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Fueling the Future: A look at an alternative fuels in India

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Abstract: It is a known fact that the transportation has become a big challenge over growing uncertainly about oil prices and availability in recent years. Here is a deep analysis towards various types of automobiles and pursuing a variety of alternative fuels and energy sources including Electric Vehicles (EV), biofuels, propane, natural gas, etc. and their respective infrastructures, this study focuses primarily on natural gas. In particular, this study will help assess the likelihood natural gas as a substitute for petroleum fuels and estimate the impacts changes in fuel prices will have on travel demand, fuel consumption, Greenhouse Gas emissions, and fuel tax revenues.

This report deals with various types of automobiles with its disadvantages and evaluates the economic competitiveness of natural gas as a transportation fuel and estimates the extent to which natural gas is likely to substitute for petroleum as a transportation fuel. Additionally, the potential impacts of natural gas vehicle adoption on vehicle miles traveled, greenhouse gas emissions (CO2) and fuel tax revenue have been assessed.

Natural gas enjoys a per cost advantage over petroleum and this price advantage is likely to persist into the foreseeable future. New low-cost extraction technology (hydraulic fracturing or "fracking") has increased the supply of domestic natural gas while petroleum prices have increased. Expert opinion suggests this price difference is likely to persist and that natural gas will enjoy a price advantage over petroleum for many years in India.

Finally, the report investigated the impact of increased fuel efficiency on future fuel tax revenues in India.

Keywords: Natural Gas, LNG, CRYOBOX, CAT Dynamic Gas Blending Engine.

I. INTRODUCTION

Over decades to decades, technology has been drastically improvised, standardized and upgraded. In the same way we have come across various types with new technology of automobiles in the market. When a new technology is been introduced and implemented in the market, there pros and cons are considered as the most important factor based on the end users requirement and usage. Considering the disadvantages of newly launched technology, Engineers try to overcome the problem faced by the introduced system to develop a new or an alternative solution. In that way we have come across various types of automobiles where they are different in their working principles.

Let's have a detailed look towards all those types of automobiles:

Analysis on different types of automobiles :

Vehicle type-Mopeds, electric bicycles, and even electric kick scooters are a simple form of a hybrid, powered by an internal combustion engine or electric motor and the rider's muscles. Early prototype motorcycles in the late 19th century used the same principle.

- In a **parallel hybrid bicycle** human and motor torques are mechanically coupled at the pedal or one of the wheels, e.g. using a hub motor, a roller pressing onto a tire, or a connection to a wheel using a transmission element. Most motorized bicycles, mopeds are of this type.

- In a **series hybrid bicycle** (SHB) (a kind of chainless bicycle) the user pedals a generator, charging a battery or feeding the motor, which delivers all of the torque required. They are commercially available, being simple in theory and manufacturing.1

- A **series hybrid electric-petroleum bicycle** (SHEPB) is powered by pedals, batteries, a petrol generator, or plug-in charger - providing flexibility and range enhancements over electric-only bicycles.

1.1 Heavy vehicles

Hybrid power trains use diesel-electric or turbo-electric to power railway locomotives, buses, heavy goods vehicles, mobile hydraulic machinery, and ships. A diesel/turbine engine drives an electric generator or hydraulic pump, which powers electric/hydraulic motor(s) - strictly an electric/hydraulic transmission (not a hybrid), unless it can accept power from outside. With large vehicles conversion losses decrease, and the advantages in distributing power through wires or pipes rather than mechanical elements become more prominent, especially when powering multiple drives — e.g. driven wheels or propellers. Until recently most heavy vehicles had little secondary energy storage, e.g. batteries/hydraulic accumulators — excepting non-nuclear submarines, one of the oldest production hybrids, running on diesels while surfaced and batteries when submerged. Both series and parallel setups were used in WW2 submarines.

1.2 Engine type- Hybrid electric-petroleum vehicles

When the term hybrid vehicle is used, it most often refers to a **Hybrid electric vehicle**. These encompass such vehicles as the Saturn Vue, Toyota Prius, Toyota Yaris, Toyota Camry Hybrid, Ford Escape Hybrid, Toyota Highlander Hybrid, Honda Insight, Honda Civic Hybrid, Lexus RX 400h and 450h and others. A petroleum-electric hybrid most commonly uses internal combustion engines (using a variety of fuels, generally gasoline or Diesel engines) and electric motors to power the vehicle. The energy is stored in the fuel of the internal combustion engine and an electric battery set. There are many types of petroleum-electric hybrid drivetrains, from Full hybrid to Mild hybrid, which offer varying advantages and disadvantages.

The plug-in-electric-vehicle (PEV) is becoming more and more common. It has the range needed in locations where there are wide gaps with no services. The batteries can be plugged into house (mains) electricity for charging, as well being charged while the engine is running.

1.3 Continuously outboard recharged electric vehicle (COREV)

Given suitable infrastructure, permissions and vehicles, BEVs can be recharged while the user drives. The BEV establishes contact with an electrified rail, plate or overhead wires on the highway via an attached conducting wheel or other similar mechanism. The BEV's batteries are recharged by this process—on the highway—and can then be used normally on other roads until the battery is discharged. Some of battery-electric locomotives used for maintenance trains on the London Underground are capable of this mode of operation. Power is picked up from the electrified rails where possible, switching to battery power where the electricity supply is disconnected.

This provides the advantage, in principle, of virtually unrestricted highway range as long as you stay where you have BEV infrastructure access. Since many destinations are within 100 km of a major highway, this may reduce the need for expensive battery systems. Unfortunately private use of the existing electrical system is nearly universally prohibited.

The technology for such electrical infrastructure is old and, outside of some cities, is not widely distributed. Updating the required electrical and infrastructure costs can be funded, in principle, by toll revenue, gasoline or other taxes.

1.4 Hybrid fuel (dual mode)

In addition to vehicles that use two or more different devices for propulsion, some also consider vehicles that use distinct energy sources or input types ("fuels") using the same engine to be hybrids, although to avoid confusion with hybrids as described above and to use correctly the terms, these are perhaps more correctly described as dual mode vehicles:

Some electric trolleybuses can switch between an on-board diesel engine and overhead electrical power depending on conditions. In principle, this could be combined with a battery subsystem to create a true plug-in hybrid trolleybus.

Eg: Flexible-fuel vehicles, Bi-fuel vehicle.

1.5 Fluid power hybrid

Hydraulic hybrid and pneumatic hybrid vehicles use an engine to charge a pressure accumulator to drive the wheels via hydraulic (liquid) or pneumatic (compressed air) drive units. In most cases the engine is detached from the drive train, serving solely to charge the energy accumulator. The transmission is seamless. Regenerative braking can be used to recover some of the supplied drive energy back into the accumulator.

Eg. Petro-air hybrid, Petro-hydraulic hybrid.

1.6 Parallel hybrid

In a parallel hybrid vehicle an electric motor and an internal combustion engine are coupled such that they can power the vehicle either individually or together. Most commonly the internal combustion engine, the electric motor and gear box are coupled by automatically controlled clutches. For electric driving the clutch between the internal combustion engine is open while the clutch to the gear box is engaged. While in combustion mode the engine and motor run at the same speed.

The first mass production parallel hybrid sold outside Japan was the 1st generation Honda Insight.

1.7 Mild parallel hybrid

These types use a generally compact electric motor (usually <20 kW) to provide auto-stop/start features and to provide extra power assist during the acceleration, and to generate on the deceleration phase.

On-road examples include Honda Civic Hybrid, Honda Insight 2nd generation, Honda CR-Z, Honda Accord Hybrid, Mercedes Benz S400 BlueHYBRID, BMW 7-Series hybrids, General Motors BAS Hybrids, and Smart fortwo with micro hybrid drive.

1.8 Power-split or series-parallel hybrid

In a power-split hybrid electric drive train there are two motors: an electric motor and an internal combustion engine. The power from these two motors can be shared to drive the wheels via a power splitter, which is a simple planetary gear set. The ratio can be from 100% for the combustion engine to 100% for the electric motor, or anything in between, such as 40% for the electric motor and 60% for the combustion engine. The combustion engine can act as a generator charging the batteries.

Modern versions such as the Toyota Hybrid Synergy Drive have a second electric motor/generator on the output shaft (connected to the wheels). In cooperation with the "primary" motor/generator and the mechanical power-split this provides a continuously variable transmission.

Passenger car installations include Toyota Prius, Ford Escape and Fusion, as well as Lexus RX400h, RX450h, GS450h, LS600h, and CT200h.

1.9 Series hybrid

A series- or serial-hybrid vehicle is driven by an electric motor, functioning as an electric vehicle while the battery pack energy supply is sufficient, with an engine tuned for running as a generator when the battery pack is insufficient. There is no mechanical connection between the engine and the wheels, and the purpose of the range extender is to charge the battery. Unless there has been a rework of the drivetrain since its first release there is a mechanical linkage in the Chevrolet Volt. Series-hybrids have also been referred to as extended range electric vehicle, range-extended electric vehicle, or electric vehicle-extended range (EREV/REEV/EVER).

The **BMW i3** with Range Extender is a production series-hybrid. It operates as an electric vehicle until the battery charge is low, and then activates the generator to maintain power, and is also available without the range extender. The **Fisker Karma** was the first series hybrid production vehicle.

1.10 Plug-in hybrid electric vehicle (PHEV)

Another subtype of hybrid vehicles is the plug-in hybrid electric vehicle (PHEV). The plug-in hybrid is usually a general fuel-electric (parallel or serial) hybrid with increased energy storage capacity, usually through a lithium-ion battery, which allows the vehicle to drive on all-electric mode a distance that depends on the battery size and its mechanical layout (series or parallel). It may be connected to mains electricity supply at the end of the journey to avoid charging using the on-board internal combustion engine.

This concept is attractive to those seeking to minimize on-road emissions by avoiding – or at least minimizing – the use of ICE during daily driving. As with pure electric vehicles, the total emissions saving, for example in CO2 terms, are dependent upon the energy source of the electricity generating company.

II. Pros and Cons of Vehicles (Automobiles)

Hybrid vehicles are becoming more popular and more common. Basically, a hybrid vehicles is one that uses two or more engines i.e. an electric motor and a conventional engine (either petrol or diesel). The electric engine powers the vehicles at lower speeds and gas engine powers it at higher speeds. A hybrid vehicle like Toyota Prius and Civic Hybrid not only conserves fuel but also produce less CO2 emissions. Though hybrid vehicles are now growing in popularity but still few people are actually using it mainly due to lack of knowledge of how hybrid vehicles work and whether they're as good as other gasoline powered vehicles.

While the technology has existed since the early 1900's, it has only been in the past decade or so that the price of manufacturing them has brought them into the range of possibility for the average driver. There are also more government incentive programs that use credits and special discounts to support the purchase and use of hybrid vehicles. Many cities are switching their public transportation and service vehicles over to hybrid cars and buses as a part of the program to become more environmentally responsible.

Wikipedia defines hybrid vehicle as,

"A hybrid vehicle uses two or more distinct types of power, such as internal combustion engine+electric motor, e.g. in diesel-electric trains using diesel engines and electricity from overhead lines, and submarines that use diesels when surfaced and batteries when submerged. Other means to store energy include pressurized fluid, in hydraulic hybrids."

On the other hand, there are electric vehicles that use rechargeable batteries. Here are few of the advantages and disadvantages of having an electric vehicle.

While most people associate hybrid vehicles with the kind that use electricity as their primary alternate fuel, there are more options available now. There are cars that use hybrid technologies with propane and **natural gas** as well. A hybrid car is best defined as a vehicle that has an engine that can switch between a fossil fuel and an alternate fuel source.

2.1 Advantages of a Hybrid vehicles:

Here are few of the top advantages of having a hybrid vehicles:-

1. Environmentally Friendly: One of the biggest advantage of hybrid car over gasoline powered car is that it runs cleaner and has better gas mileage which makes it environmentally friendly. A hybrid vehicle runs on twin powered engine (gasoline engine and electric motor) that cuts fuel consumption and conserves energy.

2. Financial Benefits: Hybrid vehicles are supported by many credits and incentives that help to make them affordable. Lower annual tax bills and exemption from congestion charges comes in the form of less amount of money spent on the fuel.

3. Less dependence on Fossil Fuels: A Hybrid vehicle is much cleaner and requires less fuel to run which means less emissions and less dependence on fossil fuels. This in turn also helps to reduce the price of gasoline in domestic market.

4. Regenerative Braking System: Each time you apply brake while driving a hybrid vehicle helps you to recharge your battery a little. An internal mechanism kicks in that captures the energy released and uses it to charge the battery which in turn eliminates the amount of time and need for stopping to recharge the battery periodically.

5. Built from Light Materials: Hybrid vehicles are made up of lighter materials which means less energy is required to run. The engine is also smaller and lighter which also saves much energy.

6. Higher Resale Value: With continuous increase in price of gasoline, more and more people are turning towards hybrid cars. The result is that these green vehicles have started commanding higher than average resale values. So, in case you are not satisfied with your vehicle, you can always sell it at a premium price to buyers looking for it.

There are many advantages to owning a hybrid vehicle. The one you will like the best is how it helps you to control your budget as gas prices continue to get higher. The other benefit that is not seen directly is how owning and driving a hybrid car impacts the environment. It reduces the dependence on fossil fuels and lowers your carbon imprint on the environment.

2.2 Disadvantages of a Hybrid vehicle:

There are disadvantages to owning a hybrid vehicle, but they are probably not what you think. Contrary to popular myth, hybrid vehicles have just as much power as regular vehicles and have no issue with mountain driving or towing. The disadvantages will depend on the type of hybrid fuel that your vehicle uses.

Here are few of the disadvantages of a hybrid vehicle:-

1. Less Power: Hybrid vehicles are twin powered engine. The gasoline engine which is primary source of power is much smaller as compared to what you get in single engine powered vehicle and electric motor is low power. The combined power of both is often less than that of gas powered engine. It is therefore suited for city driving and not for speed and acceleration.

2. Can be Expensive: The biggest drawback of having a hybrid vehicle is that it can burn a hole in your pocket. Hybrid cars are comparatively expensive than a regular petrol car and can cost $5000 to $10000 more than a standard version. However, that extra amount can be offset with lower running cost and tax exemptions.

3. Poorer Handling: A hybrid vehicle houses an gasoline powered engine, a lighter electric engine and a pack of powerful batteries. This adds weight and eats up the extra space in the vehicle. Extra weight results in fuel inefficiency and manufacturers cut down weight which has 0resulted in motor and battery downsizing and less support in the suspension and body.

4. Higher Maintenance Costs: The presence of dual engine, continuous improvement in technology, and higher maintenance cost can make it difficult for mechanics to repair the vehicle. It is also difficult to find a mechanic with such an expertise.

5. Presence of High Voltage in Batteries: In case of an accident, the high voltage present inside the batteries can prove lethal for you. There is a high chance of you getting electrocuted in such cases which can also make the task difficult for rescuers to get other passengers and driver out of the vehicle.

2.3 The Pros and Cons on Alternative Fuels

1. Hybrids

Pros: Potential for excellent fuel economy, run on existing gasoline supplies, and drive just like regular cars, requiring no change in lifestyle habits.

Cons: Some hybrids cost much more than similar conventional cars. Some don't live up to the gas mileage buyers may expect, especially considering the extra purchase price. On a mass scale, they are considered too little, too late, but big savings mean we'll see lots more of them.

2. Plug-in hybrids

Pros: All-electric range can address short commutes for many drivers, home recharging infrastructure is available, gas engine can extend range for long trips, cheaper cost per mile and no vehicle emissions when running in electric mode.

Cons: Big, expensive batteries plus a gas engine drive up prices, daytime recharging could strain electric grid, and they need to be plugged in to deliver any benefit. Gas-mileage benefits are highly dependent on driving habits and frequently overstated.

3. Battery electric vehicles

Pros: Quiet running, instant torque from electric motor, no emissions from the car, cost per mile is a fraction of that for a gasoline-powered car, widespread electric infrastructure, and electricity can be partially derived from renewable sources.

Cons: Long recharging times, limited range, expensive batteries, electricity production in much of the country uses coal—not a clean-burning source. High-voltage home chargers can be expensive, and public chargers scarce.

4. Diesel

Pros: Thirty-percent better fuel economy than an equivalent gasoline vehicle, widely available, lower cost premium than for hybrid vehicles, engines deliver lots of torque for a given displacement, and any diesel car can run on a blend of renewable biodiesel fuel. With effort and investment, older diesel engines can be converted to run on pure waste vegetable oil.

Cons: Traditionally more engine noise and vibration. Additional emissions equipement drives up vehicle prices, which along with currently higher cost of diesel fuel takes a big bite out of any savings. Most clean diesels require refills of urea solution. Manufacturers won't warranty biodiesel blends of more than 5 percent biodiesel.

5. Biodiesel: A promising blend

Pros: Renewable, fairly widely available, and older diesel cars can seamlessly burn biodiesel or diesel. Used vegetable oil can sometimes be free.

Cons: Using vegetable oil requires a costly conversion and a lot of effort. Quality of biodiesel varies widely, so carmakers will only honor warranties up to 5 percent biodiesel. And biodiesel costs more than petroleum diesel. So far, supply issues have prevented biodiesel supply from becoming widespread.

6. Ethanol

Pros: Reduces demand for foreign oil, low emissions, high octane, and can potentially be produced from waste materials; existing cars can use 10-percent blends (called E10), and more than 8 million cars already on the road can use E85.

Cons: Twenty-five percent lower fuel economy on E85 than gasoline. Less than 1 percent of U.S. gas stations carry E85. Federal fuel economy credits awarded to automakers for E85 cars lower overall fuel economy for all cars. Ethanol made from any food crop can adversely affect food prices. Farm equipment involved in crop production runs on petroleum, limiting the net benefits.

7. Compressed natural gas

Pros: Costs much less than gasoline, burns much cleaner, and provides comparable power. It is an abundant natural resource in the United States.

Cons: Huge gas tanks reduce trunk space and carry the equivalent of only a few gallons of gasoline. CNG provides limited range, and there are few places for consumers to refuel in most of the country, plus refueling is relatively slow.

8. Hydrogen fuel cells

Pros: No vehicle emissions other than water vapor. Fuel economy equivalent to about twice that of gasoline vehicles. Hydrogen is abundant, and can be made from renewable energy.

Cons: This space-age technology is expensive. Acceptable range requires extremely-high-pressure, on-board hydrogen storage. Few places to refuel. Hydrogen is very expensive to transport and there is no infrastructure in place yet. Currently hydrogen fuel is made from nonrenewable natural gas in a process that creates enormous CO2 emissions.

9. Alternative green vehicles

Other types of green vehicles include other vehicles that go fully or partly on alternative energy sources than fossil fuel. Another option is to use alternative fuel composition (i.e. biofuels) in conventional fossil fuel-based vehicles, making them go partly on renewable energy sources.

To overcome the above mentioned problems faced by the automobile technologies, why don't we think about an alternative vehicle? In that way as a solution to the problem, here is a proposal to implement **natural gas** based vehicles. **Alternative fuel composition** (i.e. biofuels) is an option to use in conventional fossil fuel-based vehicles, making them go partly on renewable energy sources and those vehicles are called as **Alternative green vehicles**. So, let us discuss about Natural gas in detail before we try to implement it with the automobiles.

III. Natural Gas

Natural gas is a gas consisting primarily of methane, typically with 0-20% of other hydrocarbons. Natural gas is crated in two primary ways. Biogenic mechanisms create natural gas by methanogenic organisms. This natural gas can be plentiful in landfills and is often harvested to be for fuel. Thermogenic gas is created inside the earth at great temperature and pressure from buried organic material, many oil rigs capture or burn off natural gas created around oil deposits.

3.1 Advantages of natural gas:

In some sense, Natural gas can be a renewable resource. In places like landfills it is created from the degradable matter in trash. A major plus of natural gas is that it can be efficiently and safely stored. Like petroleum, it is a fossil fuel in the thermogenic sense, however it is considered to be more environmentally friendly due to its low emissions after burning. It emits 60-90%less smog-producing pollutants. One of the most notable facts about natural gas is that most of the natural reserves of natural gas field are underutilized.

3.2 How Natural-gas Vehicles Work

The biggest advantage of NGVs is that they reduce environmentally harmful emissions. natural-gas vehicles can achieve up to a 93 percent reduction in carbon monoxide emissions, 33 percent reduction in emissions of various oxides of nitrogen and a 50 percent reduction in reactive hydrocarbons when compared to gasoline vehicles. NGVs also rate higher in particulate matter 10 (PM10) emissions. PM10 particles transport and deposit toxic materials through the air. NGVs that operate in diesel applications can reduce PM10 emissions by a factor of 10.

3.3 Natural-gas vehicles also offer these benefits:

- NGVs are **safer**. The fuel storage tanks on an NGV are thicker and stronger than gasoline or diesel tanks. There has not been an NGV fuel-tank *rupture* in more than two years in the United States.
- Natural gas **costs are lower** than gasoline. On average, natural gas costs one-third less than gasoline at the pump.
- Natural gas is **convenient and abundant**. A well-established pipeline infrastructure exists in the United States to deliver natural gas to almost every urban area and most suburban areas. There are more than 1,300 NGV fueling stations in the United States, and more are being added every day.
- Natural gas prices have exhibited significant **stability** compared to oil prices. Historically, natural gas prices have exhibited significant price stability compared to the prices of petroleum-based fuels. This stability makes it easier to plan accurately for long-term costs.
- NGVs have **lower maintenance costs**. Because natural gas burns so cleanly, it results in less wear and tear on the engine and extends the time between tune-ups and oil changes.

3.4 Natural Gas Cars: The Pros

There are two types of CNG vehicles **— Liquefied Natural Gas (LNG)** and **Compressed Natural Gas (CNG)**. Both are fuel-efficient vehicles that burn low-emissions fuel that's better for the environment than petroleum-based fuels. They aren't expensive to build and don't pose any danger greater than that of traditional gasoline vehicles. Here are the pros of driving a CNG car.

- The **fuel's cheap**. Because of the rise in fracking — an efficient, if environmentally problematic, method of extracting natural gas from underground shale —natural gas is abundant and inexpensive.
- CNG vehicles have **low emissions**. Compared to gasoline, compressed natural gas reduces carbon-monoxide emissions by 90 to 97 percent and nitrogen-oxide emissions by 35 to 60 percent. Natural gas is also domestically produced, for the most part, so driving a CNG car means you're not dependent on foreign oil.
- Compressed natural gas vehicles **look and feel like conventional cars**. While their engines and fuel systems are modified to make use of natural gas, CNG vehicles are otherwise quite similar to existing gasoline or diesel cars. You can even convert a conventional car to run on natural gas.

- CNG **hybrids are available**. Some CNG cars are designed to run on both CNG and gasoline, eliminating "range anxiety" and allowing the driver to go a long, long time between fill-ups. The 2016 Chevrolet Impala Bi-Fuel can go for about 600 miles on the highway when both tanks are full.
- You get a **few perks** for driving a CNG car. In California, CNG vehicles can get a decal that allows them to use the carpool (HOV) lanes even with a single occupant. Your state may offer tax incentives and other rewards.

IV. INDIAN NATURAL GAS

4.1 Introduction

India had 38 trillion cubic feet (Tcf) of proven natural gas reserves as of January 2007.The total gas production in India was about 31,400 mcm in 2002-03 compared with 2,358 mcm in 1980-81. At this production level, India's reserves are likely to last for around 29 years; that is significantly longer than the 19 years estimated for oil reserves. Almost 70% of Indias natural gas reserves are found in the Bombay High basin and in Gujarat. Offshore gas reserves are also located in Andhra Pradesh coast (Krishna Godavari Basin) and Tamil Nadu coast (Cauvery Basin). Onshore reserves are located in Gujarat and the North Eastern states (Assam and Tripura). (Here's a nice article on India's natural gas status)

4.2 Consumption

Dry natural gas production & consumption (2003) - 0.96 tcf (consumption equalled production in 2003)

4.3 Current Energy Production --16,385.61 MW

4.4 Major Gas Based Projects

Project	State	Commissioned Capacity (MW)
RGPPL, Anjanvel	Maharashtra	1480
Dadri	Uttar Pradesh	817
Paguthan	Gujarat	654.73
Auraiya	Uttar Pradesh	652
Jhanor-Gandhar	Gujarat	648
Kawas	Gujarat	645
Faridabad	Haryana	430
Anta	Rajasthan	413
Vemagiri Power Generation Ltd.	Andhra Pradesh	388.5
Rajiv Gandhi CCPP Kayamkulam	Kerala	350

4.5 Problems with Natural Gas

- Not a renewable source of energy.
- India has only limited reserves of natural gas, though further discoveries are being made from recent explorations
- Owing to the high percentage of methane in natural gas, it is highly combustible
- The process of extraction of natural gas involves making large cavities in the ground. Natural gas requires highly complex treatment plants and pipelines for its delivery.
- Natural gas occupies four times the space of gasoline-equivalent energy.

V. LNG

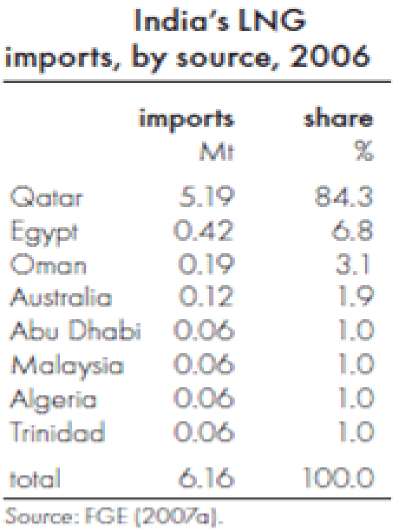
LNG is a clear, colorless, non-toxic liquid that can be transported and stored more easily than natural gas because it occupies up to 600 times less space.

When LNG reaches its destination, it is returned to a gas at regasification facilities. It is then piped to homes, businesses and industries.

5.1 LNG Terminals

LNG Terminal	Capacity (MMTPA)
Dahej	5
Dahej Exp	5
Kochi	2.5
Shell Hazira	2.5
Dabhol	2.5
Mangalore	5
Kakinada	2.5
Total	25

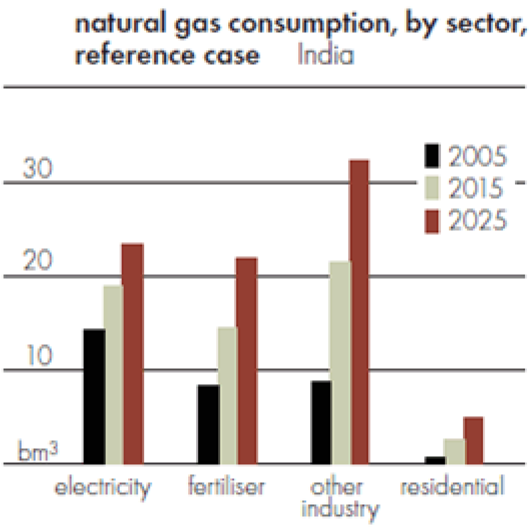
5.2IndiaLNGImports


India's LNG imports, by source, 2006

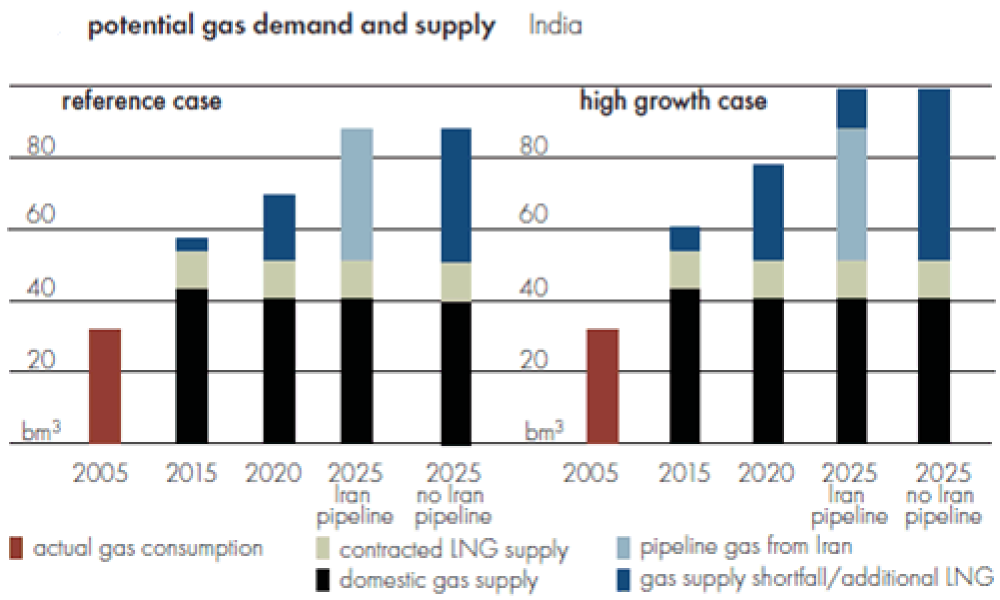
	imports Mt	share %
Qatar	5.19	84.3
Egypt	0.42	6.8
Oman	0.19	3.1
Australia	0.12	1.9
Abu Dhabi	0.06	1.0
Malaysia	0.06	1.0
Algeria	0.06	1.0
Trinidad	0.06	1.0
total	6.16	100.0

Source: FGE (2007a).

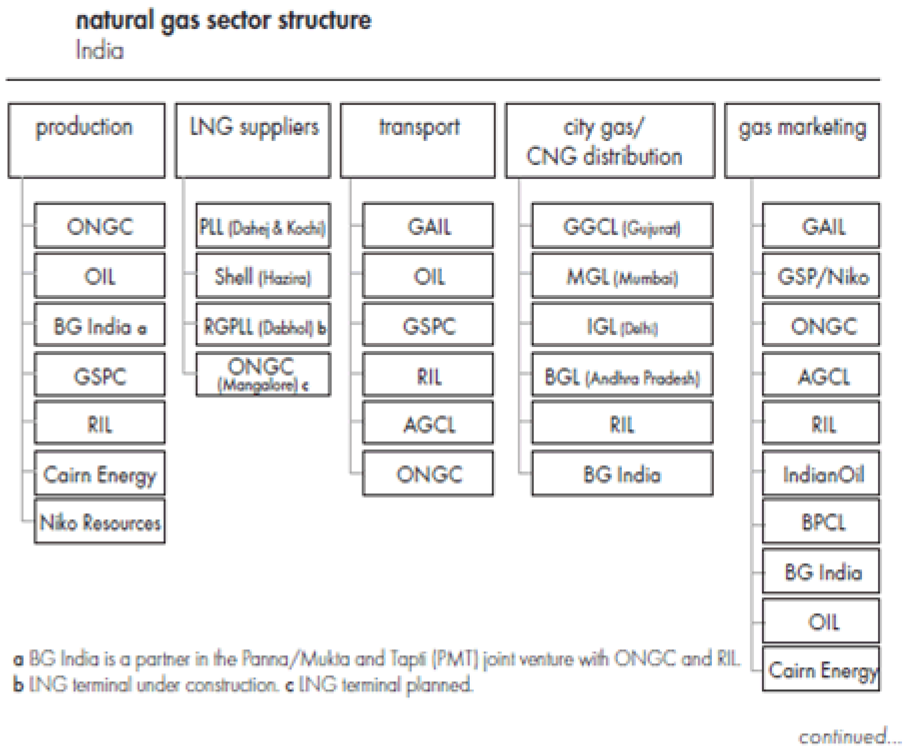
5.3ConsumptionTrends



5.4 Potential Supply and Demand



5.5IndiaNaturalGasSector



VI. CNG

Compressed Natural Gas, or CNG, is quite simply gas that has been compressed such that it can be transported in pressure vessels rather than by pipeline as is the traditional method. CNG is generally used to fuel transit and fleet vehicles in large cities, as well as in a limited number of personal Natural Gas Vehicles (NGVs).

India CNG Scenario:

In India CNG is primarily used as an alternative fuel for transportation.

The Table Summarizes the LNG activities in India in terms of stations, growth in vehicles etc.

6.1 Problems with Natural Gas

- Not a renewable source of energy.
- India has only limited reserves of natural gas, though further discoveries are being made from recent explorations
- Owing to the high percentage of methane in natural gas, it is highly combustible
- The process of extraction of natural gas involves making large cavities in the ground. Natural gas requires highly complex treatment plants and pipelines for its delivery.
- Natural gas occupies four times the space of a gasoline-equivalent energy.

6.2 The Limitations of Natural gas Vehicles

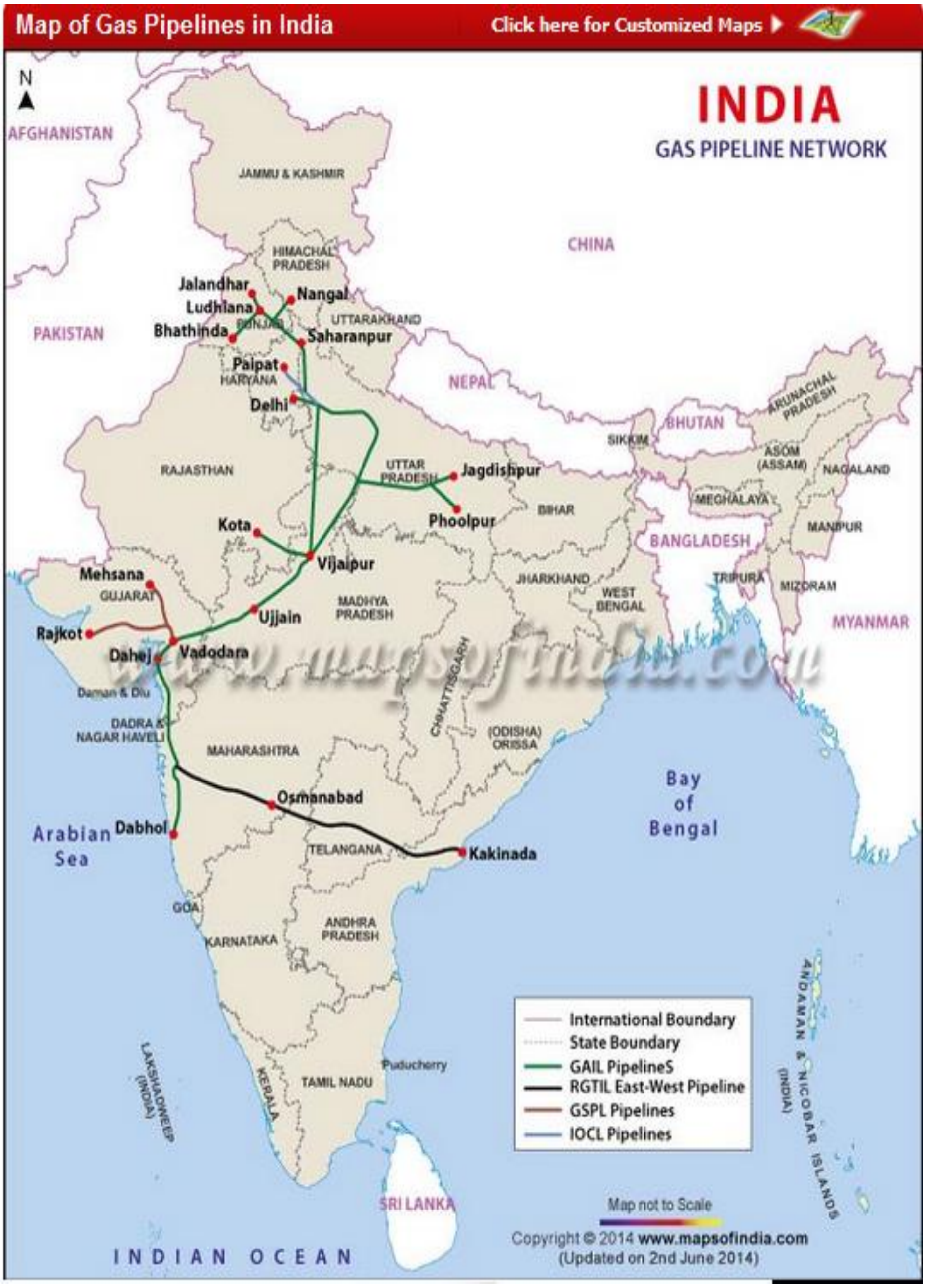
- While CNG is cheap, it isn't always cheaper than gasoline. If a gallon of compressed natural gas costs $2.25, that sounds pretty good — but if gasoline costs $2.50 per gallon, you're not saving a ton. Fuel prices can be volatile, so savings aren't guaranteed.
- You need a nearby network of CNG fuel stations. Look at CNG Now's map of stations in the United States, and you'll see that some metro areas — like Boston, New York City and Los Angeles — have dozens of fuel stations. But smaller cities, like Memphis and New Orleans, may only have one, and vast parts of the country have none. Home fueling is possible but can be a slow process.
- CNG fuel efficiency isn't great. Compared to gasoline, natural gas is cheaper and cleaner — but it's just not as good a fuel. Fuel efficiency for compressed natural gas vehicles can be difficult for the consumer to calculate, as the metric for fuel efficiency in CNG and LNG vehicles isn't actually miles per gallon (MPGs), but is MPGe — miles per gasoline gallon equivalent. The 2015 CNG Honda Civic gets 31 MPGe, according to federal fuel-economy stats. The 2016 Chevrolet Impala Bi-Fuel gets 19 MPGe. That's not knocking anyone's socks off.
- CNG cars are more expensive. On Cargurus.com, the price of a low-mileage 2015 Chevrolet Impala Bi-Fuel varies wildly, but we found a few listed for around $23,000. Considering they cost $37,000 new, that sounds like a good deal. Trouble is, you can buy a newer, nicely equipped conventional Impala for the same price — or less.
- Compressed natural gas vehicles are hard to find in the U.S. consumer market. Honda stopped manufacturing the natural-gas Civic in 2015. Chevrolet discontinued the bi-fuel Impala in 2017. Aside from fleet sales, there's really no automaker offering CNG vehicles in the U.S. market right now.

6.3 Should you buy a Natural Gas vehicle?

Despite the many drawbacks, **Natural Gas vehicles** have their devotees. And there's a good chance gasoline prices will rise, making low-cost natural gas more appealing. If you live in an urban area with plenty of CNG fuel stations, or you're willing to invest in a home fueling system, a natural-gas vehicle might be the perfect fit for your daily commute.

Then again, if your primary goal is to drive a cleaner, greener car, you have lots of options!

Map of Gas Pipelines in India



VII. MOTIVATION FOR ADOPTING NATURAL GAS

In recent years the growing uncertainty about oil prices and availability has made long-range transportation planning even more challenging. Rather than relying on trend extrapolation, this study uses market mechanisms to shed light on key long-range transportation planning assumptions. Although pursuing a variety of alternative fuels and energy sources including Electric Vehicles (EV), biofuels, propane, natural gas, etc. and their respective infrastructures, this study focuses primarily on natural gas. In particular, this study will help assess the likelihood natural gas as a substitute for petroleum fuels and estimate the impacts changes in fuel prices will have on travel demand, fuel consumption, Greenhouse Gas emissions, and fuel tax revenues.

The results of the modeling show that the potential impacts of Natural Gas Vehicles (NGV) have the potential to have effects on vehicle miles traveled (VMT), emissions, and fuel tax revenue. The effects of these vehicles are muted by the current lack of natural gas vehicles in the fleet. The usage of natural gas vehicles is limited to fleet vehicles and vehicles with high mileage usage. Challenges with widespread integration currently include the increased upfront capital costs associated with vehicles with natural gas, decreased power for heavy vehicles, and range anxiety in locations without developed natural gas fueling infrastructure. The modeling and analysis provided in the document can be used to analyze changing conditions in the NGV market and the effects on key transportation metrics.

Ryder's fleet customers are interested in natural gas to help them address the challenge of volatile fuel pricing, because it is more stable and sold at a lower price than diesel. *Ryder's* motivation is to demonstrate the feasibility of using natural gas fuels in commercial trucking applications, provide a domestic and low-carbon fuel source to its customers, and reduce criteria pollutants and greenhouse gas emissions. Placing these trucks in a rental and leasing fleet can allow fleet customers, with minimal outlay, to gain confidence in how natural-gas-fueled vehicles will perform for their applications.

VIII. Implementation of Natural Gas Engine in Vehicles

The various Technology and Techniques which are used in extracting the natural gas are given by Dynamic gas blending Engine and CryoBox. Let's have a detail look about the above mentioned techniques.

8.1 Analysis on Cat@ Dynamic Gas Blending

Use gas when it is available and continuously modulate gas substitution when needed. Dynamic Gas Blending is optimized to handle variations is fuel quality and engine operating conditions. You save fuel and your diesel power and transient performance is consistently maintained.

Lowering operating costs while maintaining emissions compliance with a single technology is exciting... but it's just the beginning.

Strike a new balance

1. Where profitability

- Lower fuel costs with up to 70%* replacement of diesel with gas
- Maintain existing service intervals and component life
- Increase display and diagnostic performance with the ADEM™ A4 and EMCP 4.4* controls

2. Meets responsibility

- Capability to run on field gas as an alternative to flaring
- Designed with CSA certified components
- Safety features built into the integrated controls
- Maintain original emissions certifications with retrofit kit

3. Be flexible

Dynamic Gas Blending automatically adjusts to changes in incoming fuel quality and pressure allowing your engines to run on a wide variety of fuels, from associated gas to gasified LNG.

- Continuously modulates gas substitution under all transient loading to optimize fuel savings
- Accepts up to 55% inerts
- Requires no recalibration when equipment is moved or gas supply changes

4. Well Stimulation Product Overview

- Single ADEM A4 engine control maximizes substitution while maintaining performance and emissions compliance.

- Maintains diesel engine performance while maximizing substitution throughout a wide range of speed and load conditions.
- Achieves maximum substitution and maintains Tier 2 emission standards while running on a wide variety of gaseous fuels with no additional calibration.
- Diesel oxidation and muffler combination designed for ease of installation.
- Integrated controls and hardware designed with safety, reliability, and durability in mind.

Engine Model	3512C (HD)	3512C (HD)	3512C (HD)	3512C (HD)
Rated Speed	1900 rpm	1900 rpm	1900 rpm	1900 rpm
Retrofit Offering	X	X	X	X
Power	1678 bkW (2250 bhp)	1864 bkW (2500 bhp)	1678 bkW (2250 bhp)	1864 bkW (2500 bhp)
Emissions	NR Tier 2	NR Tier 2	NR Tier 2	NR Tier 2
Cooling System	ATAAC	ATAAC	SCAC	SCAC

5. Drilling and Production Product Overview

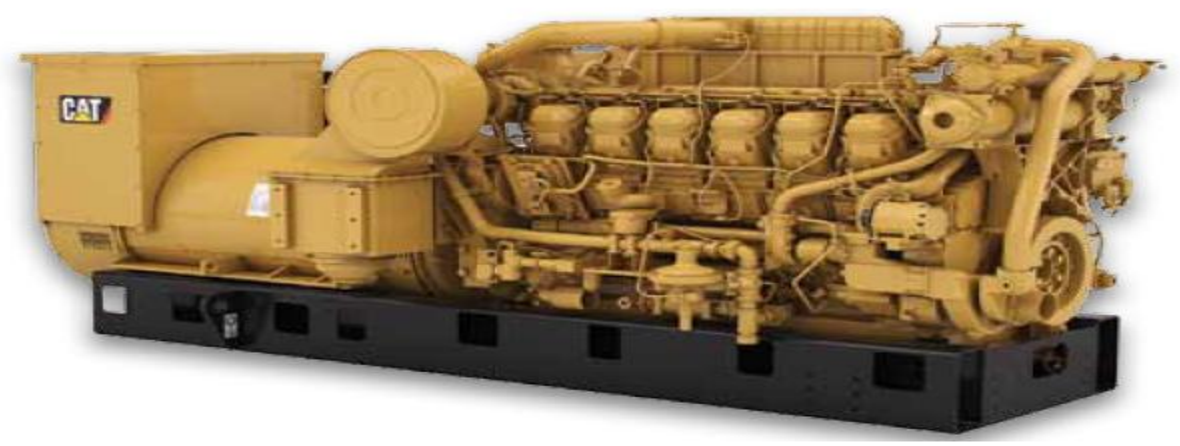
Using proven gas engine hardware with no change to core diesel engine components, you can be up and running quickly with Dynamic Gas Blending.

- Optimized diesel and gas fuel system controls maximize substitution while maintaining power output and safe engine operation
- Certified retrofit kits maintain original emission standards over a wide range of gaseous fuels
- Simple integration to rig monitoring equipment to track engine health and substitution performance

Engine Model	3516B	3512C	3512B	3512B	3512B	3512B	3512B
Application	Production Prime	Drilling	Drilling	Production Prime	Production Continuous	Production Prime	Drilling
Frequency	50 Hz	60 Hz	50 Hz	50 Hz	50 Hz	60 Hz	60 Hz
Speed	1500 rpm	1200 rpm	1500 rpm	1500 rpm	1500 rpm	1800 rpm	1200 rpm
Package Offering	X		X	X	X	X	X
Retrofit Offering	X	X	X	X		X	X
Power	1.6 eMW	1045 ekW (1476 bhp)	1245 ekW (1757 bhp)	1.3 eMW	1.05 eMW	1.36 eMW	1045 ekW (1476 bhp)
Emissions	Non-regulated	Tier 2/ Non-Regulated	Non-regulated	Non-regulated	Non-regulated	Non-regulated	Tier 1/ Non-regulated
Max Gas %	70	70	70	70	70	70	70
Transient Performance	G1 ISO8528-5	G1 ISO8528-5	G1 ISO8528-5	G1 ISO8528-5	G1 ISO8528-5	G1 ISO8528-5	G1 ISO8528-5
Generator Mode	Standalone	Standalone	Standalone	Standalone	Standalone	Standalone	Standalone

8.2 CAT Dynamic Gas Blending Engine Upgrade Kit

Dynamic Gas Blending automatically adjusts to changes in incoming fuel quality and pressure, allowing your engines torun on a wide variety of fuels, from associated gas to gasified LNG.



8.3 Upgrade Features and Benefits

Sustainable Development

- Continuous Monitoring of generator output and response
- – Automatically adjusts to changing gas quality
- – Sustained gas substitution
- – Operates on a wide range of Methane number and up to 55% inerts
- Compliance for critical areas
- – Kit maintains factory emissions rating of the diesel engine while lowering overall emissions

Lower Cost of Ownership

- Gas substitution can substantially reduce fuel costs
- No change to core diesel engine components
- Maintains existing maintenance and overhaul intervals
- Improved controls capability can reduce additional infrastructure needed to operate multiple generator sets in parallel
- No recalibration needed when equipment is moved or gas supply Changes

Improved Diagnostic Capability

- Upgraded to ADEMTM A4
- Descriptive diagnostic codes improve time-to-diagnose speed
- Analog gauge display allows for quick check of key engine health Parameters

8.4 LNG Truck Conversions at Fording River Operations

Last year, Teck embarked on a pilot project, demonstrating our commitment in finding more sustainable ways to operate by testing liquefied natural gas (LNG) as a cleaner and more cost-effective potential fuel solution at Fording River Operations (FRO) in southeastern B.C.

The pilot marks the first use of LNG as a **haul truck fuel** at a Canadian mine site and will allow Teck to gain important knowledge, experience and data to evaluate LNG use, while reducing operating costs and emissions. Should the LNG and diesel hybrid fuel be expanded across Teck's steelmaking coal operations, there is the potential to eliminate approximately 35,000 tonnes of CO2 emissions annually and reduce fuel costs by more than $20 million annually.

8.5 How Does It Work?

To replace full diesel usage with a diesel/ LNG blend on four 830E and two 930E haul trucks at FRO, conversion technology was designed to allow for in-field retrofitting of diesel engines without the need to change or modify the original design. The new hardware, mounted externally on the engine, did not require modification of engine controls. Also, if a haul truck equipped with an LNG conversion kit runs out of LNG, it automatically switches over to diesel and continues to run.

FortisBC is a key partner in the project, transporting and supplying LNG to the mine site, providing financial support towards upgrading the truck maintenance shop, and supporting the implementation of the comprehensive safety program developed by FRO.

8.6 LNG 101

Liquefied natural gas (LNG), a clear, colorless, odorless, non-toxic and non-corrosive fuel, is the same as the natural gas delivered to your home but stored below -162°C. Since it must be kept at such cold temperatures, LNG is stored in double-walled, vacuum-insulated pressure vessels.

When spilled, LNG does not contaminate soil or water due to rapid evaporation, and when compared to diesel, LNG a less expensive, cleaner-burning fuel.

8.7 Safety First, Always

Safety is the first consideration in everything we do and the pilot was no different. Extensive safety procedures, policies and training were implemented before the pilot began. Operator safety features on the LNG trucks include automatic gas shut-off in the event of collision or rollover, excess gas flow protection and dedicated LNG fuel attendants. Shop safety additions included new methane detection and alarm systems, and mine rescue scenarios and training related to LNG are now in place.

8.8 CRYOBOX

Now, LNG can drive your projects The Cryobox Nano LNG-Station makes it happen.

Cryobox® is the technology for LNG production that Buquebus has chosen to feed the gas turbines of the first environmentally clean and high speed ferry in the world.

1. Clean transportation that carries

The LNG produced by the Cryobox® Nano Station can supply the fuel for your company, whether it's a heavy transport venture, a mining enterprise, an industry located in a remote region or a community far removed from a gas pipeline. Neither technological limitations nor large investment capital requirements will prevent you from using low CO2 emission LNG in place of diesel or fuel oil.

Cryobox will allow you to become your own producer of LNG, meeting all environmental requirements even in the fuel-production and storage phase.

2. Clean transportation that carries you further.

While Cryobox® turns LNG into an available and nancially convenient source of clean fuel, there are even more benefits. Compared with any other Diesel substitute, LNG has superior energy density. This means that a given tank of this fuel will carry you further. For this reason LNG is the most appropriate and cleanest fuel for heavy, long-distance transport such as heavy trucks, buses, ships, barges, ferries and railroad locomotives when long distances need to be covered and refueling opportunities are scarce.

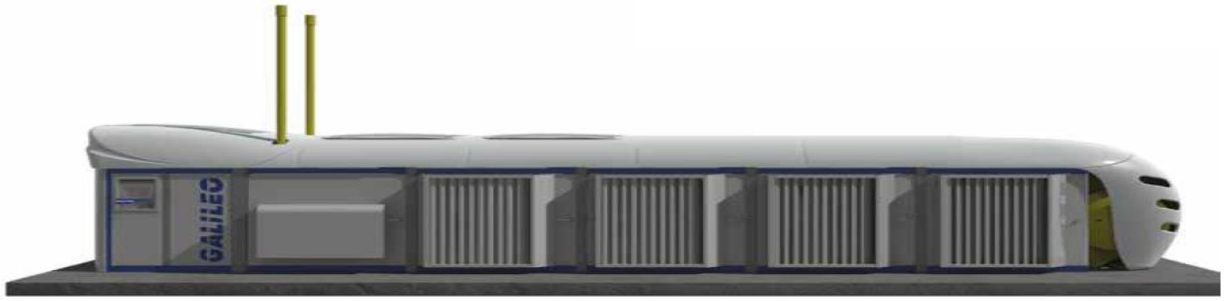


Fig. 8.2.2 : A neat picture of Cryobox

Cryobox® has an adjustable production capacity of up to 9013 gpd (gallons per day). The high-pressure, thermodynamic cycle of the Cryobox converts natural gas to the liquid state as temperatures are reduced to less than -225 °F . This multi-stage compression process includes a “boil-off” recovery system which eliminates all gas-venting usually associated with LNG storage and loading facilities. This process avoids gas waste while complying with all safety and ecologic regulations.

3. Be a pioneer, not simply an early adopter

Cryobox® packages all the capabilities of a large scale LNG plant into one compact and transportable module which shares the off-the-shelf components and main features of Galileo´s compressor packages, namely: modularity, low weight, economies in transport and ease of installation. You can be a leader in the LNG revolution by implementing the widely proven technology of Galileo.

4. “Plug & play” and enjoy the benefits of LNG

Since no additional constructions —such as perimeter containment walls— are necessary, Cryobox® can be hauled anywhere by a simple trailer for immediate connection and start-up. Due to its packaged con_guration, Cryobox® can be placed in a fuel-station and connected to the natural gas distribution line. It can also be installed right at the well-head of a distant oil & gas field. In this latter location, Cryobox® creates an additional environmental benefit by converting contaminating vented gas into a high value added liquid fuel.

5. LNG can become part of life and business

When natural gas demand does not justify the investment in a conventional pipeline, Cryobox® is the best complement to Galileo´s Virtual Pipeline, supplying natural gas by highway to mines, remote industries and isolated communities beyond 250 miles. This is possible because the Virtual Pipeline can optimize truck capacity and transport costs owing to LNG properties.

As an additional bonus, you get CNG for your urban mobility. The Cryobox® has the alternate capacity to supply CNG for your own local _eet of vehicles, or to refuel other urban vehicles.

6. More key features

- Low operating costs.
- Low power consumption.
- Fully automated operation.
- Remote monitoring through Global SCADA.
- Minimal storage.
- Intrinsic safety.
- Minimal noise and vibrations.
- Scalability: installation to demand changes.

		CRYOBOX-500-11	CRYOBOX-600-15
Inlet pressure			
	psi	156	213
	bar R	11	15
LNG production capacity			
	gal/day	7 683	9 013
	ton/day	12.48	14.64
	l/day	29 091	34 128
	nm^3/day	16 640	19 520
	kg/h	520	610
LNG delivery conditions			
Pressure	psi	29–58	29–58
	bar R	2–4	2–4
Temperature	- F	243.4–225.4	243.4–225.4
	- C	153–143	153–143
Transfer method to the storage tank: differential pressure, no need for venting or pumping		+	+
No boil-off / No emissions		+	+
Energy consumption			
Consumed power	kw	444	493
Installed power	kw	450	494
Gas or electric driven		+	+
Dimensions			
Length	ft	41.306	41.306
	m	12.328	12.328
Length with open doors	ft	43.307	43.307
	m	13.200	13.200
Width	ft	8.681	8.681
	m	2.646	2.646
Width with open doors	ft	17.783	17.783
	m	5.725	5.725
Height	ft	9.226	9.226
	m	2.812	2.812
Sources			
Natural gas from pipelines		+	+
Stranded / Associated gas		+	+
Biomethane		+	+
Application fields			
Filling stations for long haul vehicles, vessels and trains		+	+
Industrial use		+	+
Gas distribution		+	+
Bunker fueling		+	+
Alternative fuel production			
CNG (Compressed Natural Gas)	mscf/day	1.015	1.260
	gge/day	8 120	10 080
	dge/day	7 519	9 333
	nm^3/day	29 000	36 000
Operational management			
Remote monitoring		+	+
Compliance with international standards		+	+
Low maintenance		+	+
Low operative cost		+	+

Fig. 8.8 : Types of Cryobox

8.9 Galileo’s Cryobox® LNG nano stations

There will be seven Cryobox® units, developed and patented by Galileo, to feed with LNG the tanks of the “López Mena”, the world´s first high speed passenger RO-RO ship, which will daily cross the Río de la Plata between Argentina and Uruguay. It will also be the first time that a sea transportation company, such as Buquebus, becomes its own self supplier of a fuel.

“The integration of Cryobox® Galileo’s technologies in this challenge will demonstrate that LNG is the most suitable and cleanest power alternative for long-haul trucks; delivery fleets; buses; ships, barges and ferries; and railroad locomotives, when long distances should be covered, even when the odds of refueling are widely scattered. Since LNG has a superior energetic density than any other diesel substitute, it is possible to charge more fuel to cover longer distances in the same tank,” said Osvaldo del Campo, CEO of Galileo.

Cryobox® nano LNG station offers a cost effective solution, characterized by a high-pressure thermodynamic cycle that converts natural gas into liquid by cooling its temperature below -153 °C. Having a customizable LNG production capacity, it can reach a peak of 12 tpd (tons per day) or 7,000 gpd (gallons per day). It is a small-scaled mobile and packaged LNG production plant, which is ready to be shipped anywhere on a trailer for its immediate start-off.

Also would like to add a note that the Cryobox stations are be placed on the surrounding nearby pipelines where the gas is burnt in tern leads to inexpensive or cost effective fuel extraction. Infact Cryobox saves a lot of money because a separate fuel extraction system is not required to generate the gas fuel.

Operating together, the seven Cryobox® nano stations commisioned by Buquebus will be able to produce 84 tpd or 49,000 gpd of LNG and then trucked from the surroundings of Buenos Aires to the Buquebus' wharf.

Developed in Australia by Incat Tasmania Pty Ltd, the "López Mena" is the first high speed craft built under the British Code of Safety for High-Speed Craft (HSC code) powered by Gas Turbines using LNG as the primary fuel and marine distillate for standby and ancillary use.

IX. Comparison and Result Analysis

9.1 Effects of natural gas vehicles and fuel prices on key transportation economic metrics

New drilling and recovery techniques have resulted in a dramatic increase in the amount of recoverable natural gas and a consequent decrease in domestic natural gas prices. These increased levels of production have influenced outcomes in many sectors of the domestic and global economy. Because natural gas is a substitute for oil, coal, and other energy sources, it is important to consider these changes in the context of global energy demand.

Figure shows yearly world, OECD (Organization for Economic Cooperation and Development), and U.S. oil demand (consumption) over the time period 1997-2012

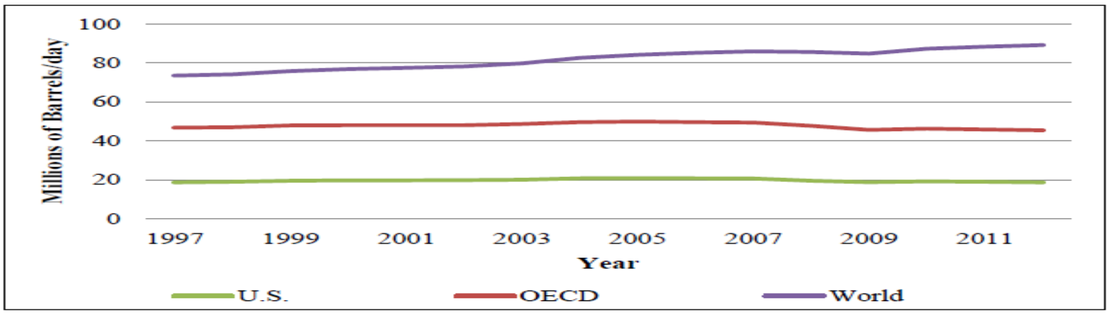
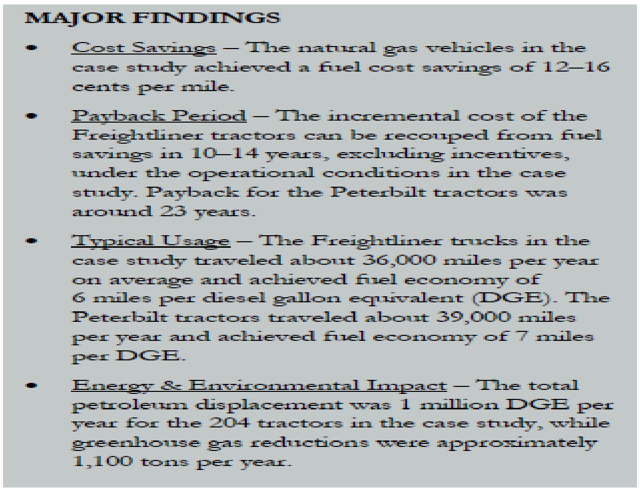


Fig 9.1 :World, OECD, and U.S. Oil Demand (U.S. EIA, 2012)

9.2 Case Study: Natural-Gas-Fueled Regional Transport Trucks


MAJOR FINDINGS

- Cost Savings — The natural gas vehicles in the case study achieved a fuel cost savings of 12–16 cents per mile.
- Payback Period — The incremental cost of the Freightliner tractors can be recouped from fuel savings in 10–14 years, excluding incentives, under the operational conditions in the case study. Payback for the Peterbilt tractors was around 23 years.
- Typical Usage — The Freightliner trucks in the case study traveled about 36,000 miles per year on average and achieved fuel economy of 6 miles per diesel gallon equivalent (DGE). The Peterbilt tractors traveled about 39,000 miles per year and achieved fuel economy of 7 miles per DGE.
- Energy & Environmental Impact — The total petroleum displacement was 1 million DGE per year for the 204 tractors in the case study, while greenhouse gas reductions were approximately 1,100 tons per year.

Fig. 9.2 : Major Findings

9.3 Costs of Energy

Global economic growth has led to rising prices for many energy sources. The recession that started in 2007 contributed to a slight dip in the overall trend, but global demand for oil has continued to increase. The fact that world oil demand is more resistant to recessionary pressure than is oil demand in advanced economies indicates future of oil demand is likely to be very strong.

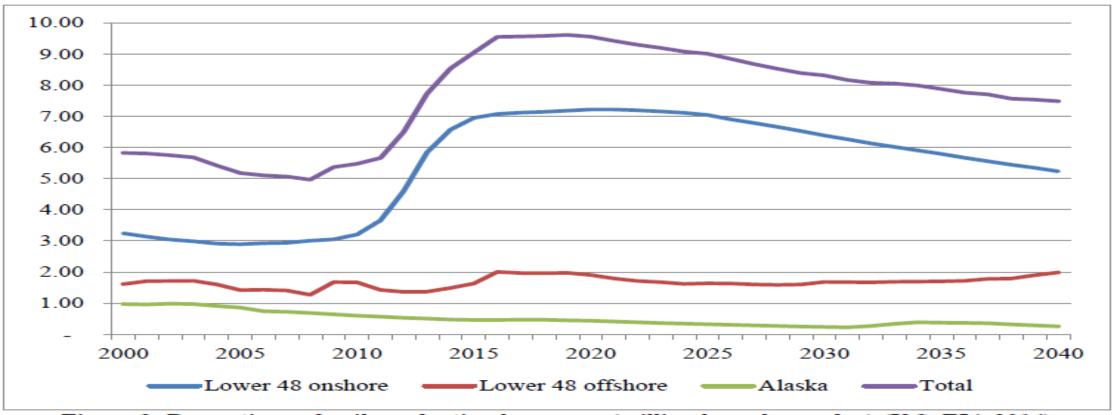


Fig. 9.3: Domestic crude oil production by source (million barrels per day)

9.4 The Cost of Extraction

In the oil and natural gas industry, rising prices are the mechanism that drives innovation in extraction techniques**.** The changes in extraction technologies should provide some relief to the cost curve and the supply curve for transportation energy. During the last dozen years these technological advances have enabled a very large increase in the economical production of natural gas. The following section provides more details of the technological advances in natural gas supply.

9.5 Natural Gas Supply

India had 38 trillion cubic feet (Tcf) of proven natural gas reserves as of January 2007.The total gas production in India was about 31,400 mcm in 2002-03 compared with 2,358 mcm in 1980-81. At this production level, India's reserves are likely to last for around 29 years; that is significantly longer than the 19 years estimated for oil reserves. Almost 70% of Indias natural gas reserves are found in the Bombay High basin and in Gujarat. Offshore gas reserves are also located in Andhra Pradesh coast (Krishna Godavari Basin) and Tamil Nadu coast (Cauvery Basin). Onshore reserves are located in Gujarat and the North Eastern states (Assam and Tripura).

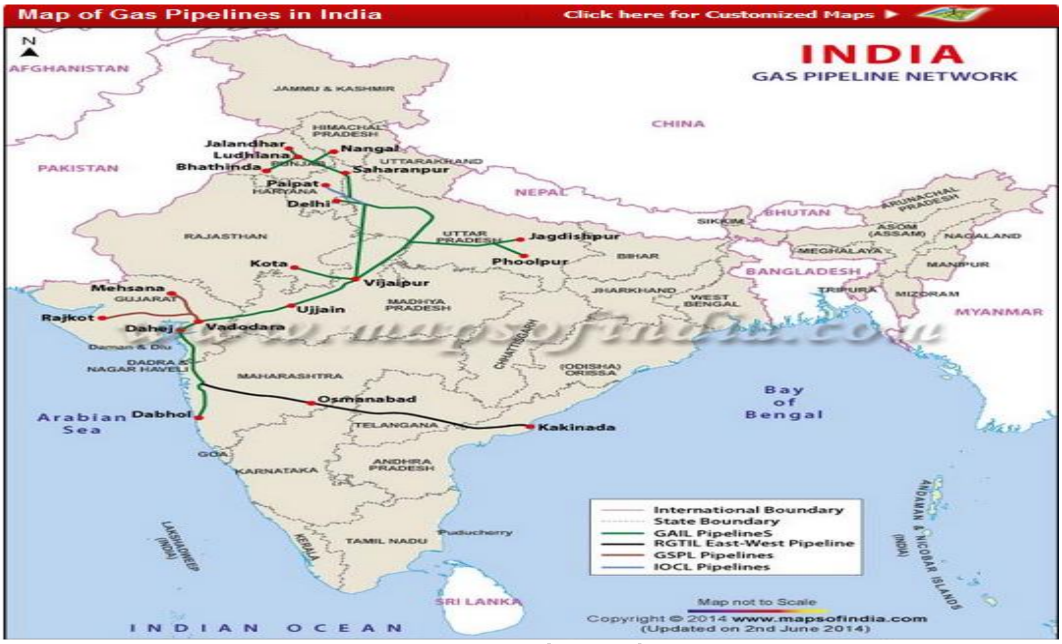


Fig 9.4: Gas Pipe lines in India

Year	Crude Oil Production (MMT)	% Growth in Crude Oil Production	Natural Gas Production (BCM)	% Growth in Natural Gas Production
2009-10	33.690	0.54	47.496	44.61
2010-11	37.684	11.85	52.219	9.94
2011-12	38.090	1.08	47.559	-8.92
2012-13	37.862	-0.60	40.679	-14.47
2013-14	37.788	-0.19	35.407	-12.96
2014-15	37.461	-0.87	33.657	-4.94
2015-16(P)	36.950	-1.36	32.249	-4.18

Fig 9.5 : Crude Oil and Natural Gas Production in India

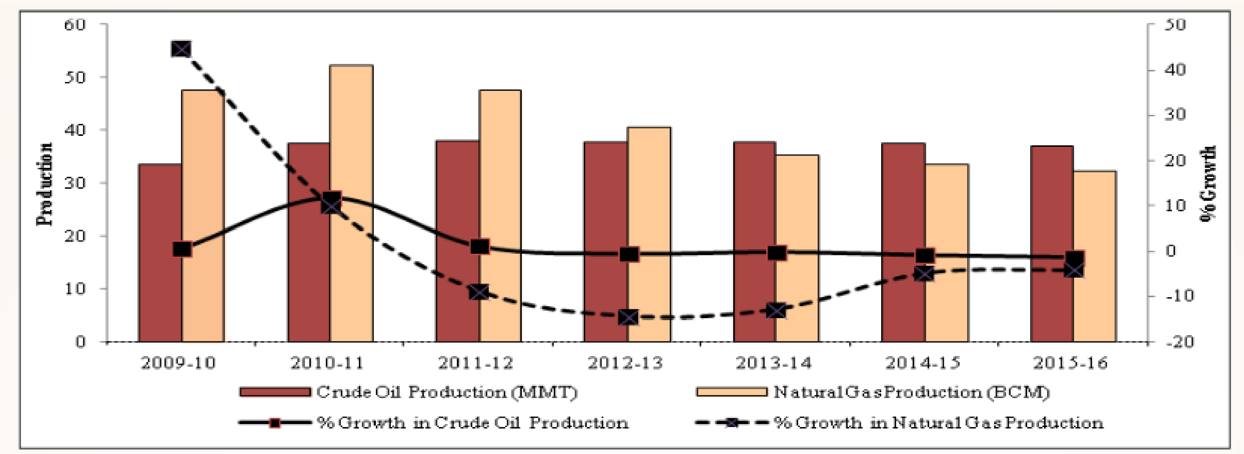


Fig 9.6: Crude Oil & Natural Gas Production in India

9.7 Price of Crude Oil & Natural Gas

Natural gas typically tracks below oil but since 2009 the price is 'decoupling' (to the benefit of natural gas!)

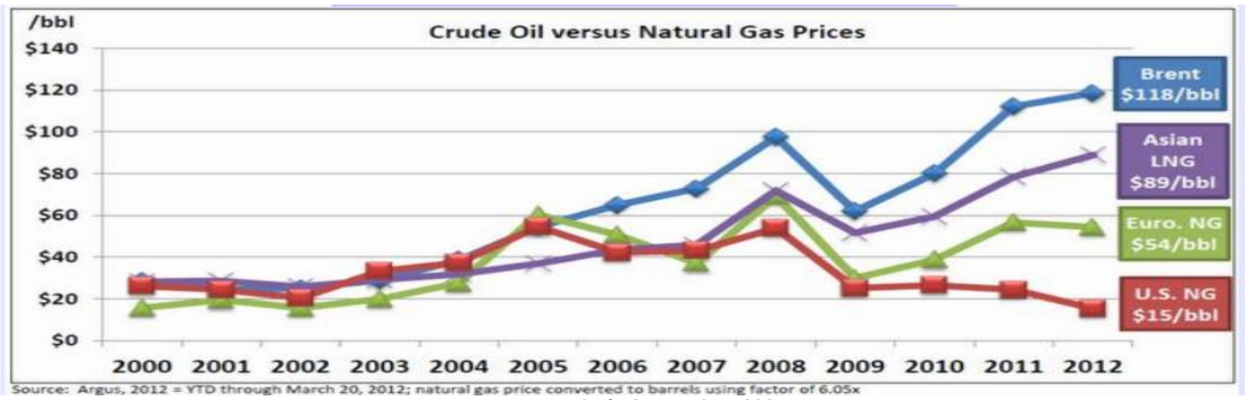


Fig 9.7: Barrel of oil equivalent (bbl)

9.8 World NGV Growth --Vehicle Numbers & % Growth Rate

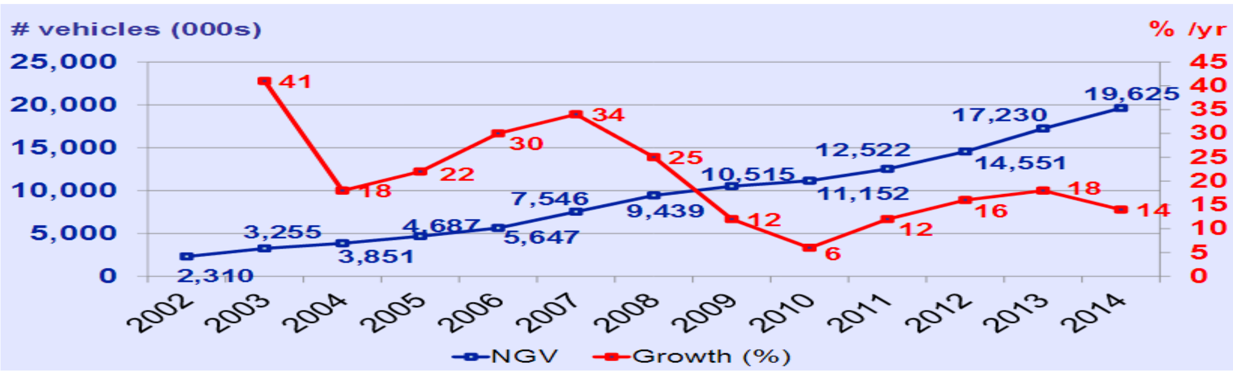


Fig 9.8.1 : World Ngv Growth --Vehicle Numbers & % Growth Rate

9.9 World Fuelling Station Growth --Station Numbers & % Growth Rate

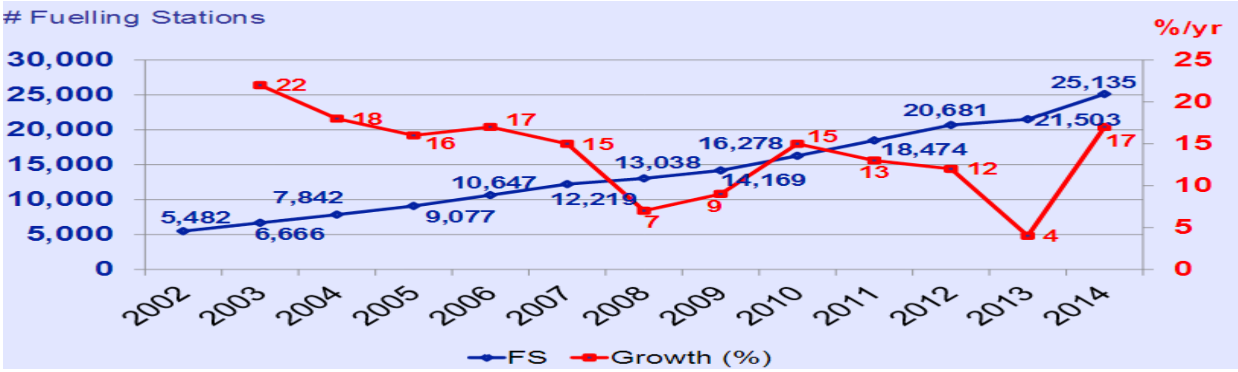


Fig.9.9 : World Fuelling Station Growth --Station Numbers & % Growth Rate

9.10 World Wide NGV Growth –Actual & Various Projections to 2020

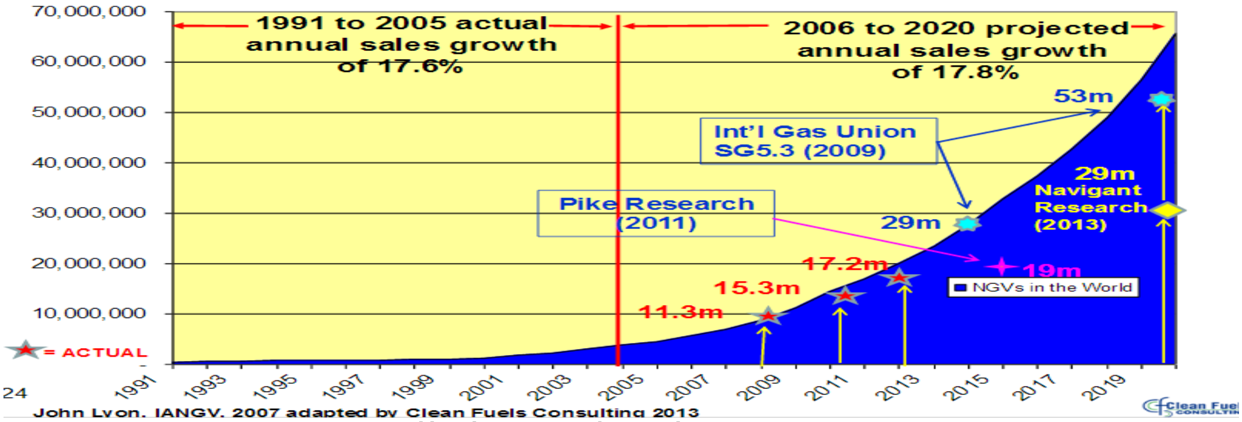


Fig. 9.10 : World Wide NGV Growth –Actual & Various Projections to 2020

9.11 Projected global regional sales volume outlook

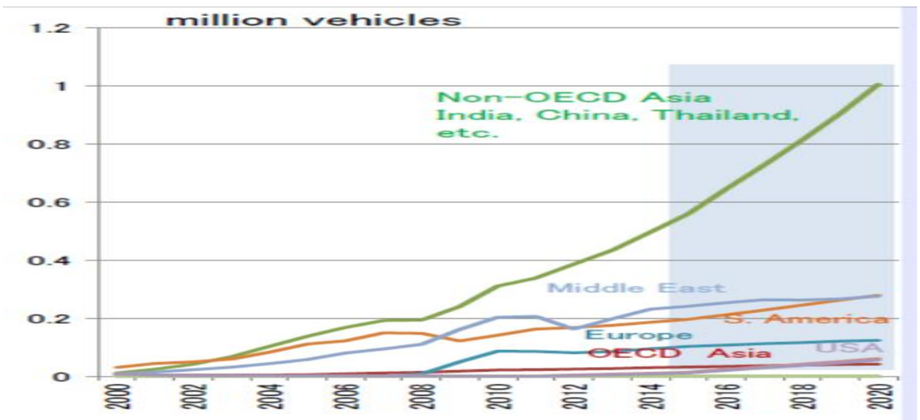


Fig. 9.11 : global regional sales volume outlook

9.12 Forecast NGV registrations by segment U.S. & Canada 2012 - 2023

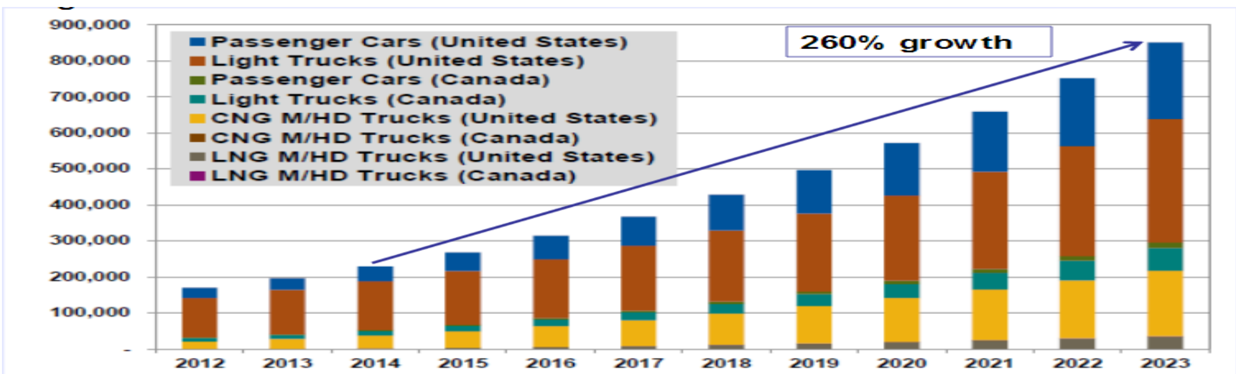


Fig. 9.12 : NGV registrations by segment U.S. & Canada 2012 - 2023

9.13 Methane Is a Diverse & Flexible Fuel For The Transport Sector

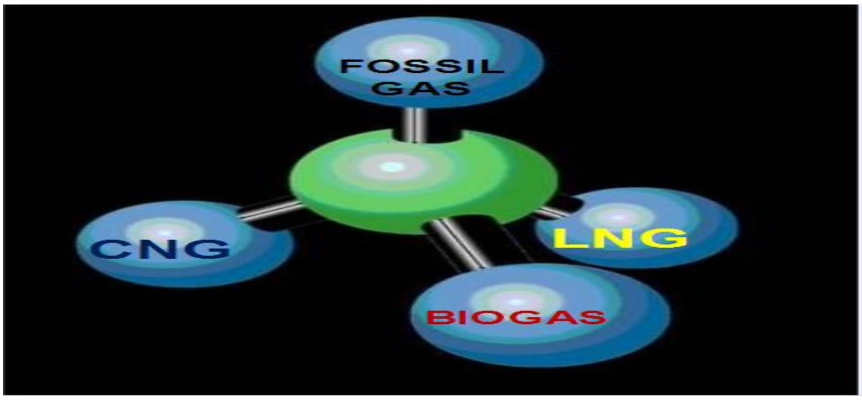


Fig. 9.13 : Methane Is a Diverse & Flexible Fuel For The Transport Sector

9.14 Natural Gas Prices and Energy Substitutability

The recent increase in natural gas production has led to a dramatic decrease in the price of energy produced from natural gas relative to other sources.

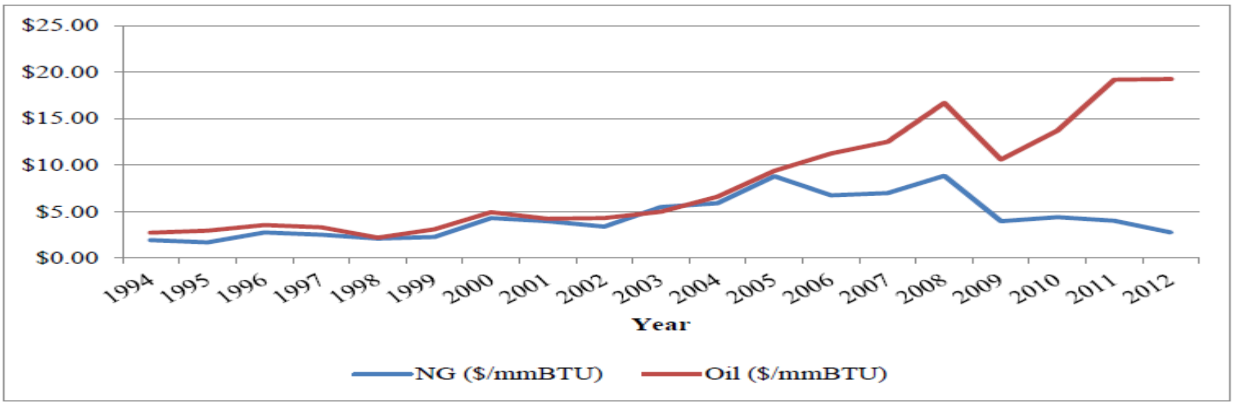


Fig. 9.14 : Natural Gas Prices and Energy Substitutability

Importantly, research suggests that natural gas will continue to enjoy a cost advantage over oil. One reason for this is that, in contrast to world oil markets, natural gas markets are not highly integrated. Oil is transported across regions via pipelines, tankers, railways, and other means and the research suggests that the world oil market is a single integrated market In contrast, markets in coal, natural gas, and substitute energy sources tend to be more regional—they are not as integrated and regional price differences can persist for long periods of time.

9.15 Increased Electricity Generation via Natural Gas

Natural gas easily substitutes for coal in the production of electricity. This may put upward pressure on natural gas prices if electric utilities shift a large percentage of generating capacity from coal-fired to natural gas.

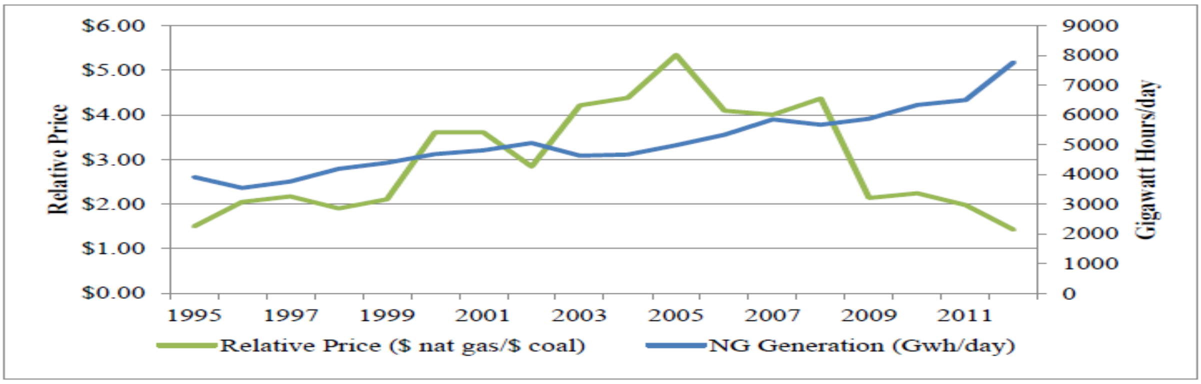


Fig 9.15 : Relative Price in Dollars of Natural Gas to Coal and NG Generation

9.16 Future Prices for Natural Gas and Oil

It shows that natural gas will likely continue to enjoy a large cost/BTU advantage over oil through 2040, but the cost difference of the two fuels narrows over time. EIA estimates that even though both crude oil and natural gas prices will increase through 2040; the oil price rises more slowly than the natural gas price

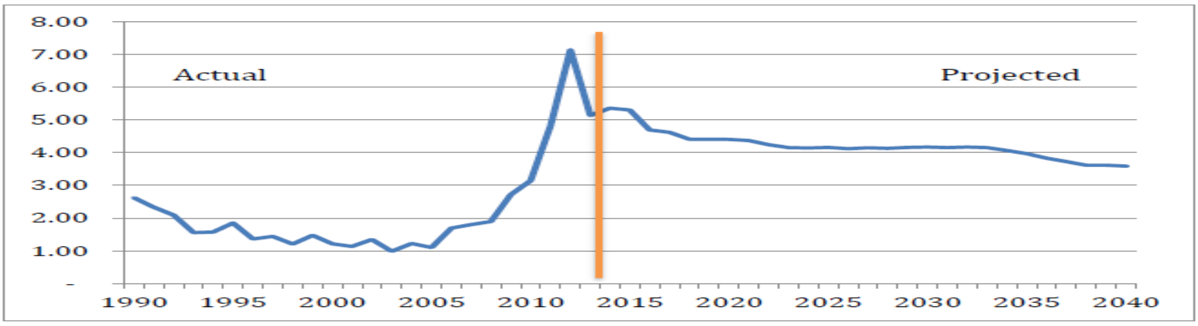


Fig. 9.16: Ratio of Oil Price to Natural Gas Price in Energy-Equivalent Terms

9.17 Natural Gas Vehicles: Current State of the Market

According to the Natural Gas Vehicle Association of America there are currently approximately 120,000 NGVs in the U.S. fleet and 15.2 million NGVs worldwide (NGV America, 2012).

Country	Number of Vehicles	% of Total NGVs Worldwide
Iran	2,859,386	18.82%
Pakistan	2,850,500	18.76%
Argentina	1,900,000	12.50%
Brazil	1,694,278	11.15%
India	1,100,000	7.24%
China	1,000,000	6.58%
Italy	779,090	5.13%
Ukraine	390,000	2.57%
Columbia	348,747	2.30%
Thailand	300,581	1.98%
United States (17th)	~120,000	> 1%

Fig. 9.17 : Top 10 Countries for NGV Deployment and U.S. Ranking

Advantages to NGV's include the cost of fuel being $1.50 to $2.00 less than gasoline on a per gallon equivalent basis. Home-fueling options are available to consumers that provide additional convenience to vehicle owners. According to the Natural Gas Vehicle Association of America (2012), replacing an older vehicle with a new NGV can provide the following reductions in emissions of:

- Carbon monoxide (CO) by 70%–90%
- Non-methane organic gas (NMOG) by 50%–75%
- Nitrogen oxides (NOx) by 75%–95%
- Carbon dioxide (CO2) by 20%–30%

9.18 Natural Gas Vehicles: Cost of Gasoline, Diesel, and LNG over Time

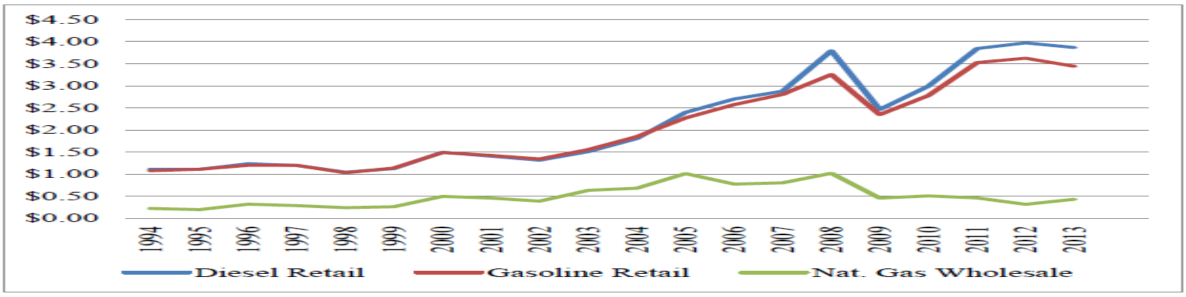


Fig. 9.18: Cost of Gasoline, Diesel, and LNG over Time

Despite these potentially large cost savings, barriers to widespread adoption of heavy-duty CNG and LNG vehicles remain. Deal (2012) summarizes some of the factors limiting the application of CNG and LNG in heavy-duty vehicles:

- Refueling infrastructure is still limited compared to diesel.
- Natural gas trucks are substantially more expensive than diesel trucks.
- There is high capital costs associated with upgrading a maintenance shop to deal with CNG vehicles.
- The limited capacity of economical CNG fuel tanks limits operational range and adds weight to the truck.
- LNG use is limited to situations where trucks are re-fueled every 1-2 days.
- Fleets are apprehensive about new “high risk” technology.

9.19 Trend of Number of Registered Vehicles

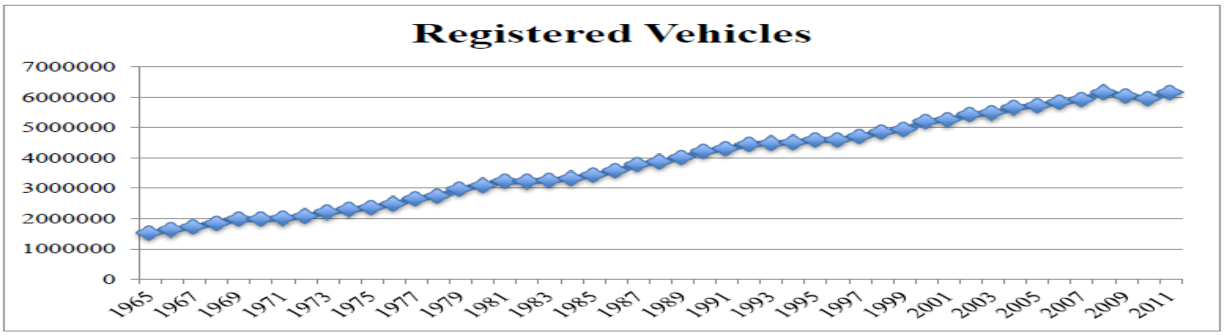


Fig. 9.19: Trend of Number of Registered Vehicles 1965-2011

The number of registered vehicles has steadily increased during the period of study. Figure 19 shows that the number of registered vehicles dropped in 2008 at the time of the economic downturn. This effect continued until 2010. However, since 2010 the number of registered vehicles began to increase.

9.21 Trend of Employment

Fig. 9.21: Trend of Employment

9.22 Consumption

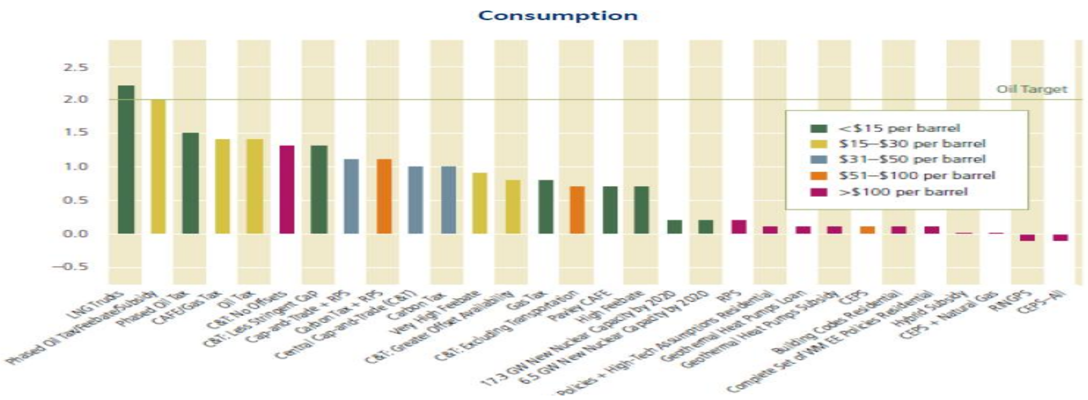


Fig. 9.22: Effectiveness (in 2030) and Cost-Effectiveness (2010-2030) in Reducing Oil Consumption

X. CONCLUSION

This report deals with various types of automobiles with its disadvantages and evaluates the economic competitiveness of natural gas as a transportation fuel and estimates the extent to which natural gas is likely to substitute for petroleum as a transportation fuel. Additionally, the potential impacts of natural gas vehicle adoption on vehicle miles traveled, greenhouse gas emissions (CO2) and fuel tax revenue have been assessed.

Natural gas enjoys a per-BTU cost advantage over petroleum and this price advantage is likely to persist into the foreseeable future. New low-cost extraction technology (hydraulic fracturing or "fracking") has increased the supply of domestic natural gas while petroleum prices have increased. Expert opinion suggests this price difference is likely to persist and that natural gas will enjoy a price advantage over petroleum for many years.

Despite the per-BTU cost advantage enjoyed by natural gas relative to gasoline, as a transportation fuel natural gas faces some substantial disadvantages. In addition to competition from other alternative fuels, widespread adoption of natural gas vehicles would require substantial investment in fueling infrastructure. Very few natural gas vehicles are available directly to consumers from manufactures and those vehicles that are available are more expensive and suffer from several other disadvantages. For example, because natural gas is less energy dense, NGVs are typically less powerful, heavier, have less storage/trunk space, and have more limited range due. Despite the fuel cost savings, these disadvantages and the additional cost tend to make natural gas vehicles an uneconomical choice for most consumers. Models of consumer preference suggest that a substantial decrease in the price of natural gas vehicles would be necessary to induce a notable increase in light-duty NGVs adoption rates. However, natural gas may represent an attractive alternative for a substantial portion of the heavy-duty vehicle fleet and there is evidence of increasing adoption rates in this sector. These estimates suggest that natural gas vehicle adoption is unlikely to substantially affect VMT. Additionally, VMT is more highly sensitive to variables that are correlated with overall population size (the number of registered vehicles and total employment) than to fuel prices. Although per-capita VMT has been declining in recent years, aggregate VMT in Washington State has been increasing steadily due to increased population. Higher fuel prices do have a negative effect on VMT although the estimated elasticity is relatively low. Finally, the adoption of natural gas vehicles is unlikely to have a substantial effect on VMT.

Natural gas vehicle adoption has the potential to reduce greenhouse gas emissions because natural gas is about 20% less CO2 intensive than gasoline. This model of consumer adoption of light-duty NGVs, combined with reasonable assumptions about NGV adoption in the heavy-duty vehicle sector, indicates that under current price conditions, only modest reductions in CO2 emissions due to NGV adoption are expected. Baseline estimates suggest about a 0.02% decrease in CO2 emissions from the light-duty vehicle sector is possible due to NGV adoption. If price conditions for light-duty vehicles become much more favorable (lower NGV prices and a larger fuel price differential), this figure could rise to 1.16%. Reasonable assumptions suggest that reductions from the heavy duty sector of the fleet are unlikely to exceed 7%, even under conditions of extremely optimistic adoption rates. Overall, transportation sector emissions (light- and heavy-duty fleet combined) are unlikely to be reduced by more than 4% overall, even under conditions of aggressive CNG adoption.

Finally, the report investigated the impact of increased fuel efficiency on future fuel tax revenues. Alternatively fueled vehicles such as natural gas vehicles and electric vehicles have started to erode fuel tax revenues. In addition, automobile manufacturers have started to make all vehicles more fuel-efficient. If the current taxing structure continues into the 2020s then WSDOT will experience significant decreases in revenue generated by the fuel tax.

XI. WILL NATURAL GAS VEHICLES BE IN OUR FEATURE?

The economics of natural gas penetration into transportation—coupled with its ability to improve energy security and reduce tailpipe CO2 emissions and its reasonable cost-effectiveness50,51— makes this fuel deserving of more attention. Under certain assumptions about fuel and vehicle price differentials, fuel economy, and vehicle miles traveled (such as being driven

125,000 miles per year), LNG-fueled heavy-duty trucks can return their added investment in two years, but generally, payback periods would be much longer. Additionally, this somewhat optimistic assessment does not directly account for infrastructure and safety costs.

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