SAVONIA

Analysis of Natural Gas Vehicle Industry

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SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS**
Abstract

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Abstract

A vehicle powered by natural gas is becoming a prevalent trend and direction in automobile manufacturing. The thesis is aiming at analyzing the natural gas vehicle industry from its environmental effectiveness, economic effectiveness, recent status and its development in the near future with statistical data. And also it will find out the potential problems and relevant technologies. Investigation and literature research method are mainly used to fully collect the correct information and data. The main statistical sources are gathered from International Energy Agency documents.

In the text, compressed natural gas and liquefied natural gas are mentioned frequently. These two types of natural gas fuel are most commonly used at present. Compressed natural gas usually applies to low-duty vehicles and liquefied natural gas is more widely used in heavy-duty vehicles. The comparison between each fuel type and modern application areas has been presented in the 3rd chapter. In terms of current market status, the Asia-Pacific and Latin-America are the leading of NGV applications. In these regions, NGV has occupied a large part of market share and is continuously increasing. While in Europe, the share of NGV is quite limited.

Natural gas's utilization benefits a lot GHG reduction and other environmental issues. As for a long-term development, the governments' incentives are becoming increasingly attractive. On the other hand, natural gas fuel has its weaknesses and is still in a developmental stage. Compared with the oil-based fuel, the biggest problem is the lack of infrastructure. In technical aspects, many new types of natural gas engines and fuel-mixture methods are under exploration.

Keywords
Natural gas, automobile, vehicle,engine, environmental, application, technology, development.

CONTENTS

ABBREVIATIONS

NGV	natural gas vehicle
CNG	compressed natural gas
LNG	liquefied natural gas
CNGV	compressed natural gas vehicle
LNGV	liquefied natural gas vehicle
HCNG	Hydrogen CNG
LDV	low-duty vehicle
MDV	medium-duty vehicle
HDV	heavy-duty vehicle
SNG	synthetic natural gas
OEM	original equipment manufacturer
PM	particulate matter
GHG	greenhouse gas

1 THE TARGET OF THESIS

NGV, which stands for Natural Gas Vehicle, is a new model of automobiles powered by natural gas. The thesis is aiming at analyzing the NGV industry from different aspects worldwide. And it will also find out the potential problems and the relevant technologies to handle the deficiencies. The precise research targets of NGV are as follows:

- Basic understanding
- How is the current status in market
- What are the strengths and weaknesses
- What are the factors that drive the future development
- What are the technologies in applications
- What are the potentials and possibilities in the future

1.1 Method to handle knowledge

The thesis is primarily using investigation and literature research method to fully collect correct relevant information and materials. The main statistical sources are gathered from International Energy Agency documents.

In order to get a more intuitive description, a number of line charts, pie charts and tables are used to illustrate the differences and make comparisons in the paper. It also contains a few real cases and status in different regions as concrete evidences.

2 INTRODUCTION TO NATURAL GAS VEHICLE

Natural gas is undeniably the one of the cleanest energy source on earth. Nowadays, it is widely used in automobile industry.

2.1 Definition of natural gas vehicle

Simply speaking, a natural gas vehicle or NGV is a vehicle that uses natural gas as the power resource. It falls into three categories according to the chemical components and speciations of natural gas, which are compressed natural gas (CNG) vehicle, liquefied natural gas (LNG) vehicle and liquefied petroleum gas (LPG) vehicle. Currently, most of the NGVs used in our life are converted by gasoline vehicle or diesel vehicle. After modification, either gasoline (or diesel) or natural gas is capable for running the engine. And it still has two types of engines, bi-fuel egine and dual-fuel engine. Bi-fuel engine has the capability to switch back and forth from gasoline or diesel to the other fuel, manually or automatically, and the one has the capability of running on a blended fuel is called dual-fuel engine. [1]

NGV's development is attributed to its low-pollution. Compared to the exhaust from gasoline vehicle, NGV produces aproximately 90% less carbon monoxide (CO), 70% less sulfur dioxide (SO_2), 23% less carbon dioxide (CO_2) and 40% less exhaust particulates in the same condition. It indicates that natural gas is undeniably a perfect green alternative fuel. In addition, natural gas costs nearly 50% less than gasoline, and it not only has a high safety coefficient, but also supports a longer driving distance. Thus, it is quite applicable to taxies or public city-buses.

2.2 Classification of NGV

Molecularly, natural gas is a simple fuel, which is approximately 90% composed of methane (CH4). It is just one carbon atom attached with four hydrogen atoms, with the remainder comprising of propane, butane and other components. The simple composition of natural gas makes it easier to achieve complete combustion. In addition, it does not dilute lubricating oil, so that the engine's life-time could be extended compared to the use of gasoline.

Natural gas apparently occupies more volume than gasoline or other liquid fuels, thus it is quite necessary to compress or liquefy the natural gas, thereby to make it practical for transporting. According to the different forms of natural gas, it falls into three categories:

- CNGV, which stands for compressed natural gas vehicle, is the most common application for NGVs worldwide. It is stored in cylindrical or spherical containers at a pressure of usually 200-250 bar.

- LNGV is the liquid natural gas at the temperature of -162 ℃ (-260℉) under the normal atmospheric pressure. It is stored in the on-board insulated cylinder. LNG has a high ignition point, which makes it safer for long-distance transport or storage.

- LPGV is liquefied petroleum gas or simply propane and butane. It is a flammable mixture of hydrocarbon gases and heavier than air, which is often used for cooking fire. Recently, LPG has been widely used instead of gasoline or diesel as the fuel for vehicles, because of lower noxious emissions. [2]

Classified by fuel types:

- Dedicated, using 100% natural gas.

- Bi-fuel NGV. It has the capability to switch back and forth from gasoline or diesel to the other fuel, manually or automatically,

- Dual-fuel NGV. It has the capability of running on a blended fuel.

2.3 NGV leads the future of automobile industry

Replacing the gasoline or diesel with gas fuel has been widely developed in the world since the end of 20th century. The reason is that people have been focusing on shortage of petroleum and the deterioration of eco-system, which are closely connected to human’s life. The lack of energy resource will directly influence the economic sustainable development in each country. That is a great challenge.

Nevertheless, natural gas is no doubt one of the cleanest energy on earth. Nowadays, natural gas is also widely used in automobile industry and natural gas vehicle is becoming a prevalent trend around the world. Not only the case of increasing environmental pressure in each country, and also the reason that the extensive natural gas reserves on earth make it possible that gasoline or other fuel types will be replaced by natural gas. The data indicates that the proven reserve volumes of natural gas on the earth can be used for more than a hundred years. And rational exploitation and utilization of natual gas will bring enormous economic benefits, which will solve the current energy crisis without harm to the environment. Furthermore, the cost of natural gas is generally lower than that of gasoline or other fuels. These factors push natural gas to become a vital developmental item at the moment. [3]

“Natural gas is the only real immediate alternative to petrol”
- Sergio Marchionne, CEO of Fiat.

3 THE APPLICATIONS AND CURRENT STATUS OF NGV MARKETS

Natural gas is almost suitable for any kind of vehicles, such as cars, vans, forklifts, buses, trucks, trains, vessels and even aircrafts. In past years, road transportation was heavily dependent on oil. 96% of all fuels used in 2010 were oil-based. After that, the use of natural gas in vehicles has relieved the oil tension to some extent. The time is coming for NGVs. Currently, the market share for NGV is constantly growing in many countries. Gas stations have been widely built and technology is also being continuously improved.

3.1 The CNGV application

Compressed natural gas (CNG) is mainly applied to light-passenger vehicles and small commercial vehicles, and most of them are retrofitted. The capacity of storage cylinder for CNG is relatively small, generally 70 liters. That size is more suitable for light-duty vehicles.

CNG Tank Package Features	
Tank Type	Type III pressurized
Tank Material	Aluminum wrapped in carbon fiber
# Tanks	75 DGE: 5; 60* DGE: 4
Tank Size	15 DGE each
Pressure Rating	3600 psi*
System Weight (with fuel)	75 DGE: approx 2150 lbs; 60 DGE: approx 1650 lbs

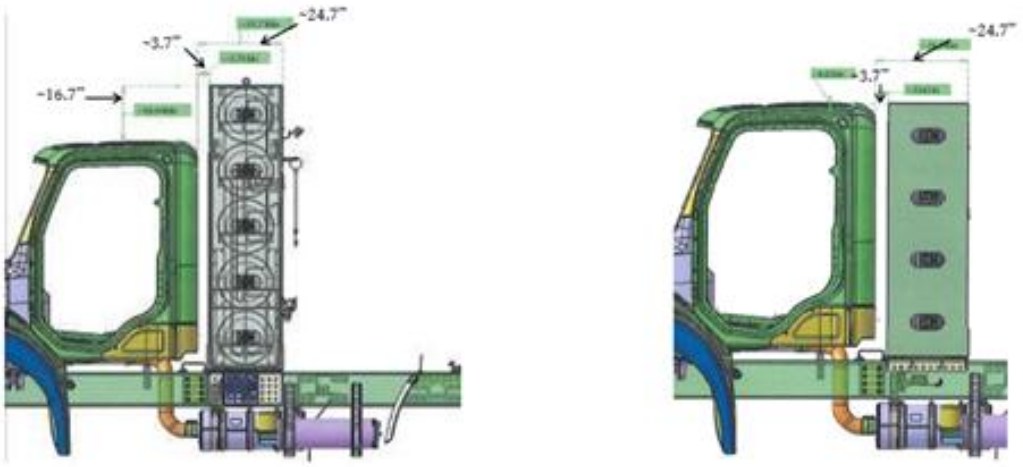

Figure 1: CNG tank package features. Source: Daimler Trucks North America.

In China, the modified private cars cannot be registered in Department of Motor Vehicles. Due to these restrictions in terms of the policy, few OEMs for light-duty NGVs existed in the domestic market until present. Most of retrofitting CNG cars on the road are mainly taxis and public buses. Actually, the retrofitting process of a CNGV is simple. Only an extra set of CNG storage device is needed, and the original fuel feeding system is retained. By estimate, a CNG taxi conversion costs about 5000yuan, equal to about 600euros.

The application field has a great impact on the sustainable development of CNGVs. It is wise to set the beginning on taxis and other public transportation. Because taxis and buses are the infrastructures of a city, they are closely connected to people's life. And the follow-up developments on private cars, logistics or other expanded markets are becoming easier to achieve.

For CNG converted sedans and estate cars, the gas tank is often installed in the trunk of the car because of the limited inter-space. So the luggage space is occupied. But for vans, it is more suitable to use CNG based on a large space inside the vehicle. In the case of public bus, the gas storage tanks are usually installed on the roof of the bus. In addition, CNG is also widely used in forklifts. Due to the fact that forklifts often work indoors, emissions become a vital factor. The use of CNG can not only provide low emissions but is also easy to refuel on site. It is a better choice than electric forklifts.

Figure 2: Gas storage tank installed in the trunk of a private car. Source: online-source, NGV market in Latin America.

Real cases:

A. Sagawa Express

- One of the largest transport companies in Japan
- Owns more than 4200 CNG trucks, which is the world's largest fleet of CNG trucks
- Owns 23 private CNG refueling stations
- Eager to expand to low CO_2 trucks

B. *"LA to DC on CNG"*

As can be seen from the *Figure 3*, an interesting activity named "LA to DC on CNG" was held in May, 2012. A Daimler freightliner powered by CNG travelled across the country. It is the first natural gas transcontinental trip in North American. The trip was from Long Beach, CA to Washington, DC with a CNG, and the return way was from Richmond, VA to Los Angeles, CA. It was like a moving expo to attract people and let them know more about the CNGV technology. [4]

Figure 3: "LA to DC on CNG" tour and its route in North America. Source: Daimler Freightliner.

3.2 The LNGV application

Liquefied natural gas (LNG) is mainly applied to large and heavy-duty commercial vehicles, and the OEM market is the main distribution channel. Compared to the CNG storage tank, LNG tank has much larger capacity, generally 450liters, which is 6 times bigger than CNG. Therefore, it is more suitable for long-distance transportation, such as heavy-duty trucks, coaches and logistics transportation.

On the other hand, the high cost of the conversion of LNG engine from heavy-duty diesel engine and manufacturability requirements are so high. Thus, those heavy-duty LNGVs are generally not using the retrofitting pattern but primarily depend on OEMs. That is the reason for the higher price of LNG trucks than diesel trucks.

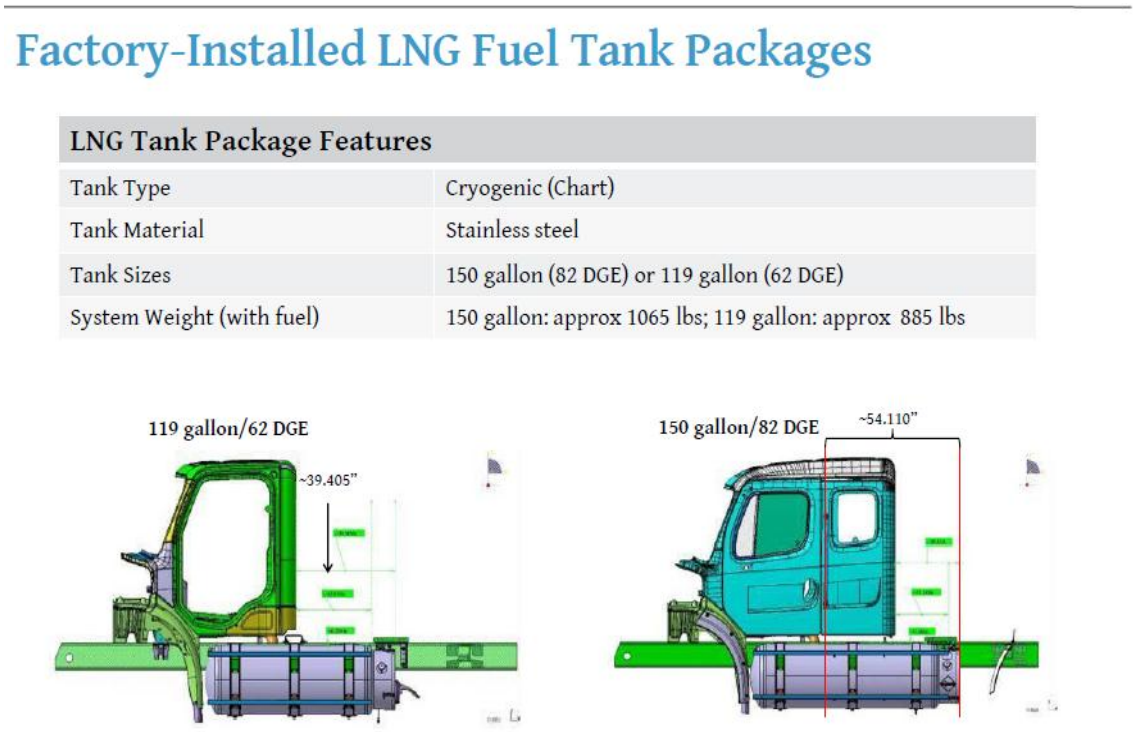

Figure 4: LNG tank package features. Source: Daimler Trucks North America.

Trucks occupy the largest applied area of LNG. Most of the large commercial activities cannot be preceded without trucks. And all the things round us like, food, furniture, oil or timber all depend on trucks for transportation. Those commercially vehicles often do higher mileages annually than private cars. Thus, the more diesel fuel consumption and air pollution are generated during the transport.

LNG as an alternative fuel can greatly reduce the bad emissions and it is also cost-effective. By contrast, 1 liter diesel oil is equal to 1.8 liters of LNG. Undeniably, LNG truck opens the way for the medium and long-distance road transport.
The engine system of heavy-duty vehicles is divided into two categories. One is 'Dedicated', which means using 100% LNG. And other one is 'Dual fuel', which uses diesel injection for ignition and LNG as the main fuel.

Figure 5: LNG truck models in North America and Australia. Source: NGVA Europe.

A. Large scaled application

Recently, the application of LNG has been expanded to larger scale commercial applications, such as railway, vessels and even aircrafts:

- Russian-developed GT1-001 locomotive with 8300KW gas turbine engine running on LNG has been used for daily services since 2010. [5]

- In 2012, a few LNG vessels existed in Norwegian waters. It includes passenger ferries and tender vessels. And Viking Line's new cruise ship and more are on order belong to this category. [6]

Figure 6: LNG in railways and vessels. Source: NGVA Europe

B. Application in motorsports

Recently, natural gas vehicles have also been applied in motor racing events.

- In April 2012, the Maxximus LNG super car, which is powered by LNG and developed in the United States broke the world record for accelerations from 0 to 90kph in 1.96 seconds.

- In the 2012 Swedish Touring Car Championships, four Volkswagen cars running on biomthane took the 1st, 3rd 5th and 6th place, respectively. It is a good way to display not only the talent of drivers but also the natural gas technology. The good result in hard racing is enough to prove that the natural gas can be applied to people's daily life. [7]

Figure 7: The Maxximus LNG Supercar and STCC team. Source: www.iangv.org

More possibilities are mentioned in the 5th chapter.

3.3 Comparison between LNGV and CNGV

From the information in previous chapters, CNGV is more cost-effective and LGNV has more market potential in large scale commercial applications. A comparison table between LNGV and CNGV can be made as follows:

Table 1: Comparison between LNGV and CNGV

Fuel type	Device feature	Applicable models	Marketing	Cost
LNG	Big storage tank, suitable for long-distance and heavy-duty transportation.	Heavy-duty truck, coach, public bus	OEM market	Approximately 80,000 Yuan more expensive than general diesel truck.
CNG	Small storage tank, simple retrofitting processes	Light-duty commercial vehicle, private car, taxi, public bus	Retrofitting from original oil-based vehicle	Retrofitting cost is about 5000 Yuan/ 600€

Speaking of quantity, the CNGVs occupied a larger market share than the LNGVs, which is partly caused by the cost differences. As in China, the number of CNGV was around 1.43 million and the number of LNGV accounted only for 70 thousand at the end of 2012. On the other hand, the smaller market share of LNGV at present signifies its potential and the higher increasing rate after years. For example, China had 29,952 of LNGVs in 2011, but nearly 70,000 in 2012. The growth rate is more than 100%. [8]

3.4 The development of NGVs globally

A. Total amount

Until the end of 2012, the latest rank of NGV global indicated the significant growth of NGVs. As can be seen from the chart below, Iran ranked first with nearly three million NGVs followed by Pakistan and Argentina with 2.9 million and 2.14 million, respectively. But Pakistan owned the largest amount of NG refueling stations. And a remarkable increase can be witnessed in China by one million plus NGVs compare to the year 2011.

In total, more than 15 million NGVs in 84 countries were recorded at the end of 2011. And by contrast with one billion motors in the world, the market share of NGVs is still small, at nearly two percent at present.

Table 2: NGV count and rank in countries at the end of 2012. Source: NGV Global

NGV Count - Ranked Numerically

As at December 2012 (NB - Some data from earlier reported dates)

	Country	Natural Gas Vehicles	Refuelling Stations	Data Year	Data Month
1	Iran	3,000,000	1,960	2012	December
2	Pakistan	2,900,000	3,330	2012	December
3	Argentina	2,140,000	1,902	2012	October
4	Brazil	1,739,676	1,701	2012	December
5	China	1,577,000	2,784	2012	December
6	India	1,250,000	724	2012	December
7	Italy	746,470	959	2012	June
8	Ukraine	390,000	324	2012	May
9	Colombia	380,000	690	2012	December
10	Thailand	358,000	470	2012	December
11	Uzbekistan	300,000	213	2012	December
12	Bolivia	254,722	156	2012	December
13	Armenia	244,000	345	2011	December
14	Bangladesh	210,000	587	2012	December
15	Venezuela	185,073	166	2012	December
16	Egypt	185,000	162	2011	July
17	Peru	150,000	190	2012	December
18	United States	127,735	1,120	2012	December
19	Germany	95,498	915	2012	December
20	Russia	90,000	247	2012	December

B. Market share

In terms of market share, Bangladesh has the largest market share, accounting for 61%, followed by Armenia with 30%. And the data of Pakistan, Bolivia, Argentina and Colombia are all over 20%. The rest of countries are staying in the range from 1% to 15% and the market share in total motor amount was only 2%. However, it will be a long-term reformation for the world.

Table 3: Market share of NGV in total motors in each country. Source: NGVA Europe.

Country	NGV market share (%)	Country	NGV market share (%)
Bangladesh	61	Tajikistan	5
Armenia	30	India	5
Pakistan	26	Egypt	5
Bolivia	26	Kyrgyzstan	3
Argentina	24	Ukraine	3
Colombia	24	Bulgaria	2
Iran	14	Italy	2
Malaysia	11	Moldova	1
Myanmar	8	Trinidad & Tobago	1
Peru	7	China	1
Brazil	5		

C. NG consumption

The biggest part of natural gas fuel consumption is in Asia-Pacific area, and most of the fuels are used for buses and trucks. But America and Canada are generally different from that pattern, 43% of the NGVs are applied in private cars followed by light-duty trucks at 33%.

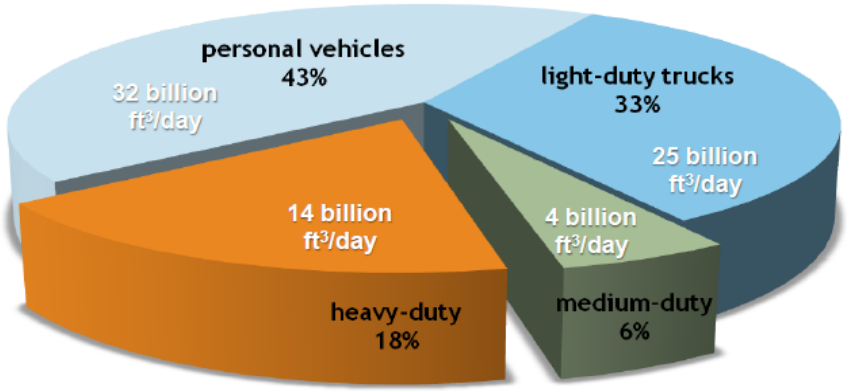

Figure 8: Canada and USA natural gas fuel consumption by vehicle class (75 billion ft3/day). Source: EIA, Canada.

D. Infrastructure

In infrastructure construction, Latin American is still in the leading place as well as the number of NGVs. And until the end of 2012, more than 20,000 NG refueling stations were built worldwide. Europe has about 4000 NG fueling stations, which are mainly located in Germany and Italy. [9]

In Brazil, with the coming event of World Cup 2014 and Olympic Games in 2016, a theme of “Green event” is appealed. Hundred more NG refueling stations were opened in the past year. [10]

Overall, Latin America seems to have great potential for growth of NG used in commercial vehicle applications but uncertainty about the future support also existed. Natural gas prices are expected to remain low until the period to 2035. In order to reach its full potential, a performance similar to diesel must be offered in the following years.

4 THE STRENGTHS OF NGV

The dependence on crude oil gives rise to lots of domestic and international problems. A clean, abundant, inexpensive and applicable alternative fuel is urgently needed and natural gas meets all the requirements. Natural gas offers lots of attractive features. Either in aspect of economy, environment, or government incentives, natural gas is the compelling choice for making clean future real.

4.1 Environmental benefits

The environmental pressure is beneficial to the NGV popularization.

A. Air pollution:

Recently, a wide range of hazy weather has frequently appeared in China. And the index of PM2.5 (PM2.5 particles transport and deposit toxic materials through the air) has also reached a new high. It is getting more serious with the air pollution issue. Nevertheless, exhaust emission is regarded as one of the chief culprits. Thus, how to improve and control the emissions has become a hotspot in market. So far, the alternatives that can take place of conventional fuel are electric vehicles and natural gas vehicles. Why not electric vehicle?

Electric vehicles have to face three major difficulties, which cannot be solved in a short term:

1) Lack of charging infrastructure,

2) Generally high price, low market penetration,

3) The air pollution issue is hardly relieved and radically solved by electric vehicles. Because most of the electricity is coming from the batteries, which still burn coal, the source of pollution has not changed.

Natural gas vehicle has remarkable advantages for energy conservation and environmental protection. The main composition of natural gas is methane, it has fewer impurities. Its combustion generally causes less pollution. And the great merit of NGV is the reduction of harmful emissions. Compared to conventional fuel vehicles, the

one using natural gas as fuel can reduce emissions of carbon monoxide and nitrogen oxides by nearly 80%, reduce carbon dioxide emissions by 25% approximately, and the reduction of sulfur dioxide, hydrocarbon and various particulates is close to 100% according to the data from International Energy Agency. Natural gas is the cheapest and fastest way to achieve significant CO_2 emission reductions. [11]

Table 4: Emission comparison between NG and conventional fuels in China. Source: IEA documents.

Emissions (tons/year)	Natural gas	Conventional fuels
Carbon dioxide (CO_2)	5800	7600
Nitrogen oxides (NO_x)	24	183
Sulfur oxides (SO_x)	0	48
Dust & particulates	0	9.4

Table 5: Comparison of air emission from other fossil fuels, Source: Energy Information Administration - www.eia.doe.gov.

Comparison of Air Emissions from Fossil Fuels

(Pounds of air emissions produced per billion Btu of energy)

Emission	NATURAL GAS	OIL	COAL
Carbon Dioxide	117,000	164,000	208,000

As well-known, carbon dioxide is a primary greenhouse gas, sulfur dioxide is the primary source of acid rain and nitrogen oxides are the primary cause of smog, and also other particulate matters, which can closely affect human's health and visibility. In that case, using natural gas as alternative fuel can alleviate many large environmental problems.

B. Sound pollution:

Noise is the one of the great environmental issues in the world. And the noise from traffic bothers a lot. With the increasing number of private cars, noise really matters in people's life especially in metropolis. It may cause insomnia, hypertension or other negative impacts on human's health by a long term noise-exposure. The most cost

effective measures are those at the level of vehicles in order to address the root of the problem.

Noise reduction is the advantage of NGV that people often ignore. Generally, diesel engines emit heavier noise, especially in heavy-duty vehicles. By comparison, many individual cases indicate that NGVs can make 10 dB less noise than vehicles running on diesel. For instance, a specific Iveco truck, which runs on liquefied natural gas, is the first to be certified for meeting the PIEK light norm in the Netherlands, which sets a 72dB maximum to reduce noise from urban delivery. And normally, a diesel truck makes a 79-90dB of noise. [12]

4.2 The economy and efficiency of Natural Gas Vehicle

The price gap between petroleum and gas results in the high economy and efficiency of using natural gas as an alternative fuel. On average, natural gas generally costs 50% ~ 70% much per unit of that gasoline or diesel costs with less price volatility. And the stable price helps a lot with the long-term plan for the fuel cost and makes it more accurate.

Table 6: Price for fuels in the world. Source: NGV European.

Country/Region	Diesel (USD/lge)	Gasoline (USD/lge)	CNG (USD/lge)
OECD Europe	1.32	1.39	0.74
OECD North-America	0.57	0.59	0.30
OECD Asia	1.39	1.79	0.62
Argentina	0.56	0.63	0.26
Bangladesh	0.42	0.67	0.22
Brazil	0.89	1.25	0.71
China	0.62	0.77	0.42
Egypt	0.19	0.16	0.07
India	0.65	1.04	0.33
Iran	0.01	0.10	0.04
Malaysia	0.57	0.63	0.22
Pakistan	0.70	0.93	0.49

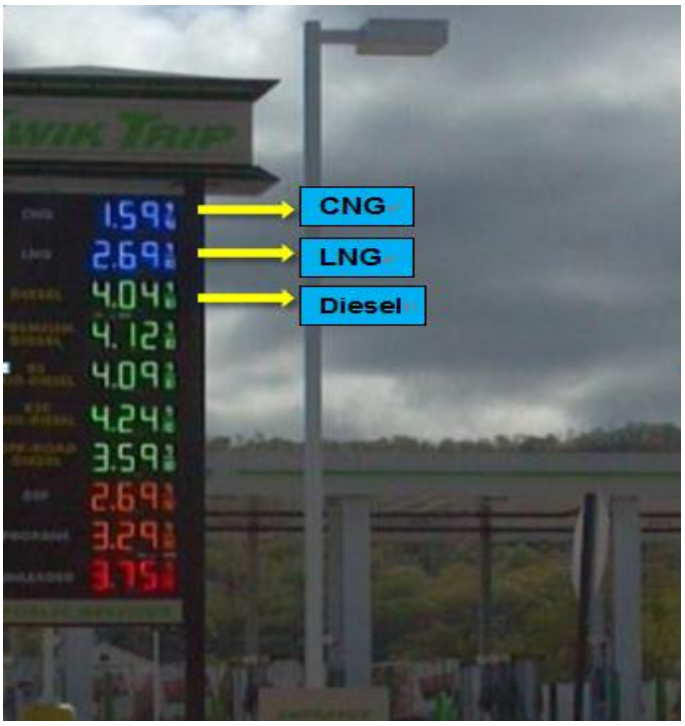

Figure 9: The price of NG in North American. Source: Twik Trip.

Typically, NGV is more expensive than vehicles running on gasoline or diesel. The reason is in the relatively high-cost in specific fuel containers of NGV. But in any way NG is cheaper per equivalent gallon than other fuels. The saving in fuel cost is a long-term benefit. By estimate, the NGV user would see a payback of those additional costs from the fuel costs in a relatively short period of time (For LNG commercial vehicles in less than 2 years, for CNG vehicle in less than half a year). Especially for heavy-duty vehicles and high-mileage driven vehicles, the saving could be seen as significant. The table on the next page will show the price comparison of each fuel in China in 2012.

For example:

- A general truck using 1,000 gallons of diesel per month,
  Diesel at $4.00 is $4,000 per month in fuel costs,
  Retail natural gas 50% of diesel – savings $2,000 /month,
  Annual fuel savings for a fleet of 100 trucks would be $ 2,400,000.

Natural gas has high efficiency. About 90% of the energy that natural gas produced is worked as useful energy. By contrast, only about 30% of the energy is generated by conventional fuels. But the performance of NGV can still be improved. In addition,

NGV has lower maintenance costs. Because the combustion of natural gas produces less particulates, it causes less wear and tear on the engines. [13]

With the higher penetration of natural gas and rapidly expanding product offerings, lots of large diesel based corporations have invested hundreds of millions in natural gas. It really helps with the growth of domestic economy. A great market potential can be seen on NGV industry.

Table 7: The comparison of the price of each fuel type in China. Source: Ubs estimates in China.

	燃料 Fuel types	百公里耗油/气 Fuel consumption per 100km (liter or	燃料价格 Fuel price/unit (Yuan/liter)
Taxi and LDVs	Gasoline	10 升	6 元/升
	CNG	9.5 方	5.2 元/方 (87%)
Private car	Gasoline	10 升	6 元/升
	CNG	9.5 方	5.2 元/方 (87%)
Public city bus	Diesel	40 升	7 元/升
	LNG	52 方	4.9 元/方 (70%)
Coach	Diesel	40 升	7 元/升
	LNG	52 方	4.9 元/方 (70%)
HDVs	Diesel	50 升	7 元/升
	LNG	60 方	4.9 元/方 (70%)

4.3 Encouragement from governments

Typically, the promotion of natural gas vehicle is inseparable from the support of the government. In countries with significant NGV market penetration, the governments all support a series of incentive policy. Where countries stopped policy support, the market failed to mature. The reason is that the policy greatly helps to provide long-term guidance for customers to accept a new technology. And however, the key poli-

cy motivations were energy security and urban air pollution, along with abundant gas resources in all cases.

In Pakistan:

The Pakistani governments have given support in conversion of diesel engines into natural gas engines. Gas price was controlled at 35% of diesel, 45% of gasoline and either NGVs or its spare parts had a preferential tariff. In addition, the speed up and simplification of the approval processes for the infrastructure construction project accelerates the popularization of NGVs. [14]

In Iran:

In Iran, the supports for NGVs' industry were reflected in the technical requirements. The Iranian government entrusted the world's leading automobile companies taking charge of the personnel training and project management. And the Germany, Netherlands and other countries' manufacturers were invited for bidding of the NGVs' devices. [14]

Iranian department of energy used to hold two bidding activities in just one month. The items were respectively 300,000 sets and 250,000 sets of NGV modified parts. It can be the largest bidding activity on NGV. [14]

In Japan:

In the aspect of infrastructure construction, the Japanese government has given financial support for building more natural gas refueling stations. And individually, while a citizen buys a natural gas vehicle, preferential loans as well as taxes are provided by local government. [14]

In the United States:

President Obama used to present his blueprint about NGVs, in order to reduce the dependence on petroleum by encouraging use of natural gas. The speech contained:

- New policies for heavy-duty vehicles running on natural gas or other alternative fuels

- A competitive grant program to support communities to overcome the obstacles towards NGV

- Program to develop liquefied natural gas transportation corridors

- Programs to support refitting city buses and trucks to run on natural gas

35 states in the USA have different type of incentives for NGVs, such as tax credits offered in Oklahoma, grants provided in Texas.

As in Peru, 0% import tax is needed for natural gas vehicles. Similarly, most of governments' incentive legislation is aiming at putting downward pressure on prices, air and noise polltion reduction, employment opportunities and broadening diversity and security of gas supply. [14]

Current minimum levels of taxation		Equivalence €/GJ (LHV)
Petrol	359 €/1.000 l	**11,396**
Gas Oil	330 €/1.000 l	**9,311**
Kerosene	330 €/1.000 l	**9,372**
LPG	125 €/1.000 Kg	**2,741**
NG	2,6 €/GJ	**2,886**

Figure 10: Fuel tax in European Union. Source: NGVA Europe.

4.4 NGVs safety and energy security

A. NGVs safety

Natural gas is naturally safer than gasoline or diesel because of its chemical properties. Firstly, it is odorless. That makes the leak detection easier. A human can easily detect the smell of natural gas at the concentration of 0.3% by volume in air, which is far lower than the concentration for combustion. And natural gas also has a high kindling point, at 600℃, twice higher than the kindling temperature of gasoline. [16]

Secondly, natural gas is lighter than air. It means that when there is a leakage happened, the leaking gas will go up to the atmosphere instead of gathering on the ground to cause a fire. Unlike gasoline or diesel fuels, which are all heavier than air, natural gas vehicle could be a safer choice for avoiding the explosion or other risks caused by the fuel leakage.

In terms of the storage safety, natural gas is stored in high-pressure cylinder. And it is much stronger than gasoline or diesel tanks. It is hard to get a rupture in most real cases. If there was a leakage, the gas would run out rapidly from the cylinder because of the high pressure inside. But also because of the pressure difference between inside and outside the container, a discordant sound would be made and heard while the gas is leaking. That helps the driver to get an alarm immediately. In spite of that, abundant of gas with high concentration suddenly gathering around the tank is also dangerous. In any case, precaution should be taken.

B. Energy security

Energy security means the uninterrupted availability of energy sources at an affordable price. In past years, many countries have imported an abundance of petroleum and transportation occupies the largest petroleum consumption. The intensive world's petroleum reserves give rise to the supply-disruptions in many countries. Nevertheless, NG reserves are abundant. The proven reserve volumes of natural gas on the earth can be used for more than a 100 years by forecast. And as an alternative fuel, it enables to displace the petroleum for transportation use.

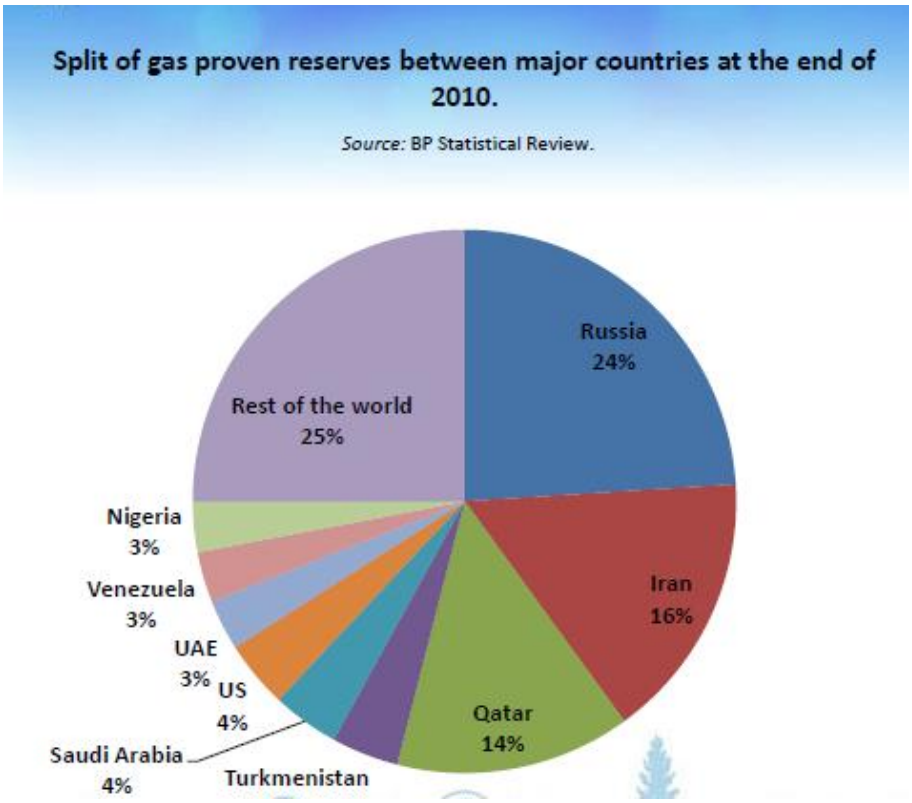

Figure 11: Split of NG proven reserves between major countries at the end of 2010. Source: BP statistical review.

As can be seen from the pie chart in previous page, it is obvious that Russia owns the largest NG reserves accounting for 24% of the whole volums, which is followed by Iran and Qatar. Russia may become the most potential exporter country in the future. And most countries can achieve domestic supply of natural gas.

5 DRAWBACKS AND TECHNOLOGIES

In this chapter, the defects of NGV and relevant technologies are presented with illustrative data and figures.

5.1 Drawbacks

- Ignition:

Table 8: Efficiency comparison between natural gas engine and diesel engine. Source: Cummins Wesport.

Efficiency Factors	Natural Gas (SI)	Diesel (CI)	Advantage
Pumping efficiency (intake)	Throttled	No throttle	Diesel
Combustion efficiency:			
– Compression Ratio	11/1	18/1	Diesel
– A/F Ratio	15/1 up to 23/1	30/1 up to 50/1	Diesel
Mechanical friction	Same mechanical hardware		Similar
Pumping efficiency (exhaust)	3 way catalyst	DPF/SCR	Similar

Overall impacts, it shows around10-15% less efficiency for spark ignited natural gas engines than a diesel engine.

- Lack of power

Presently, the vehicle powered by natural gas produces less power than a diesel engine. Because the calorific value of natural gas is lower than diesel. Thus, it results in the smaller out-put torque and power from the engine. One of the solutions is adopting the membrane oxygen enrichment of combustion-supporting to improve the power performance, but it still has not been fully developed.

- Infrastructure and maintenance

There is a big problem between the infrastructure construction and NGVs' consumers. Especially for those countries that had just started NGV programme, people need the guarantee and motivation for buying a NGV. And basic thing is the construction of infrastructure. On the other hand, the governments should take a lot of risks. But many examples of successful countries bring much motivation to other NGV developing countries and make the problem disappear.

- Space

Natural gas cylinders require storage space. Especially for a converted NGV, a certain space in the trunk or in the truck bed will be sacrificed. And the natural gas cylinder is also heavy. But it is balanced with the less fuel weight compared to gasoline or diesel.

5.2 Technology and performance

The continuous increasing of NGV has a propulsive effect on relevant technologies. In recent years, a remarkable improvement has been witnessed in either NGV engine, storage system or refueling system.

A. NGV Engine

The engine efficiency always depends on the combustion method it uses. And natural gas as a high octane fuel, it can be combusted quite efficiently. The natural gas technology evolution can be seen as follows:

- Stoichiometric combustion

Stoichiometric combustion is the first technology used in heavy-duty natural gas engines. A so-called stoichiometric combustion means that the combustion proceeds by using a certain chemical amount of the fuel in order to produce less exhaust gases. The reaction formula is as follows:

$$CH_4 + 2O_2 = CO_2 + 2H_2O \qquad (1)$$

The drawback is the smaller power generation and the bigger fuel consumption. And the combustion temperature has an influence on the power density, efficiency and durability. [17]

- Lean burn

Lean combustion is a way to improve fuel control by burning the fuel with more air than the stoichiometric combustion in order to reduce combustion temperature in cylinder and improve power density. It can also reduce fuel consumption in the cylinder. Due to the good fuel economy and lower emission, lean burn technology was replacing stoichiometric way. [17]

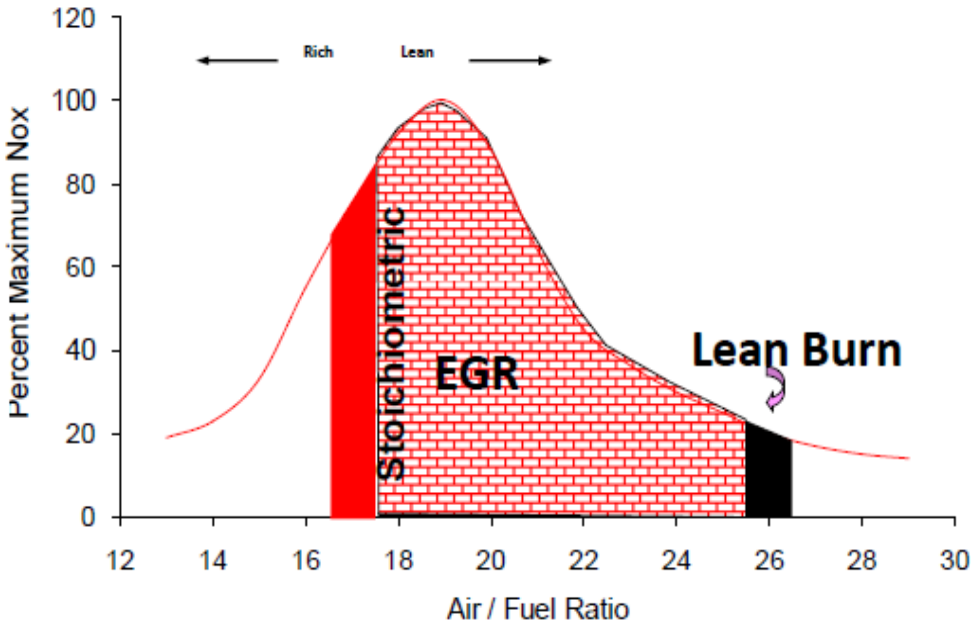

Figure 12: Stoichiometric and lean combustion. Source: Cummins Wesport.

- Stoichiometric with cooled EGR

Stoichiometric with cooled EGR is the combination of the good parts of stoichiometric and lean burn combustion. The employment of the EGR system (Emission Gas Recirculation) takes the place of the exceed air in lean burn. While the emission gas was reused, the fuel in the cylinder was diluted by emission gas. Then less air in the cylinder could make less NO_x emissions. However, the fuel economy, low-end torque and about 5% engine efficiency was improved by stoichiometric with EGR system. [17]

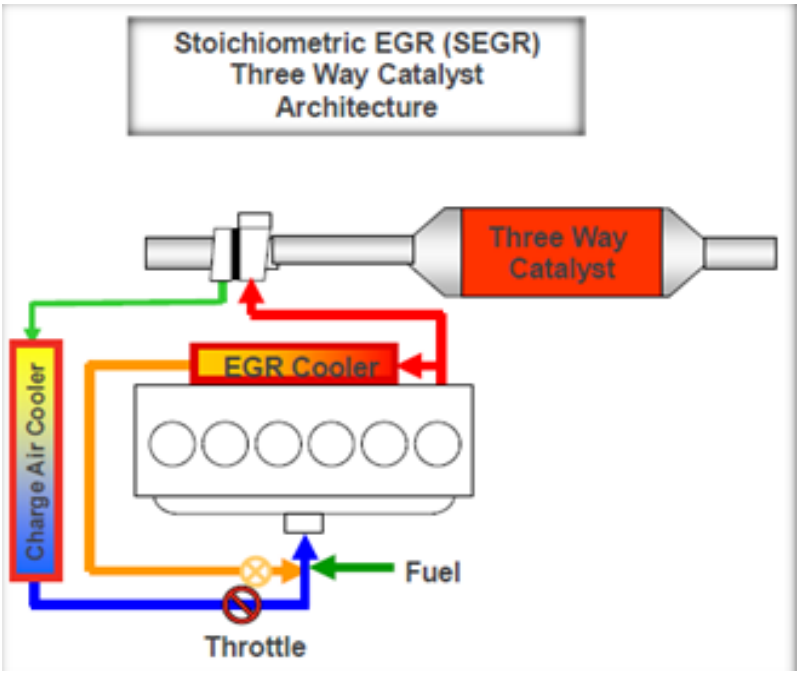

Figure 13: Stoichiometric with cooled EGR. Source: Cummins Wesport.

- Single point injection

The single point injection is an electronic controlled carburetor. It can accurately adjust the balance of the gas supply and engine's demand. But it offers an unsatisfactory performance due to the distance between the injector and intake port of the cylinder. Nowadays, it is only used by cheap cars. [18]

- Multi-point injection

Obviously, for a multi-point injection, each cylinder has a particular injector. Then the distance between injector and inlet can be shortened. It is like a separated control for each cylinder and each precise control improves the system's performance. The further reduction in fuel consumption and greater efficiency, the multi-point injection becomes the most sophisticated system that is used by most vehicles currently. [18]

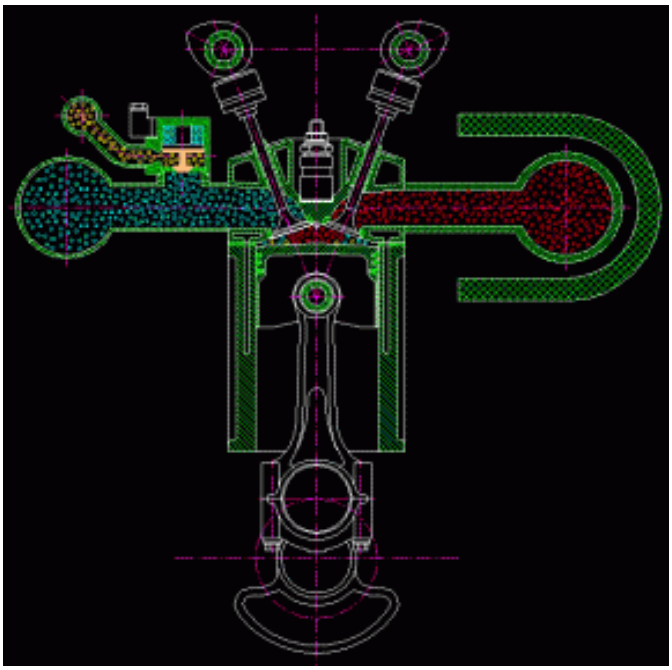

Figure 14: Multi-point Injection. Source: Clean Fuel System - cesys.cz

B. Fuel storage

Different types of natural gas fuel have diverse storage methods.

- CNG storage

CNG, which stands for compressed natural gas, is commonly stored in cylindrical or spherical containers at a pressure of usually 200-250 bar. And different appllications have different types of storage cylinders. Generally, it is differentiated by its weight, size , shape and raw materials. The costs are usually depending on its weight, less weight, less cost. And the duty of the vehicle determines the choice of the storage cylinder. If the weight of cylinder is too big, then the insufficient CNG can be carried on board. The balance between fuel needs of target vehicle and the weight of cylinder needs to be carefully considered. For a converted sedan vehicle, the location of the gas cylinder is usually in the trunk of the car. Thus, the cylinder cannot be so heavy that it influences the balance of the car. As for a public bus or coach, the gas cylinders are commonly installed on the roof of the vehicle, in order to distribute the weight of those cylinders in central axis of the body. [19]

Due to the smaller fuel storage of CNG than diesel or gasoline tank, the refuelling should replace frequently. It means that more time will be taken in gas refuelling. But in fact, the natural gas can be delivered to every single house, so that home refuelling becomes true. In the case of a private car, refuelling at private garage could save a lot of time on the way to gas station and also cost-savings.

In terms of safety and durability, the CNG cylinder must be strong enough to contain high-pressure gas. Bullet, fire test and other relevant tests must be taken, and the relevant standards must be reached, especially for those cylinders with fibre wrapped. Furthermore, inspection needs to be made regularly, and all installed gas cylinders must be stamped with the date of latest inspection.

- LNG storage

LNG is liquefied natural gas at the temperature of -162 ℃ (-260℉) under the standard pressure. As a liquid fuel, the density of LNG is nearly six hundred times of the gas at normal condition. Therefore, more fuel can be carried on board and longer distance can be travelled. That is the reason why LNG commonly works for heavy-duty vehicles.
Compared to CNG cylinder, LNG does not need a high pressure tank. But in order to avoid the evaporation of liquefied natural gas, LNG cylinder must be made of insulating materials to keep the low temperature inside. At present, the LNG cylinders in the market usually can keep cold for more than 2 weeks. [19]

- ANG

ANG, which stands for absorbed natural gas, is a developmental storage type. Basically, it is stored in nanoporous materials at the pressure of around 35 bar. ANG has even higher density than LNG. That means more fuels can be carried on board. But it is still in a developmental stage and not viable for daily use. [19]

C. Refuelling system

The refuelling for NGV generally has three patterns : public refuelling, home refuelling and depot based refuellng.

- Public refuelling

The CNG or LNG in public refuelling stations are commonly supplied by the gas pipe. The natural gas is compressed and liquefied at central station, and then dispensed through the pipes or a tanker truck to each single gas station. NGV refuelling takes nearly the same time as gasoline and diesel if the demand volume is not extremely high. And the refuelling processes are similar to the gasoline or diesel, but gloves need to be worn for insulating the cold of the fuel.

- Home refuelling

Home refueling obviously means refueling the NGV at home in a garage by using the same pipe of the home natural gas supply (like for cooking). It is quite convenient that refueling happens at home instead of frequently visiting the gas station. The costs are saved and also the fuel can be conveniently paid along with the home natural gas bill.

- Depot based refueling

Typically, a depot based refueling station has its limited amount of service. And fast-fill system and slow-fill system all exist in a depot based station. As for a fast-fill system, it takes around 5 minutes the same as in a public gas station. And a slow-fill system usually fills the vehicle in a period of time or overnight, which is the ideal refueling system for LNG trucks with downtime. Because of slow-fill system can refuel multiple units concurrently. And compared to fast-fill system, it can save costs on refueling equipment and maintenance. [20]

Figure 15: Slow-fill depot based refueling system. Source: www.iangv.org

6 POSSIBILITIES

The key drivers to promote NGVs for the future are energy diversification in transport sector and reduction of greenhouse gas emission. The target markets in transportation are continuously expanding.

- Large scaled application

Currently, many designs and researches are approaching the application in large scaled transportation, like railways, ships and aircrafts.

In 2012, Boeing Company disclosed its Subsonic Ultra Green Aircraft Research Project (SUGAR Freeze), which is proposed to design a LNG powered commercial aircraft. According to the technical estimate, the LNG aircraft could reduce fuel burn by 60% compared to a typical Boeing 737 used today. It is getting closer to achieving commercialization on LNG aircrafts by exploration and experiment. [21]

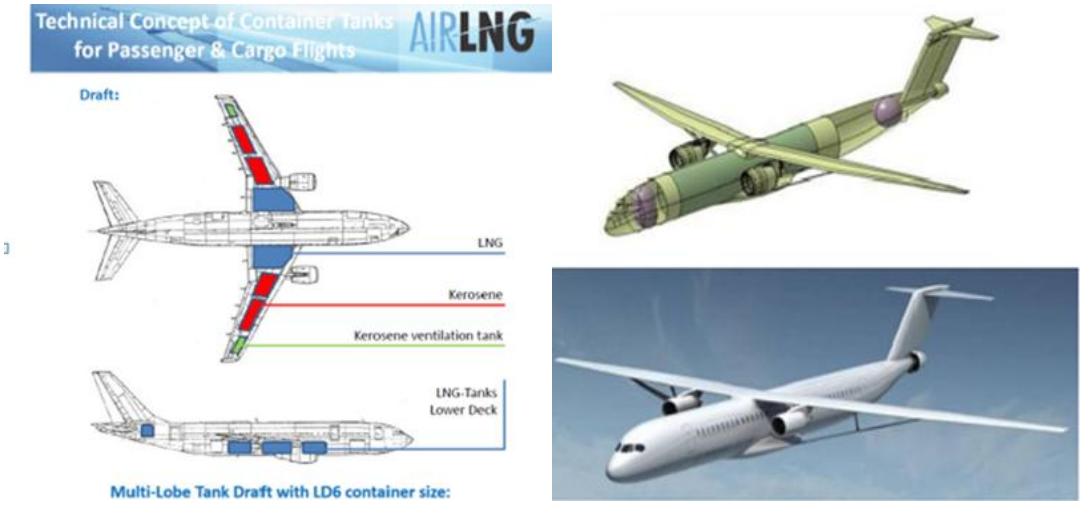

Figure 16: Boeing SUGAR Freeze proposal. *Source: NGVA Europe*

- Biogas and Biomethane

Biogas is commonly produced from biomass or fermentation of raw materials such as animals, recycled waste and sewage. The composition of biogas is mainly methane and carbon dioxide. It is a renewable energy source that is often used in heating and cooking. The gas can also be used for transportation purpose. If it has been upgraded to nearly 97 percent of methane, then it becomes biomethane. In the same way as

CNG, it also can be compressed and used as fuel for vehicles. The flow carbon emission and low cost renewable features get itself lot of value. Nowadays, biomathane is widely used in Sweden and Germany. However, it has not fully developed yet for transport use, but it still has potential stepping onto the international stage.

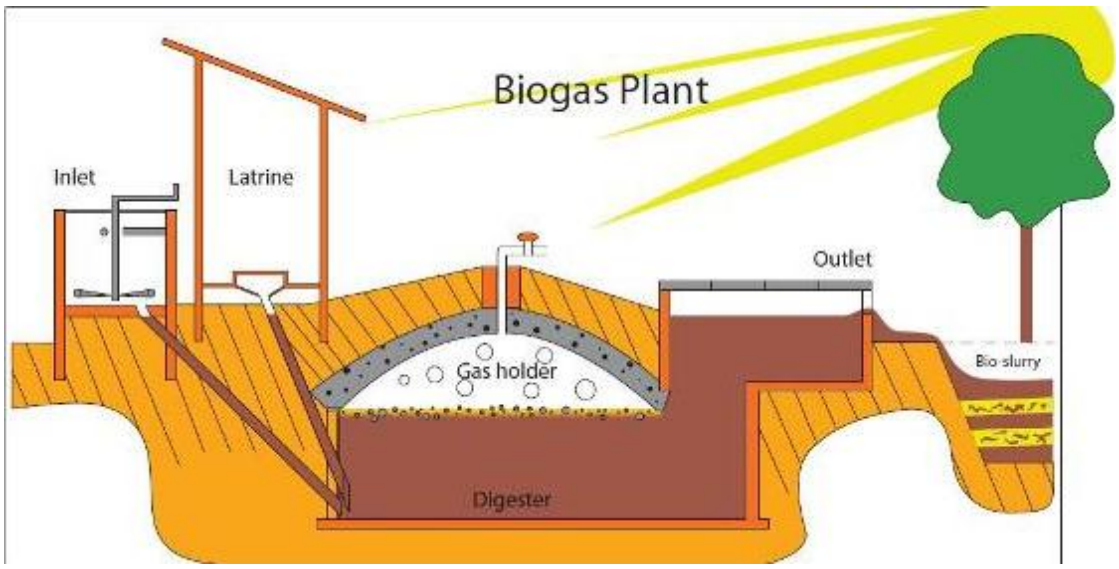

Figure 17: A simple biogas plant. Source: SNV.

- HCNG

HCNG is simply compressed natural gas mixed with hydrogen in a certain ratio, which reduces more harmful emissions, especially carbon dioxide, carbon monoxide and nitrogen oxides. And there are also some research results about the improvement in engine efficiency. Due to the lower ignition point of hydrogen, the engine needs to be tuned. Relevant technology is being developed. Currently, the hydrogen methane mixed fuel in lean combustion and dual fuel engines are becoming the primary direction for further research. [22]

7 CONCLUSIONS

The development of NGV has been paid a lot of attention by the world. In the current status of market, the Asia-Pacific and Latin-American are the leading land of NGVs applications. In these regions, NGV has occupied a large part of market share and is continuously increasing. In Europe, the share of NGV is quite limited. The International Gas Union forecasts that about 93 million NGVs will be on the road and nearly 150,000 gas stations will be found after two decades.

Table 9: Forecast for regional NGV gas consumption. Source: IEA documents, 2012.

Region	NGV gas consumption (bcm)				Share regional gas demand (%)			
	2015	2020	2025	2030	2015	2020	2025	2030
Asia-Pacific	24	46	67	91	4	6	8	9
Europe	2	4	6	10	0	1	1	2
Eastern-Europe/Eurasia	6	10	14	17	1	1	2	2
ME & Africa	9	17	26	35	2	3	4	4
Latin America	15	25	34	44	9	14	17	19
North America	3	5	6	8	0	1	1	1
Total	59	107	152	206	100%	100%	100%	100%

The application area of NGV is also continuously expanding. But primarily they are applied in light-duty vehicles and retrofitting market. CNG is the main stream, while LNG trucks OEM have great potentials. And it is worth mentioning that the large scaled application such as railway, ships and even aircrafts are all explored or under exploration for commercial use. At present, the NG fuel application includes:

LDV: Taxis, private cars, etc.

MDV: delivery and commercial service trucks for food, beverage, newspaper, grocery and supermarket, furnishings and appliances, etc.

HDV: Public city buses, transit buses, school buses, Trash trucks, recycling trucks, cement trucks and other vocational work trucks, railway, ship and aircraft, etc.

NGV benefits GHG reduction and other environmental problems. It is the main reason for utilizing it as an alternative fuel. That makes a lot of sense for improving the

air quality in densely populated areas. As for a long-term development, incentives from government are important and directly influence or restrain the investments on NGV industry and growth of economy. And also the promotion of local vehicle production will stimulate the economic development.

Compared with the oil-based fuel, the biggest problem is the lack of infrastructure. Although the home refueling method brings much convenience and the government gives a green channel for infrastructure, but still a rather long period for the full development of NGV is needed. In technical aspects, many new types of natural gas engine and fuel-mixture methods are under exploration, such as Bio-SNG and HCNG in order to reach the similar performance as diesel engine.

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LIST OF FIGURES AND TABLES