

Research Article

Conversion of Gasoline Vehicles to CNG Hybrid Vehicles (CNG-Electric Vehicles)

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Abstract: The aim of this study is investigation of the feasibility and advantages of using the natural gas as an alternative to gasoline as a fuel for hybrid electric vehicles. Operating CNG vehicles are really beneficial in the Middle East region considering the fact that gasoline is offered at a heavily subsidized price and therefore, by converting a significant portion of the automobiles to run on CNG, the gasoline internal consumption could be reduced. This in turn will result in more oil being available for export which will be beneficial to the economy of country. Hybrid Vehicles mainly have a CNG engine along with an electric drive. The batteries of Hybrid Vehicles are charged by a CNG engine. The engine size is smaller and emissions may be considerably less in hybrid vehicles relative to typical vehicles since the CNG engine is employed only to recharge the electric batteries. Although CNG-Electric hybrid vehicles are less common than Diesel-Electric hybrids, but they have been tested in several U.S. cities such as Denver and Seattle. CNG-electric hybrids hold huge potential for the future in the fact that they are significantly cleaner sources of energy and are conveniently suited to serve the needs of the current economy and modes of transportation. The use of these alternative sources of fuels requires investment and significant studies need to be made to evaluate their efficiencies and reliability. This study would cover most of these aspects and also explores the use of these technologies with particular reference to Qatar and the Middle East.

Keywords: Compressed natural gas, efficiency, energy consumption, emission, hybrid electric vehicle

INTRODUCTION

Compressed Natural Gas (CNG) has emerged as one of the cleaner forms of transportation and it has been proven that the vehicles operating on CNG produce less smog and air pollutants than gasoline-powered counterparts. Dedicated factory-built CNG vehicles are the cleanest internal combustion vehicles available today and are less polluting than conventional vehicles. The increasing cost of gasoline has seriously affected the economies of many countries and the economic capabilities of the people around the world. Converting the automobiles running on gasoline to Compressed Natural Gas (CNG) could provide a better alternative by not only using a less expensive fuel compared to gasoline, but also by reducing the dependency on oil and meeting the environmental regulations and concerns.

CNG is one of the forms in which natural gas is used for providing energy. It is composed of more than 93% methane, 3% ethane and traces of nitrogen, carbon dioxide and alkenes [<http://www.tpub.com>]. In the last few years, the global pressure on the extensive use of petroleum as a fuel for vehicles has necessitated the search for an alternative. CNG compressed to 3100 PSI

has been considered as one of the primary alternatives to petroleum. Natural gas is obtained from three main sources: natural gas and condensate wells, oil wells and coal bed methane wells. Well extracted methane gas requires a cleanup process before it can be used in vehicles. CNG for use in vehicles is stored either in thick-walled steel aluminum tanks or in fuelling locations much like the petrol stations. Natural gas is produced worldwide and is a much cleaner fuel than diesel and gasoline in terms of particulate emissions and noise pollution. This study investigates the viability of using Compressed Natural Gas (CNG) as an alternative fuel to diesel and gasoline. It also describes the conversion of gasoline powered vehicles to CNG powered ones and compares them on the basis of their efficiencies and pollutants produced over a course of time [<http://www.consumerenergycenter.org>].

Experimental studies conducted by various agencies have determined that CNG buses emit about 50% less Nitrogen Oxides (NO_x), 90% less Sulphur Oxides (SO_x) and about 97% less small particulates than conventional diesel buses. Many US cities have natural gas powered buses. Los Angeles, Atlanta, Syracuse, Birmingham, Providence, Fort Worth, San Diego, among others, have adopted a policy of ONLY

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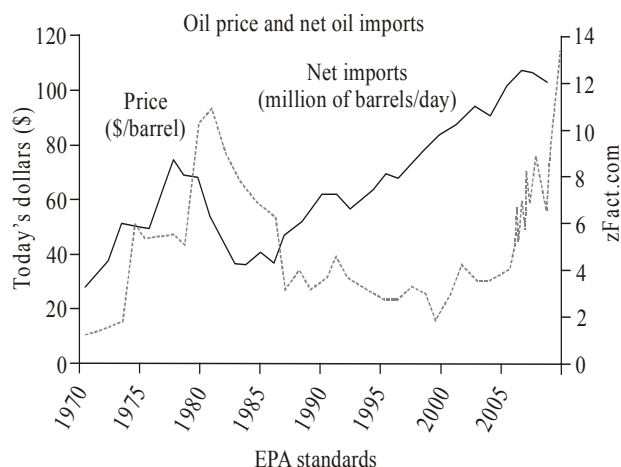


Fig. 1: Current oil prices (zFacts, 2011)

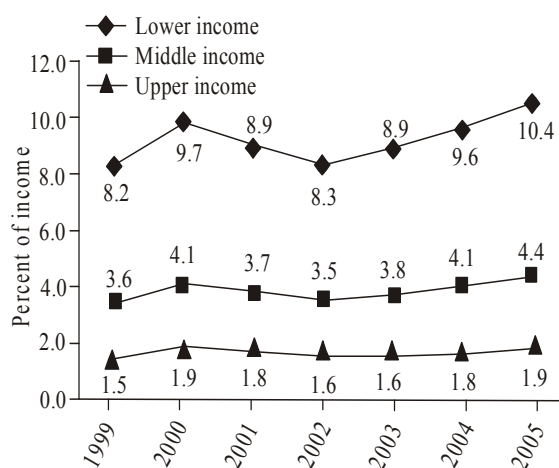


Fig. 2: Household expenditure on petroleum products (Cooper, 2004)

buying natural gas powered buses. It has been estimated that about 30% of the buses being built in North America are natural gas powered.

The Conversion of a gasoline engine to a CNG engine is really simple and economical and the basic principle behind this conversion is to deliver a CNG and air mixture to the carburetor rather than vaporized air/gasoline mixture. The cylinders for storing CNG placed either in the trunk of the car or underneath in case of vans or trucks and these tanks are connected to the regulator by stainless steel lines. A fuel-air mixer is then used for producing an air-gas mixture and then taken to the air intake manifold from where it is introduced for combustion. The engine does not have to be modified in any way as it still carries out the same basic functions of igniting the fuel and converting the energy of combustion to rotary energy.

The price of gasoline has been rising since the late 1990's with the current price hovering around 116\$/bbl (Fig. 1). This has greatly affected the economies of

nations all over the world and the domestic household of people is also getting affected. From a survey conducted by Mark Cooper on "The Impact of Rising Prices on Household Gasoline Expenditures" in September 2005, some interesting conclusions can be determined. Figure 2 shows the percentage of income spent on gasoline by a lower, middle and upper class household. We can safely conclude that the prices of gasoline are affecting the lower income class the most and serve as a great burden on them (Harris, 2000).

Examining CNG from the emissions point of view, it has the lowest emissions when compared to diesel and gasoline. Figure 3 shows the carbon dioxide emissions of vehicles run on CNG and gasoline which clearly indicate that CNG is a much cleaner fuel. With Global warming, emissions of greenhouse gases such as carbon dioxide and carbon monoxide are a matter of serious concern. From a study carried out by the U.S. Department of Energy's National Renewable Energy Laboratory W.S. Wayne and D. Smith, the John Deere CNG buses averaged 9.08 g/mi NO_x, 0.004 g/mi Particulate matter emissions and 2.173g/mi CO₂ emissions compared to 17.9 g/mi NO_x, 0.047 Particulate matter emissions and 3.159 g/mi CO₂ emissions from the MY 2004 DDC diesel buses. This data clearly suggests the environment friendly aspect of CNG over other forms of fuels (Melendezl, 2005).

CONVERSION OF DIESEL-ENGINE TO CNG-ENGINE VEHICLES

Natural Gas Vehicles (NGV) use the same principle as gasoline powered vehicles. The fuel mixture of gas and air is introduced in the cylinder of the four-stroke engine which is ignited by the spark plug moving the piston up and down. However there are minor modifications which need to be done to convert a gasoline vehicle to CNG powered. The flammability and ignition temperatures of a CNG vehicle are different from gasoline vehicles. The ignition temperature for a CNG engine is 842 °F while for gasoline engine it is 572 °F. The conversion of diesel engines to CNG is done by using retrofit systems or kits available in market. The natural gas engine is associated with an oxidation catalyst and is termed as lean burn natural gas engine. The oxidation catalyst has the feature of reducing the particulate emissions by about 90% as compared to diesel engines (Dunn, 2003).

The major modification required for a natural gas engine is the fuel storage space. Unlike gasoline vehicles which have a tank within its body, for NGV's the gas is compressed and stored in high pressure tube shaped cylinders placed at the rear end of the vehicle. This reduces the storage space in the car. However, new versions of light weight cylinders are being developed such as the Integrated Storage Systems (ISSs). These

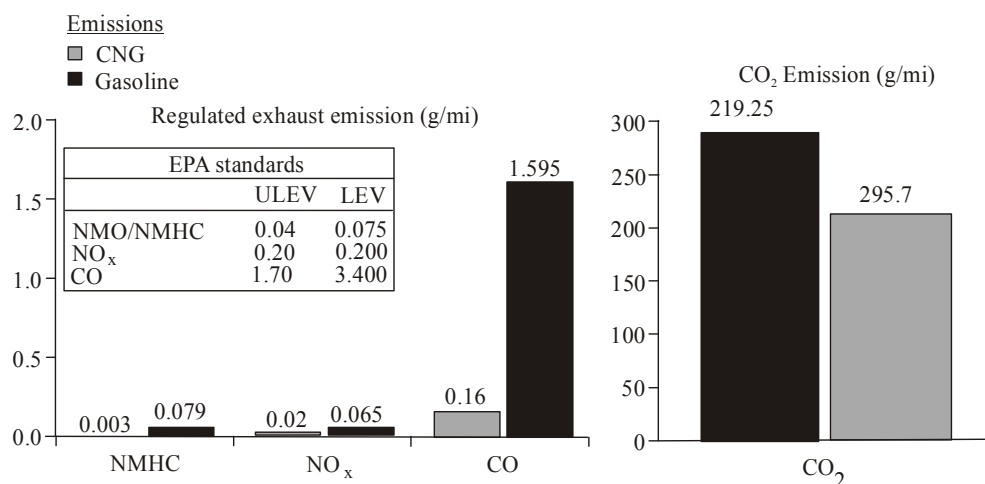


Fig. 3: Emissions from a natural gas powered versus gasoline vehicle (zFacts, 2011)

have fiberglass shells and impact absorbing foams to reduce damage on account of a car crash. When the engine in an NGV is started, natural gas flows from the storage cylinders into a fuel line. Near the engine, the natural gas enters a regulator to reduce the pressure. Then the gas feeds through a multipoint gaseous fuel-injection system, which introduces the fuel into the cylinders. Sensors adjust the fuel-air mixture so that when a spark plug ignites the gas, it burns efficiently. A natural-gas engine also includes forged aluminum, high-compression pistons, hardened nickel-tungsten exhaust valve seats and a methane-specific catalytic converter (Harris, 2000).

In the rear of the vehicle, a semi-trailing arm suspension sometimes replaces the lateral-link suspension that comes standard in many gasoline-powered cars. This creates more open space in the rear undercarriage, yet still provides a smooth, comfortable ride. NGVs also remove the spare tire and jack, which allows for a flat floor plan. "Run-flat" tires, such as the Extended Mobility Tires from Goodyear Tire, are installed to compensate for the fact that the spare tire and jack are missing. Refueling a natural-gas vehicle may also be a little different. The fueling point is typically at the front of the vehicle. An NGV can be fueled at a "fast-fill" pump in about the same time it takes to fuel any gasoline- or diesel-powered vehicle. Alternatively, an NGV can be fueled in five to eight hours using a "slow-fill" method. The home refueling stations offered by Honda are of the slow-fill variety, requiring car owners to refuel their vehicles overnight (Harris, 2000).

Korean Bus Program: One of the major initiatives to the use of a clean and green fuel was taken by Korea by launching the Korean CNG bus. Since 1990's the pollution levels in Korea were high. According to a research carried out by the director of automotive

pollution control division in Korea, he says that more than 85% of the pollution in Seoul was from heavy duty vehicles like trucks and buses. By converting these vehicles to CNG powered ones brings down the pollution level drastically. It was found that CNG buses emit 70% less ozone forming pollutants and 15% less of carbon dioxide as compared to the conventional CNG buses (Ahn, 2001)

The groundwork for running CNG buses in Korea was laid in mid-1990's when the nation had its first natural gas pipeline constructed. However, converting all the diesel run buses to CNG buses is not an easy task. CNG buses work out to be more expensive than its counterpart. Hence significant measures have to be taken by the Government of Korea to initiate this process of conversion. One step could be setting the price of CNG lower to that of diesel. This would require heavy initial investment from the Government but would be profitable to Korea in the long term. The Government has also spent considerable amount of money on building gas stations for refueling vehicles as well. Another measure taken by the Government to promote CNG has been its exemption from Value Added Tax (VAT) and acquisition tax (Ahn, 2001).

The resource allocation to this program from the Ministry of Energy has also been substantial. About US\$ 20 million were allocated to the CNG project. Another important step taken by the Ministry of Energy is increasing public awareness of the environment and pollution standards in Korea. These efforts on the part of government of Korea are really beneficial to Qatar as well. Having the world's largest natural gas field in Qatar, namely the North Field, it serves as an excellent trade opportunity between the two countries as well as a source of inspiration to Qatar to introduce CNG run vehicles and reduce their consumption of gasoline and diesel (Ahn, 2001).

CNG HYBRID VEHICLES

The CNG-electric hybrid is the newest innovation of improved engine efficiency and use of a clean and green fuel to propel vehicles. In this kind of vehicle, the internal combustion engine is associated with an electric motor. The basic principle of the hybrid vehicle is to utilize the energy wasted during coasting and braking in conventional vehicles by converting it to electricity. The energy is stored in a battery until it is used by the electric motor for accelerating on hilly slope terrain and low speeds when the internal combustion engine is least efficient. Unlike all-electric vehicles, the hybrid ones do not need to be recharged always as some of the energy required to drive the motor is stored internally during the braking and coasting process [http://www.greencarcongress.com/2008]. This is known as regenerative braking. The hybrid vehicle systems are of two types: Parallel Hybrid and Series Hybrid.

Parallel hybrid: In a parallel hybrid bus, the combustion engine and the electric motor are connected to the transmission independently. The electric motor is designed to provide power during stop-and-go traffic while at highway speeds the vehicle is powered solely by the internal combustion engine. During acceleration, both the electric motor and the combustion engine power the transmission. In addition, through a process called regenerative braking, energy lost due to braking is recovered and utilized to charge the battery (Ranganathan, 2005). The parallel electric hybrid configuration is shown in Fig. 4.

Series hybrid: A series hybrid bus is exclusively propelled by the electric motor. In a series hybrid bus, the Internal Combustion Engine (ICE) is connected to an electric generator which converts the energy produced by the ICE into electric power. This electricity supplies to a motor which turns the wheels of the vehicle. The generator also recharges a battery pack which provides supplemental power to the motor. Since the ICE is not connected to the wheels, it can operate at an optimum rate and can even be switched off for short periods of time for a temporary all-electric operation of the bus (Ranganathan, 2005). The series electric hybrid configuration is shown in Fig. 5. Parallel hybrids have a higher efficiency than series hybrids at constant speeds whereas series hybrids are better off for driving in traffic.

San Diego CNG hybrid electric bus: The San Diego Metropolitan Transit System (MTS) launched its first CNG- electric hybrid bus on April 10, 2008 which serves to be much more efficient than a CNG bus in terms of emissions and noise pollution. Though being an expensive venture involving over 1 million dollars, the hybrid bus is a new revelation in terms of efficient technology and countering environmental concerns of

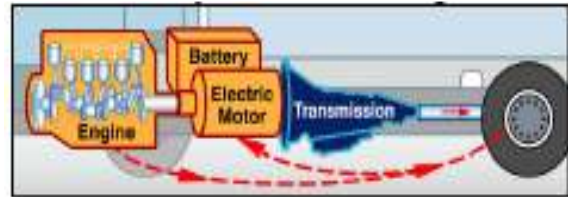


Fig. 4: Parallel hybrid electric configuration (Ranganathan, 2005); Southwest Research Institute

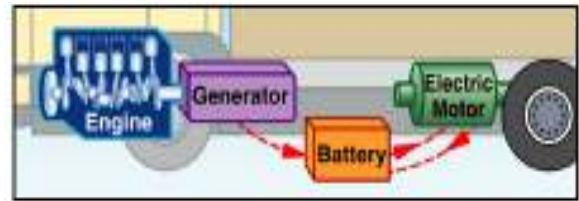


Fig. 5: Series hybrid electric configuration (Ranganathan, 2005); Southwest Research Institute

pollution. The San Diego CNG Hybrid Drive System features a Cummins ISB Gas Plus engine, a Siemens 165 kW electrical generator, two Siemens duo inverters, two Siemens 85 kW drive motors and Cobasys-developed NiMH batteries. Currently, the MTS runs 476 buses of which 75% run on CNG or CNG-electric hybrid technology and one of its goals over the next 6 years is to convert its entire fleet of buses to cleaner and greener technology of CNG and electric hybrid [https://www.cia.gov/library/publications].

ADVANTAGES AND DISADVANTAGES OF CNG VEHICLES

There are some of advantages offered by natural gas vehicles. Natural gas has a very high calorific value of 50000 kJ/kg second only to hydrogen. Moreover, Natural Gas vehicles are much safer than gasoline and diesel vehicles as the gas is present in thick containers and the chances of leakage are few. The price of natural gas is significantly lower than gasoline and diesel prices. Natural gas is abundant and an underutilized resource. There are more than 1300 fuel stations in United States and a well developed pipeline infrastructure in place for meeting the demand of fuel throughout the country. Natural gas prices have been shown significant stability as compared to oil prices which were at an unprecedented high of \$145/bbl last year to a low of about \$40 this year. Since natural gas used as fuel is filtered off from sulfur and other impurities, it is clean burning and improves the efficiency of the vehicle engine. However, natural gas has a few disadvantages as well. The biggest one being that a large portion of the trunk space is taken by the

natural gas cylinders rendering the car less spacious. Also a natural gas vehicle costs more than a conventional gasoline car. Another major drawback is that natural gas is a fossil fuel like oil however available in plenty (Harris, 2000).

ALTERNATIVE CNG TRANSPORTATION TECHNOLOGIES

A-CNG or ANG: A-CNG/ANG or absorbed CNG technology combines the safety aspects of using CNG with efficient storage and transportation. A-CNG storage is accomplished by using a porous material to store the natural gas which adheres to the absorbent molecules and is released whenever necessary. By using the absorbent CNG technology, a larger volume of gas can be stored in a container since it can effectively store a larger volume of gas at a lower pressure. Charcoal is one of the most efficient forms of absorbent materials currently available as it is highly porous and thereby provides a larger surface area for storing a larger volume of natural gas.

The advantages of A-CNG over LNG and CNG are several. One of the main advantage is that A-CNG can be stored at a much lower pressures compared to CNG which translate to significant cost savings for the filling stations, efficient use of a vehicles space and lower fuel expenditures for the motorists. A-CNG tanks do not occupy considerable amount of a vehicles trunk space and can actually be modeled in any suitable shape to fit a vehicle. A-CNG is compatible with two and three-seater vehicles and this could help in expanding this technology to the emerging Asian and African markets. This could effectively help in controlling the emerging pollution concerns in the developing world and at the same time advocate the effective use of a safer and cleaner form for the transportation and use of natural

gas. Different forms of adsorbent/absorbent technology has been tried including various organic materials such as charcoal, corncobs and even a carbon based form of polyvinyl dine chloride commonly known as Saran developed by Dow Chemicals (Siuru, 2008; Macdonald and Quinn, 1998) and shown in Fig. 6.

HCNG: HCNG vehicles make use of a blend of hydrogen with natural gas for use in transportation. The use of hydrogen blended with natural gas is a first step in a direction towards solely hydrogen powered transportation systems in the future. The primary benefit of HCNG over conventional diesel and natural gas vehicles is the immediate reductions in the emissions of toxic gases including nitrous oxides into the atmosphere in comparison to CNG alone or in cases of diesel or gasoline engines. This could also help in large reductions of excess emissions of excess air or re-circulated combustion gases as seen in Fig. 7. In addition, HCNG vehicles can also help pave the way for the widespread introduction of fuel cell technology in the world [<http://www.afdc.energy.gov>].

HCNG technology, even though it has a lot of prospects for the future, a lot more research is needed to account for the safety and risk factors associated with the use of Hydrogen gas as a fuel. It has been determined that with a hydrogen composition of about 50%, the leakage, flammability and safety risks are the same as in case of a tank of CNG [<http://www.metro.net>].

A lot of companies have started taking interest in this field and creating a hybrid transportation system has been a primary target in this fields. The American arm of Doosan Automobiles based in South Korea has already started to lay the groundwork for introducing the HCNG transportation vehicles in the U.S. The primary findings by the company indicate the cleaner

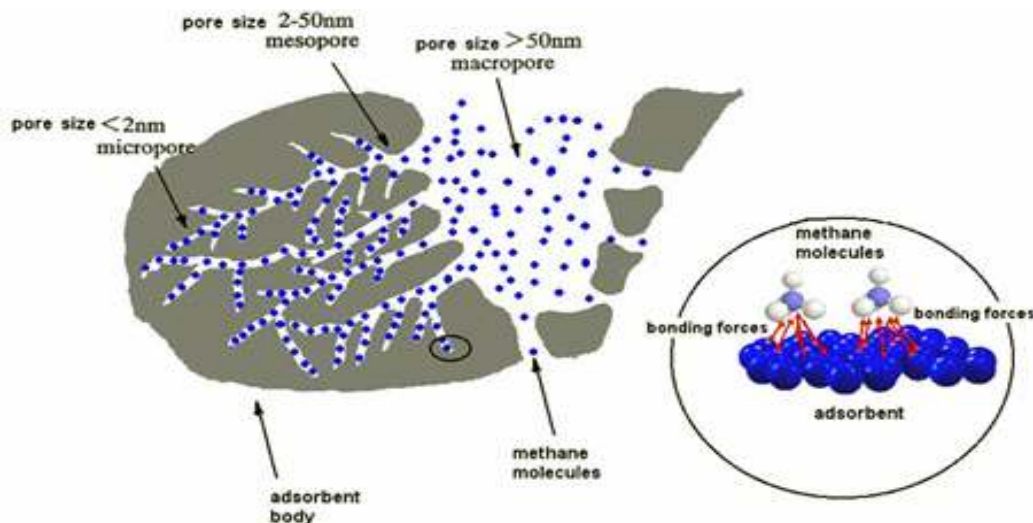


Fig. 6: Carbon based adsorbents schematic diagram (Siuru, 2008)

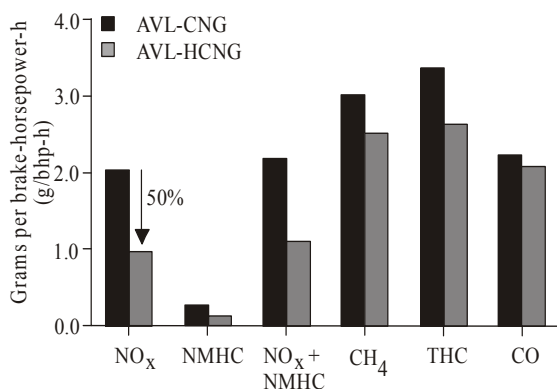


Fig. 7: Comparison of emissions of conventional CNG and HCNG vehicles [http://www.metro.net]

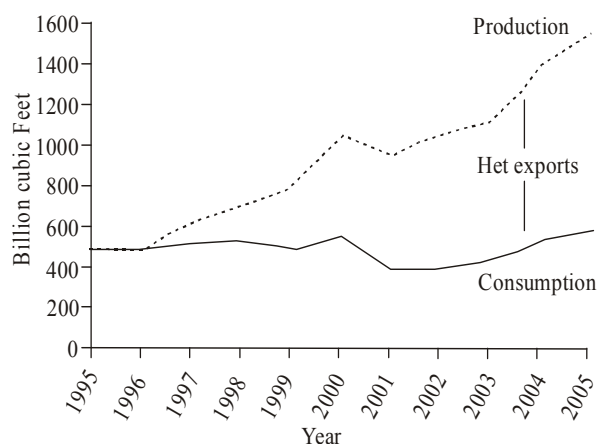


Fig. 8: Qatar's natural gas production and consumption (Ranganathan, 2005)

and more efficient aspect of HCNG over the conventional CNG technologies [http://www. Cleanvehicexpo.com].

CNG AS VEHICLE FUEL-BENEFITS TO QATAR

Qatar's location in the North Field region serves to its advantage as it contains massive reserves of natural gas. The proven natural gas reserves of Qatar have been estimated to be around 910.5 trillion cubic feet as of January 1 2007 and it has the third largest reserves of natural gas in the world. According to the CIA fact book, the natural gas production and consumption have been estimated to be 43.93 billion cu m and 17.93 billion cu m respectively. This indicates that Qatar has the resources to use natural gas for fuelling vehicles (Ranganathan, 2005). Figure 8 indicates the wide disparity in the production and consumption of natural gas in Qatar.

The conversion of conventional vehicles to CNG vehicles is however not easy. It involves huge investments in the purchase of conversion kits and

establishment of refueling stations throughout the country. With the economy booming, the time is right for Qatar to undertake this project and step on the initiative of using cleaner fuels and reduce its carbon footprint. As Qatar is in the developing stages of its public transport sector, the CNG technology can be experimented in this regard. Moreover, with the shift of the fuel impetus from petroleum to natural gas would give an opportunity to Qatar to export its petroleum and build on its economy while protecting its environment from harmful toxic fuel emissions.

CONCLUSION

The technical aspects of conversion of diesel and gasoline engines to CNG vehicles have been discussed. Examples such as those of Korean bus program and CNG-electric hybrid technology have been illustrated to build on the argument of using natural gas as an alternative fuel to petroleum. In specific interest to Qatar, the use of CNG engines has great advantages. CNG is not only a cleaner and greener fuel, but it is also available in plenty in Qatar and its production is nearly two and a half times its current consumption. Qatar is in its development phase in terms of public transportation infrastructure and the use of CNG technology from the very beginning would set high standards and show commitment towards the global fight of global warming. CNG hybrid vehicles are much more efficient with less air and noise pollution that would help energy saving and global warming.

The Hybrid technologies discussed here have been implemented in some parts of the world and have been successfully tested in many countries. Implementing and accepting of these technologies require time and capital and Qatar is situated in a potential in the future as it combines alternate forms of cleaner transportation along with the conventional unique position to do this. Abundant reserves of natural gas and a strong and vibrant economy trade positions Qatar to be an ideal candidate to implement alternate forms of transportation.

Hybrid technologies in CNG transportation hold significant fossil fuel based transportation systems. The slow migration from a society depending solely on hydrocarbons to cleaner and more sustainable forms of energy requires intermediate steps and hybrid technologies are steps in that direction. Implementation of hybrid technologies including HCNG would eventually pave the way for alternate forms of energy in the future.

Finally, investing in a CNG transportation system and converting vehicles to CNG is a positive step towards reducing the green-house gas emissions considering the current worldwide policies regarding Global Warming? CNG-powered vehicles and hybrid vehicles can contribute significantly to reduce the

global emission of green-house gases including carbon dioxide.

NOMENCLATURE

CNG	: Compressed Natural Gas
ANG	: Absorbed CNG
EPA	: Environmental Protection Agency
EIA	: Energy Information Administration
ISB	: Isothermal Saturated Boundary
NO _x	: Nitrous Oxides
PM	: Particulate Matter
Sox	: Sulphur Oxides
cu m	: Cubic meters
g/mi	: Grams/mile
psi	: Pounds per square inch
\$/bbl	: Dollars/barrel

REFERENCES

- Ahn, M.S., 2001. Korean CNG Bus Program, the Environmental Benefits. Automotive Pollution Control Division, Ministry of Environment, Korea, Retrieved from: http://www.fueleconomy.gov/FEG/FEG2006_AltFuelVehicles.pdf.
- Cooper, M.N., 2004. Rising Energy Prices Strain Household Budgets and the Economy for most Americans. Retrieved from: <http://www.consumerunion.org/pub/0929%20price%20report.pdf>.
- Dunn, M., 2003. State of the Art and Future Developments in Natural Gas Engine Technologies. Cummins Westport Inc., Retrieved from: <http://www.osti.gov/bridge/servlets/purl/829800-uU4tIF/native/829800.pdf>.
- Harris, W., 2000. Natural Gas Vehicle Design. Retrieved from: <http://auto.howstuffworks.com/ngv3.htm>, http://www.afdc.energy.gov/afdc/fuels/hydrogen_blends.html, Hydrogen/ Natural Gas-HCNG Fuel Blends, Alternative and Advanced Fuels.

- http://www.cleanvehicleexpo.com/presentations/081014_Tuesday/Kwangsup_Hwang_presentation_EXPO_2008.pdf, Doosan HCNG Engines, Doosan Infracore Engine America Division.
- <http://www.consumerenergycenter.org/transportation/afvs/cng.html>, "Compressed Natural Gas (CNG) as a Transportable Fuel", California Energy Commission.
- <http://www.greencarcongress.com/2008/04/san-diego-launch.html>, San Diego Launches CNG Hybrid-Electric Bus.
- http://www.metro.net/projects_programs/atvc/1108%20HCNG%20TECHNOLOGY.pdf, Mixed Hydrogen/ Natural Gas (HCNG) Technology -Visit to Collier Technologies, ARIELI Associates, Report No. 1108.
- <http://www.tpub.com/content/altfuels/02/2971/29710013.htm>, "CNG composition", Integrated Publishing's Archive Service.
- <http://www.cia.gov/library/publications/the-world-factbook/print/qa.html>, The World Factbook, Energy Information Association.
- Macdonald, J.A.F. and D.F. Quinn, 1998. Carbon adsorbents for natural gas storage. *Fuel*, 77(1/2): 61-64.
- Melendezl, M., 2005. Emmission Testing of Washington Metropolitan Area Transit Authority. Retrieved from: http://www.transec.oenergy.com/placed_images/pdf/NREL-WMATA_DieselvNG21606.pdf.
- Ranganathan, S., 2005. Hybrid Costs and Benefits. Retrieved from: http://www.eesi.org/files/eesi_hybrid_bus_032007.pdf.
- Siuru, B., 2008. Corncobs store gas for Natural Gas Vehicles. Green Car Journal-Web, Retrieved from: <http://www.greencar.com/articles/corncobs-store-gas-natural-gas-vehicles.php>.
- zFacts, 2011. Crude Oil Prices Drive up cost of US Addiction. Retrieved from: <http://zfacts.com/p/196.html>.