarbons emissions. Electronically controlled stoichiometric engines offer the lowest emissions across the board and the highest possible power output especially when combined with exhaust gas recirculation (EGR), turbo charging and inter-cooling and three-way catalytic converters. The octane rating of CNG is far greater than gasoline and, if handled correctly, it can produce same or more power output from an engine provided that the CNG is compressed properly and accurate amounts of BTU figures attained.

2.2. Global use of CNG

There are more than 7 million natural gas vehicles currently operating worldwide and the number of CNG driven vehicles is increasing everyday in every country. Considering the number of vehicles and market penetration relative to the total number of vehicles, Table 1 shows the historical natural gas vehicle growth in the leading nations around the world.

Figure 1 refers the growth of natural gas vehicles on a global and regional basis. Considering the average industry growth; based on vehicle numbers the average percentage of NGV growth since 2000 reaching 30.6% per annum with Asia leading the field with an eye opening 50.1% average, Europe 12.9%, North America 3.7%, South America 27.9% and Africa 21.3%. Latest updates show Pakistan has moved to second place in terms of the number of vehicles with the country how home to 1.55 million natural gas vehicles, ahead of long time second place holder Brazil on 1.425 million. Argentina remains the largest user of NGV's with last reported figures of 1.65 million.

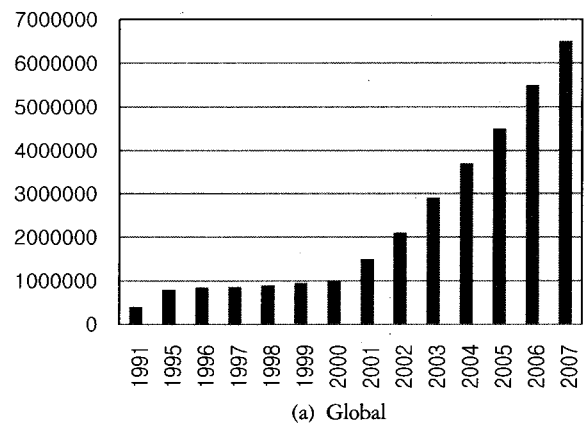
Total reported figures now exceed 6.8 million natural gas

Table 1. Leading nations adopting CNG vehicles around the world

World ranking	Country	CNG vehicles	CNG stations
1	Argentina	1,650,000	1,400
2	Pakistan	1,550,000	1,616
3	Brazil	1,425,513	1,442
4	Italy	432,900	558
5	India	334,820	321
6	Iran	263,662	179
7	USA	146,876	1,340
8	Colombia	203,292	310
9	China	127,120	355
10	Ukraine	100,000	147
11	Armenia	81,000	128
12	Bangladesh	80,000	118
13	Russia	75,000	213
14	Egypt	69,376	99
15	Bolivia	64,828	87

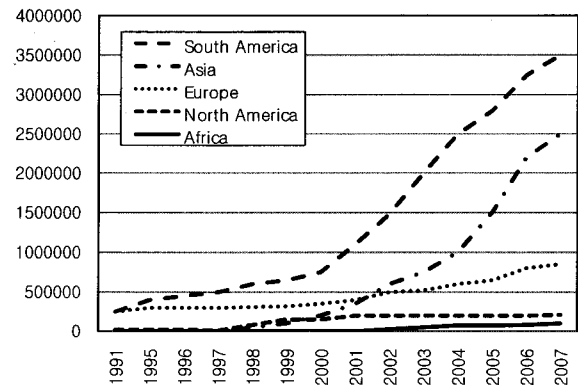
Source: IANGV [1] upgrades online statistics (as June, 2007)

Natural Gas Vehicle Growth Worldwide (1991-June 2007)



(a) Global

Natural Gas Vehicle Growth by Region (1991-June 2007) by number



(b) Regional

Figure 1. Growth of the number of natural gas vehicles [1].

Table 2. Physical properties of CNG

Stored form	Typical analysis	Physical state	Density (kg/m ³)	Water solubility	Net energy content (Btu/lb)	Boiling range (°F @ 1 atm)	Vapor density (air = 1)
Pressurized gas	100% CH ₄	Gas	8	No*	22,800	-259	0.6**

* Virtually insoluble at ambient temperatures and pressures; but can form hydrates

** NFPA [3]

Table 3. Ignition and combustion properties of CNG

Gross calorific value (MJ/m ³)*	Octane number	Flash point (°C)	Flammable limits (vol% in air)	Auto ignition temperature (°C)	M.I.E. (mJ)
12.79**	120 [§]	-184.44	L = 5 H = 15 ^{§§}	537 ^{§§}	0.28 [†]

* At 273°K and standard atmospheric pressure

** Spiers [4], [§] Gordon [5], ^{§§} NFPA [3], [†] Haas [6]

vehicles worldwide, though with no reported data from several countries so far this year, this number is likely to be in excess of 7 million.

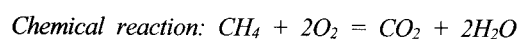
2.3. The Properties of CNG

2.3.1. Physical properties

Generally, steel cylinders are widely used for storing CNG for driving passenger cars, trucks and commercial vehicles or buses. In the cylinder when the gas is put under pressure, the density of the molecules increases and therefore the temperature rises. It takes some time, until the cylinder has adopted the temperature of its environment again. If the gas is heated up, the pressure of the gas also increases. If a cylinder can theoretically accommodate 18 kg CNG under standard conditions (19.99 MPa, 15°C), the cylinder will carry less than 18 kg. Practically that means that the cooler the cylinder and the temperature around the cylinder is the more mass of CNG can be pumped into the cylinder. Table 2 shows the physical properties of CNG [2].

2.3.2. Chemical properties

Natural gas consists of about 90% methane (CH₄). CNG in its natural stage does not smell. Therefore, the gas is odorized prior to distribution in order to detect possible leakage. Therefore gas can be smelled at a concentration of 0.3%. As CNG requires a concentration of about 5 to 15% to combust, 0.3% is far below the dangerous combustion level.



The chemical reaction shows that methane molecules are reacting with oxygen. If there was just methane without any impurities, then methane and oxygen would simply react to create water vapor and carbon dioxide. Theoretical chemical formula for the oxidation of methane is seen above. Usually, CNG consists of about 90% methane, which means there are also some other molecules included in the chemical reaction.

Table 4. Emission characteristics of CNG compared to other alternative fuels [7]

Emission check items	Gasoline	LPG	CNG	Diesel
CO (g/Km)	1.12	0.91	0.45	0.67
HC (g/Km)	0.15	0.12	0.36	0.14
NOx (g/Km)	0.15	0.21	0.13	0.74
Particulates(g/Km)	0.015	0.005	0.025	0.094

Table 5. Efficiency of CNG fuel compared with other alternative fuels

Fuels	1,3 butadiene (mg/kg)	Benzene (mg/kg)	Formaldehyde (mg/kg)	Methanol (mg/kg)
Gasoline (without catalyst)	11.8	55	43	0
Gasoline	0.6	4.7	2.5	0
M85	<0.5	1.5	5.8	79
LPG	<0.5	<0.5	<2	0
CNG	<0.5	0.6	<2	0
Diesel	1.0	1.5	12	0

2.3.3. Ignition and combustion properties

CNG basically measures in mass (kg) instead of a measure for volume (liter or m³). One cubic meter of CNG under 10 bar pressure has just a fraction of the energy value than one cubic meter of CNG under 200 bar pressure. However, 1 unit of CNG has always the same calorific value no matter whether it has a volume of 500 liters or just a volume of 60 liters under 200 bar pressure. Table 3 shows the ignition and combustion properties of CNG.

2.4. Emission Characteristics

Gaseous fuels have exhaust emission advantages over gasoline in terms of cold start. Methane of high concentration was transferred to the CNG through a purifier. From the emission point of view, CNG is the most suitable fuel in automobiles. Table 4 lists emission characteristics of different alternative fuels.

The average values of un-regulated emission components for different fuels have shown in Table 5 that indicates the efficiency of CNG fuel as compared with other alternative fuels [7].

3. Characteristics of natural gas vehicle

Presently people are more accustomed to driving liquid fueled engines (basically gasoline or diesel powered) that requires some form of a fuel delivery pump to transport the fuel from the tank to the engine. When operating on CNG a fuel pump is not used. Instead, system pressure provides the delivery of the fuel. CNG vehicles have at least one pressure regulator which maintains a steady supply of fuel regardless of fluctuations in system pressure. In addition, the ignition system must deliver a slightly higher voltage to ignite the gaseous mixture. CNG with high octane ratings up to 120, ignition timing may be advanced without resulting in spark knock. Modern CNG driven automobiles use closed-loop computer controlled technology to provide lower emission and excellent driving ability. Some equipment manufacturers offer fuel injection versions to provide even more precise mixture control. Figure 2 shows the arrangement of CNG equipments in automobiles:

4. CNG fueling in automobiles

CNG stations compress, filter, store, and deliver CNG fuels

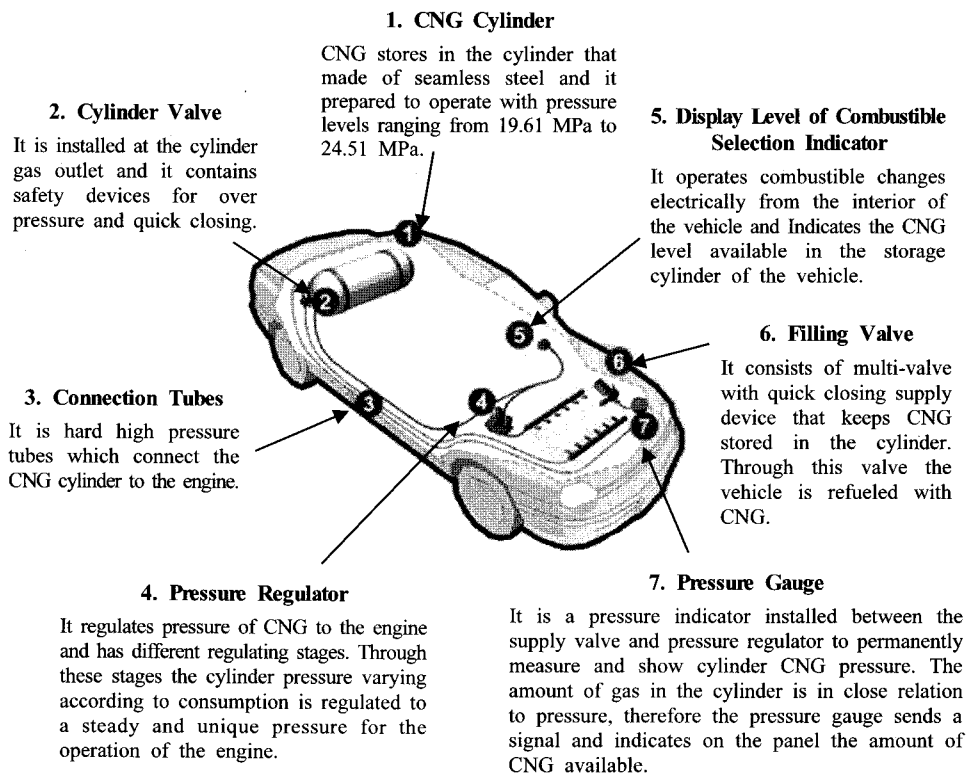


Figure 2. Major components of a CNG automobile.

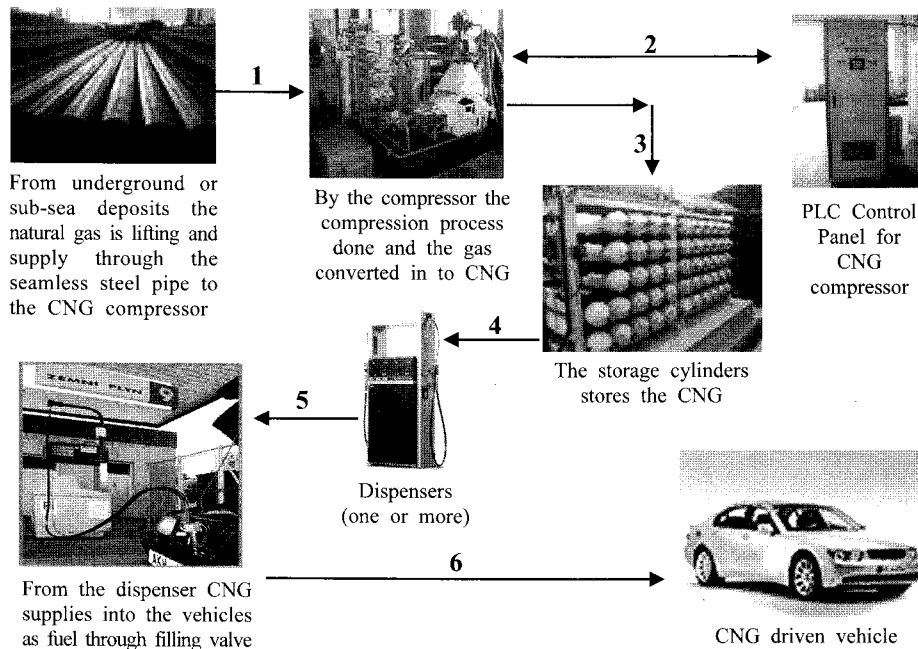


Figure 3. CNG fueling in automobile

to a natural gas vehicle (NGV) in either way, fast filling or slow filling. The fast filling provides quick and convenient refueling with a slight reduction in volume due to the heat build-up during the gas compression. The slow filling allows a complete filling of the storage tank but over a much longer time, i.e., up to eight hours. Small slow-filling dispensers are available that are attached to a consumer's household gas line can refill the fuel tank of a vehicle overnight. Both types of fuel delivery systems are regulated by standards established by the NFPA. When running automobiles with CNG fuel, the following steps occur in series:

- I. Through the natural gas dispenser, the CNG gas is compressed and enters into the vehicle.
- II. CNG flows into high-pressure cylinders that are located in the vehicle.
- III. When the driver steps on the accelerator, the natural gas leaves the on-board storage cylinder, passes through the high-pressure fuel line and enters the engine compartment.
- IV. The gas then enters the regulator which reduces pressure from up to 24.13 MPa to approximately atmospheric pressure.
- V. The natural gas solenoid valve allows natural gas to pass from the regulator into the gas mixer or fuel injectors.
- VI. The natural gas mixed with air flows down through the

carburetor or fuel injection system, and enters the engine's combustion chamber, and finally runs the vehicle.

5. Benefit analysis of CNG vehicles

Natural gas is one of the cleanest burning fossil fuels that currently used as a vehicle fuel and is most commonly seen in commercial and government fleet vehicles as well as public transportation [8]. In this form the fuel is clear, odorless and non-corrosive and stored in high pressure cylindrical tanks. Also, it is possible to use CNG in parallel to other alternative fuel like gasoline (commonly called bi-fuel engine). The cost of natural gas is generally lower than that of petroleum oil because it is abundantly produced worldwide. Maintenance costs of CNG vehicles are also notably reduced because the fuel burns so clean, spark plugs last longer, and the time between oil changes can be extended. However, for benefit analysis of CNG as an automobile fuel, both the environmental and economic issues are to be considered.

5.1. Environmental benefits

During the last few years the environmental issues come into the front face that's why the importance of CNG compared to other alternative fuels for vehicles transportation is being realized. Throughout the world, every country is focusing on the environmental awareness and importance through their

Table 6. Fuel characteristics

Items	CNG	Petrol	Diesel
Toxic to skin	No	Moderate	Moderate
Toxic to lungs	No	Moderate	Moderate
Source/feed stock	CNG	Petroleum	Petroleum

government agencies, NGO and private organizations as the rate of air pollution are increasing tremendously due to the automobile emissions, industrial wastages, shortage of green forest, etc. Therefore, CNG refers to some good potential for controlling the automobile emissions. Some reasons are as follows:

- I. The environmental benefits of CNG over conventional gasoline vehicles are staggering. CNG fuel contains fewer carbons than any other fossil fuel and that makes it the most friendly to the environment and significantly reduces emissions of carbon monoxide by 70%, non-methane organic gas by 87%, oxides of nitrogen by 87% and carbon dioxide by 20% [9]. Though the tailpipe from the gasoline-operated cars releases carbon dioxide that contributes to the global warming, it is greatly reduced with CNG.
- II. The increasing incidence of various sources (automobiles, coal burning, etc.) all over the world has been linked to higher levels of particulate pollution. It is attributed to vehicle emissions, too. In case of CNG vehicles, particulate emissions are almost non-existent. Natural gas vehicles have far lower levels of carbon monoxide, sulfur and nitrogen oxide (associated with petroleum fuels) and other non-methane organic gas emissions. In a word, CNG vehicles do not cause respiratory illness and produces far

less greenhouse gases. CNG ensures better environment.

- III. In case of electric powered vehicles (powered by coal indirectly as coal is one of the important source of electricity), the electric batteries are expensive and the batteries need to be replaced and disposed of after certain period of time and also it creates dirtier smoke which is finally spread out to the environment. But, in case of CNG vehicles, the gas is cheap and is very much friendly to the environment.
- IV. Spillage and leaking of oil and petroleum can have an impact on ecosystem, waterways, oceans and wildlife because the oil and petroleum seep into and are absorbed by the environment that causes serious disorder in the environment. But, the ecological benefits of CNG are irrefutable. Using CNG has no effect on surrounding ecosystems. CNG stem from its composition, especially the ratio of carbon and hydrogen atoms in a molecule. Natural gas consists of about 90% of CH₄ with a favorable ratio of carbon/hydrogen = 1/4 which is environment friendly [10]. In addition, for natural gas leakage due to any accident, it dissipates into the atmosphere and does not create any poison to the surrounding wildlife and ecosystems.
- V. In general, the petrochemical products contain VOCs in which high carcinogenic compounds, i.e., benzene that can be a factor of risk to the public health as well as harmful to the ozone layer. During the refueling the vehicles with petroleum products, VOCs are released to the environment. But, in CNG, no VOC is present to any comparable levels to petrochemical products. Therefore, it prevents the loss of gas to the atmosphere and keeps the loss to a minimum.
- VI. As discussed about the effect of the petroleum in

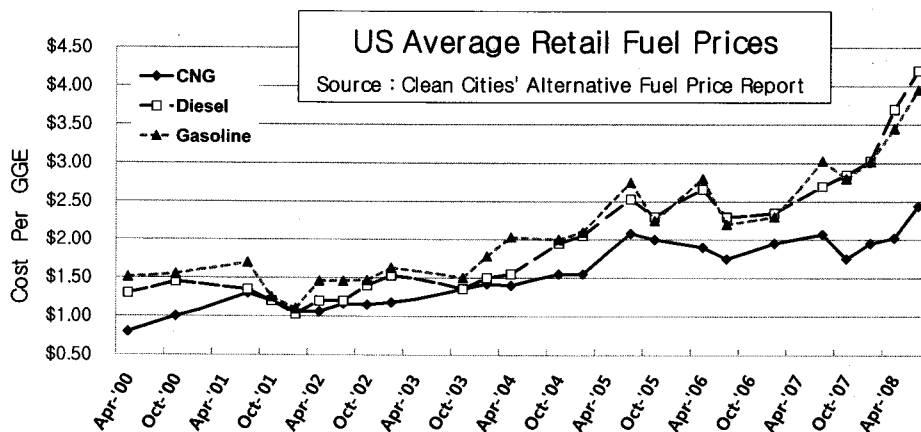


Figure 4. CNG prices compared to gasoline and diesel in USA [12].

automobile vehicles, Table 6 shows the characteristics of CNG compared with gasoline and diesel. It is seen that both the gasoline and diesel has some effect on human health, while the CNG has none.

VII. CNG is the cleanest and readily available fuel for automobiles. General rule for hydrocarbons is that the higher the ratio of hydrogen atoms to carbon atoms, the cleaner the fuel. CNG has the highest ratio of hydrogen atoms to carbon atoms of all hydrocarbons and thus its combustion produces water and a small amount of CO₂ when used as a vehicle fuel. Therefore, CO₂ emissions are around 20% less than for other petroleum product which is friendly to the environment.

5.2. Economic benefits

Due to the increasing knowledge of the adverse effects of air pollution and cost advantage issue with other alternative fuels, CNG is becoming more and more interesting to compare alternative technological strategies for reducing emission and transportation advantage in an efficient and cost effective way [11]. The economic issues that playing important roles for CNG are as follows:

- I. There is some indication for increase the price of petroleum oil all over the world due to in response of international political events like wars, natural disaster, financial market fluctuation etc. In these circumstances within next few decades the price of petroleum fuel for automobiles will reach into the alarming level. Therefore, CNG ensures the cost effective solution for avoiding the worst situation.
- II. In terms of cost, CNG is less than other fuels. Also, CNG prices fluctuate less than conventional fuels and more stable than gasoline and diesel. The lower price of CNG can help recoup the incremental cost of acquiring dedicated NGVs, which tend to be priced more than conventional vehicles. According to the National Renewable Energy laboratory (sponsored by the US department of Energy, Energy Efficiency and Renewable Energy Vehicle Technologies Program) Figure 4 refers to US average retail fuel prices [12] up to April 2008.
- III. For CNG vehicles, because of abundance and reduced processing requirements, the price is very low [13]. Moreover, CNG is supplied most of the major cities of a country at low price which has cost advantages over the gasoline and diesel with storage quantity and mileage. In

addition, the combustion products of CNG do not react with metals, while those of gasoline do. So, pipes and mufflers (silencer) last much longer [14].

- IV. The intervals between tune-ups for CNG vehicles could be extended about 30,000 to 50,000 miles and the intervals between fuel refills for CNG vehicles could be extended from 10,000 to 25,000 additional miles depending on how the vehicle is used [14]. For example, in Delhi (India) cost of CNG is only Rs 22 (considering exchange rate 1 US\$= 42-45 Rs) per unit and gives an average of 19 km for an average car. Therefore, a full cylinder of CNG has a driving range of 400 km for the average car (about 275 miles) [15].
- V. A proper utilization of natural gas (such as conversion into the CNG) for vehicle fuel could help reducing imports of crude oils significantly for all countries.
- VI. The increasing demand of CNG creates opportunities for companies/factories to build the conversion units. In addition, converting of a large number of gas stations to the CNG stations is a good investment opportunities for investors who are directly influencing the country's economic development.

6. Limitations

Some of the limitations to CNG vehicles are increased weight from the reinforced storage tanks and the limited amount of fuel they can hold which sometimes results in reduced travel distance [16].

7. Conclusions

CNG technology for running vehicles is a common issue throughout the world. The natural gas fuel is cheap, abundant, easily combustible, safe and widely available and offers also significant environment and public health advantages through reduced vehicular greenhouse gases emissions including particulate emission. In addition, using of CNG for vehicle transportation also offers a cheaper alternative to any other existing vehicle fuel and ensures independence from the oil producing countries and the oil price fluctuations resulting from international politics and oil markets. Finally, there is no alternative of CNG for automobile fuel to establish the future slogan "*Only one Earth - Care and Share*".

References

1. <http://www.iangv.org>(International Association for Natural Gas Vehicle: IANGV)
2. Astbury, G. R., A Review of the Properties and Hazards of Some Alternative Fuels, Health and Safety Laboratory, Buxton, Derbyshire, United Kingdom, 2008.
3. National Fire Protection Association Guide on Hazardous Materials (NFPA 325M/49/491M/704), 9th ed., National Fire Protection Association, Batterymarch Park, Quincy, USA, 1986.
4. Spiers H. M., Technical Data on Fuel, 4th ed., British National Committee World Power Conference, London, 1943.
5. Gordon, D., Steering a New Course: Transportation, Energy and the environment, Island Press, Washington DC, 1991.
6. Haas, H., Electrostatic Hazards—Their Evaluation and Control, Verlag Chemie, 1977.
7. Suresh, K. P., Mahanta, P., and Saha, U. K., “Emissions Characteristics of CNG in Automobiles,” Proceedings of All India Seminar on Application of Compressed Natural Gas (CNG) as an Automotive Fuel, Guwahati, India, May 31, 23-30 (2002).
8. <http://www.mckenziecorp.com>(P.C. McKenzie Company, Pittsburgh, PA, USA).
9. “CNG Alternatives Energy Source is at Your Fingertips,” Natural Communities Magazine, May 9, 2007.
10. http://www.cng.cz/en/natural_gas/facts/advantages/ecology.html (PLYN)
11. Rainer, F., and Peter, B., Environmental External Costs of Transport, Springer, 2001.
12. <http://www.afdc.energy.gov/afdc/pdfs/42946.pdf> (Clean Cities)
13. <http://www.oes.net.au>(Ocean Engineering System, CNG System, Australia)
14. http://www.newpantranco.com/Natural_Gas.htm(New Pantranco)
15. Murty, K., “The Benefits of Shifting to CNG for Fuel,” Seeking Alpha Magazine, July 27, 2008.
16. <http://www.greenauto.com/index.php/2008031966/Technologies/Technologies/GNC-Technology.html> (Green Auto Co.)